General Information

The University of Virginia takes pride in its continued development of modern engineering education and research. For over one hundred fifty years, the University has offered regular study in engineering, coinciding with the industrial development of the South and paralleling the rise of the engineering profession itself. Today, a total of 9 undergraduate and 31 graduate programs are offered by 8 academic departments.

Address
School of Graduate Engineering and Applied Science
A108 Thornton Hall
University of Virginia
P.O. Box 400242
Charlottesville, VA 22904-4242
(434) 924-3897
www.seas.virginia.edu

History

The growth of applied science into a learned profession was anticipated in the founding of the University. As early as 1825, the Rector and Visitors formally indicated that instruction in military and civil architecture would be a part of the education program of the University. Such courses were offered starting in 1827. Notable members of the early engineering staff were Charles Bonnycastle, trained in military engineering in England, and William Barton Rogers, later co-founder of the Massachusetts Institute of Technology. Engineering instruction was not sought widely by young men in the predominantly agricultural South; however, and by 1850, it was announced that the engineering program would be discontinued.

A new and more successful beginning was made in 1865 under the direction of Professor Charles Scott Venable, and by 1886 the University awarded its first degrees in engineering. Instruction was offered in civil and mining engineering until the 1881-1882 session, when engineering became a professional department. William Mynn Thornton became the first dean of engineering in 1905. Under his leadership, three new degree programs were added: mechanical engineering in 1891, electrical engineering in 1897, and chemical engineering in 1908.

Between World War I and World War II, the engineering curricula were revised and strengthened to provide a broader program of study, including the humanities. During both wars, the school offered engineering instruction to members of the armed forces; and ROTC programs for the Navy, Army, and Air Force were introduced during and after World War II.

Reorganization following World War II led again to an extensive revision of all curricula and to the graduate studies now offered.

In 1955, two new branches of engineering study were recognized by degrees: aeronautical and nuclear engineering. In the same year, the first doctoral programs were instituted in chemical engineering and engineering physics.

In 1962, the name of the School was changed to the School of Engineering and Applied Science (SEAS) in anticipation of the establishment of the Department of Materials Science (1963), the Department of Applied Mathematics and Computer Science (1964), and the Department of Biomedical Engineering (1967). The Department of Systems Engineering was established in 1975, and in 1984, Applied Mathematics and Computer Science became separate departments. Further reorganization has led to the present school academic structure with its Departments of Biomedical Engineering; Chemical Engineering; Civil Engineering; Computer Science; Electrical and Computer Engineering; Materials Science and Engineering; Mechanical and Aerospace Engineering; and Systems and Information Engineering; and the Department of Science, Technology and Society. The undergraduate program in engineering science and the graduate program in engineering physics are administered by the Department of Materials Science and Engineering. Graduate Programs in Computer Engineering are administered jointly by the Departments of Computer Science, and Electrical and Computer Engineering.

Research Centers and Institutes

Interdisciplinary research is carried out through research centers, laboratories, and consortia in which graduate students in two or more disciplines work together on a research project.

Advanced Materials and Structures Laboratory conducts thermomechanical testing with an emphasis on multi-scale approaches that establish connections between size-scale and thermomechanical performance of materials and structures. Together with conventional macroscale materials testing, this facility has a state-of-the-art nano-indentation system that allows mechanical testing on length-scales spanning from nanometers to millimeters. This system has force resolution on the order of one billionth of a Newton, and displacement resolution on the order of one angstrom; a unique capability is an environmental temperature chamber, which enables testing in the range of -50°C to 100°C. Current research is directed towards establishing connections between nanoscale material features and thermomechanical stability in thin films and MEMS, with an emphasis on compliant materials such as nano-porous ceramics and polymers.

Aerogel Research Laboratory was established in 1996 to investigate fundamental properties as well as cutting-edge applications of aerogels, which are the lightest solids ever produced. It is the only university-based aerogel research program in the United States.

Aerospace Research Lab was established in 1986 to conduct basic and applied research in advanced aerospace technologies. Research interests have expanded to include high-speed mixing and combustion, aeroacoustics, structures and materials, optical techniques, microscale heat transfer, and computational modeling.

Center for Applied Biomechanics is dedicated to vehicle safety testing with a major emphasis on studying impact and injury biomechanics. The focal point of the 10,000 square foot facility is a test sled mounted on a 66-foot track which allows simulation of high speed automobile crashes. In addition to the sled system, the CAB has a number of pneumatic and gravity driven impactors as well as state-of-the-art high speed data acquisition and digital video systems. Major research efforts at the laboratory include the study of advanced occupant restraint systems including air bag and seat belt systems. In particular, the CAB is establishing guidelines and criteria for the mitigation of airbag induced injuries.

Applied Electrophysics Laboratories (AEpl) serves as the University of Virginia’s center for research in solid-state materials, devices, and circuits. AEpl was founded in 1967 and consists of the Semiconductor Device Laboratory (SDL), the Laboratory for Optics and Quantum Electronics (LOQE), and the Millimeter-wave Research Laboratory (MRL). These laboratories share a 3,500 square-foot clean room facility for device fabrication and materials growth, as well as a variety of other facilities for microwave and optical analysis and device design and testing.

Atomic and Surface Physics Lab studies the interaction of energetic particles (ions, electrons) and photons with surfaces. Its goals are to understand the mechanisms leading to electronic excitations and how these excitations evolve and lead to the emission of light (luminescence), electrons, radiation, atoms and molecules (sputtering), and to radiation damage, chemical changes or heat. The studies have applications in semiconductor processing, nuclear fusion, gas discharges, biology, astrophysics, and space exploration. A substantial part of the laboratory’s work consists in modeling and simulations of surface processes in icy satellites, planetary atmospheres and magnetospheres, and interstellar grains. Projects are supported by NASA, NSF, and SWRI.
Laboratory develops decision-aiding systems for operators and engineers in the domains of process control, medical technology, and aviation. In all of these domains, teams of people work together to solve problems in complex, dynamic environments. Typical tasks include monitoring, diagnosis, control, scheduling, and planning, using both well-defined strategies and ad-hoc reasoning to meet objectives while satisfying constraints like organizational or industry-mandated objectives or rules.

Communications, Control, and Signal Processing Laboratory (CCSP) conducts research and development in a variety of communications, control systems, and signal processing areas, including error control coding, data compression, network protocols, detection and estimation theory, statistical signal analysis (system identification, channel equalization, sensor arrays and image processing), optical communication, adaptive control, robust control, and nonlinear control. Research in CCSP is primarily of an analytical nature, supported by computer simulations.

Computational Laboratory for Environmental Bioremediation (CLEB) complements UVA's existing experimental Bacterial Migration Laboratory—the only laboratory in the world equipped to measure bacterial transport properties at both the macroscopic and the individual cell levels. This experimental capability, combined with the CLEB's modeling and computational expertise, which draws on analogies to statistical mechanical methods for molecular transport phenomena, places CLEB in a unique position to substantially expand the state of quantitative knowledge about bacterial migration and In Situ Bioremediation (ISB), a powerful, cost-effective technology for restoring contaminated sites by exploiting the natural degradation capabilities that offer great potential to advance the state of the art in this field.

Far Infrared Receiver Laboratory (FIRLab) operates within the Departments of Electrical and Computer Engineering and Physics at the University of Virginia. The FIR-Lab is fully equipped to design, assemble and evaluate millimeter and submillimeter wavelength mixers and multipliers at frequencies from microwave to THz frequencies. Sources include two submillimeter wavelength gas laser systems (300 GHz-4.5 THz) and a variety of millimeter wavelength sources, multipliers and amplifiers. A Bruker IFS 66V Fourier Transform Infrared Spectrometer (200 GHz-225 THz) is available for materials and component evaluation, as well as a variety of power meters, microscopes and probe stations.

High-Performance Low Power Laboratory (HPLP) focuses primarily on original research in the field of low power and high performance electronics, spanning digital VLSI and analog systems, architectures, circuits, and algorithms. HPLP currently has eight active researchers, as well as a new lab facility containing PCs and workstations donated by IBM and Intel.

Hyperpolarized Gas Imaging Research is a promising option for medical imaging of air spaces and certain tissues in humans without exposing patients to radiation associated with other methods (high resolution Computed Tomography and V/Q techniques, for example.) Since spring of 1996, UVA Departmental Research Team for Hyperpolarized Gases has been exploring and conducting research in this field.

Integrated Sensing and Processing Laboratory (ISPL) merges high functional density CMOS image/signal processing mixed-signal circuits with integrated detection/transduction structures to achieve improved application performance. Its current projects are in the areas of infrared imaging, adaptive hyper-spectral imaging, biomolecular fluorescence detection, and adaptive ultrasonic imaging. The laboratory's work is supported by the National Science Foundation, the Defense Advanced Research Projects Agency, the Carilion Biomedical Institute, and Agilent Technologies.

Intelligent Processing of Materials Laboratory (IPML) is one of the nation's premier centers for research on the processing of advanced materials. Affiliated with the University's School of Engineering and Applied Sciences, the laboratory incorporates both the synthesis and processing of materials along with their modeling, sensing, and control. Goals of IPML's research include development of innovative process technologies, creating models for predicting materials evolution during processing, designing advanced in-situ sensors for tracking material changes during processing, and creating model-based path optimization and feedback control.

Interdisciplinary Research in Contaminant Hydrogeology Center is dedicated to investigation of the interplay between chemical, physical, and biological factors that control the fate and transport of contaminants in the subsurface. Its research is supported by teams of individuals from the departments of Civil Engineering, Chemical Engineering, and Environmental Sciences.

Internet Commerce Group, InterCom, is a coalition of university faculty and business leaders that promotes development of electronic commerce in Virginia by providing technical and business software, training, and consulting services to companies entering (or already participating in) the electronic marketplace.

Internet Technology Innovation Center (TIC) assists Virginia's newest emerging industry and its growing base of Internet-related businesses. The Internet TIC is tasked to nurture entrepreneurship, accelerate the creation and deployment of network-based information technology, develop the hardware/software infrastructure that Virginia needs for the coming knowledge-based economy, and expand Virginia's high-skill workforce needed to develop, support, and market Internet-based electronic products and services. Internet TIC is funded by Virginia's Center for Innovative Technology and is a partnership among the University of Virginia, Virginia Tech, George Mason University, and Christopher Newport University.

Justice Information Systems, Virginia Institute, was created to support the information technology needs of law enforcement agencies throughout the Commonwealth of Virginia and on a national level. The Institute is funded by national funding agencies including the Virginia Department of Criminal Justice Services, and the National Institute of Justice's Crime Mapping Research Center.

Light Metals Center conducts a wide range of research on light materials including alloy processing, mechanical properties and microstructural characterization, deformation mechanisms and environmental effects of light metals. The center's research advances knowledge of structural materials, which have a high strength- and/or stiffness-to-weight ratio and at the same time are able to perform satisfactorily in hostile environments.

Magnetic Bearings Center conducts applied research in the area of magnetic bear-
ings used to support a variety of machines. The Center receives funding from the Virginia Center for Innovative Technology, government agencies, and industry, and it places great emphasis on working with industry to develop magnetic bearing technology for a wide variety of applications, particularly in the area of turbomachinery. Many of the research results and computer programs developed by the faculty and students are widely used in industry, and in some cases are the industry standards.

Mathematical Computational Modeling Laboratory is dedicated to research in mathematical modeling, computer simulation, and virtual prototyping of various industrial technologies and industrial processing operations. Recent research includes studies in high-speed gas flows, two phase flow with fibrous material, rarefied gas flow, and dynamical motion of galaxies.

Microelectronics Institute serves as the University’s interdisciplinary microelectronics interface to outside organizations and within the University itself. Acting as a focal point for microelectronics communications at the University, the institute consists primarily of faculty volunteers. Through organized cooperation they seek to maximize the impact of their educational and research activities.

Microscale Heat Transfer Laboratory is dedicated to developing new techniques to assist in measuring, understanding, and utilizing microscale phenomena. The laboratory’s research is aimed at developing a fundamental understanding of energy transport on ultra short time and length scales.

Millimeter-Wave Research Laboratory focuses on building communication and receiver components capable of operating at very high frequencies. The devices have a host of applications, including communications, radar, atmospheric monitoring, and radio astronomy.

Molecular Biomechanics Laboratory, part of the Department of Biomedical Engineering, is dedicated to understanding the molecular mechanisms by which cells move, and the application of this knowledge to the improvement of American public health.

MRSEC Center for Nanoscopic Materials Design explores new directions in the nanoscale design and control of self-assembled epitaxial semiconductor quantum dots by providing new algorithms for understanding and controlling the coupling of short, medium and long range order in these structures. The Center collaborates with industrial, University, and government laboratories to support and further materials research and education in this field.

Next Generation Real-Time Computing Lab is part of the Computer Science Department at the University of Virginia. The laboratory studies a wide range of issues in all aspects of real-time computing. Real-time principles are becoming important for all systems since audio and video streams are being utilized in many new contexts from control applications to the Next Generation Internet.

Optics and Quantum Electronics Lab conducts research in photonics and optoelectronics. Current areas of interest include photonic materials, novel optical devices, micro-opto-electro-mechanical systems (MOEMS), and organic polymers like polypropylene and poly-dimethylsiloxane.

Risk Management of Engineering Systems Center develops technology to assist in the management of risk for a variety of engineering systems. Industry and government sponsors of research at the Center work closely with faculty and students, contributing their unique strengths and interests to the Center. The Center’s areas of expertise include environmental impacts, water resources and technology management, electronic, safety-critical systems, computer-based systems, including hardware and software performance and reliability, and reliability modeling of multiple failure modes in complex systems.

Rotating Machinery and Controls Laboratories (ROMAC) conduct research in the areas of rotor dynamics, turbomachinery, structural dynamics, magnetic bearings, automatic controls, turbomachinery flows, fluid film bearings, and seals. The Laboratory’s research is supported by a consortium of industries through the ROMAC Industrial Research Program.

Safety Critical Systems Center explores questions of safety in industries where safety is a matter of life and death. The goal is to make current systems even safer for the public. Projects include assessing the safety of modern rail transportation systems and studying issues of safety in the nuclear industry. The center has received support for related projects from the National Science Foundation and the U.S. Air Force.

Science and Engineering of Laser Interactions with Matter graduate training program is designed to develop students with enhanced mastery and appreciation of the knowledge and state-of-the-art technical skills required for rapid advancements in modern science and technology.

Semiconductor Device Lab maintains a position of international prominence for research on solid-state devices for millimeter and submillimeter wavelength electronics. Research is focused on development of high-sensitivity, ultra-low-noise Gallium Arsenide Schottky barrier diodes and superconducting junctions for high frequency (150 GHz and above) receiver applications. Research topics include theoretical investigations of high-frequency transport in ultra-small semiconductor devices, fundamental limits to device performance, and optimization of device design for specific applications.

Semiconductor Manufacturing

Information Technology Center is a partnership between Dominion Semiconductor Co. and Virginia’s Center for Innovative Technology. The Center’s goals are to improve productivity at Dominion’s state-of-the-art chip fabrication facility, in Manassas, while giving students hands-on experience with actual manufacturing data. The center is located at Dominion but has a companion laboratory at UVA. Both facilities are staffed by University students and researchers.

Semicustom Integrated Systems Center is an internationally respected research group in the areas of computer engineering and digital systems. The Center’s ultimate missions are to accelerate economic growth, to improve products and processes, and to integrate the results of academic research into Very Large-Scale Integration (VLSI) industry developments. Its research and education programs help satisfy the growing need for leading-edge design tools and methods in the VLSI industry.

Smart Travel Lab is a state-of-the-art facility of the Center for Transportation Studies that supports research and education in the rapidly emerging area of intelligent transportation systems (ITS). Using the latest information technologies and analysis and modeling techniques, researchers in the lab are developing prototype systems and applications that promise to improve the effectiveness of ITS. The distinguishing characteristic of the lab is the direct connection established between the lab and transportation management systems operated throughout the Commonwealth of Virginia. This connection provides researchers with direct access to real ITS data and systems.

Space Physics and Surface Physics Theory Program studies the physics and chemistry of energetic ion, electron and UV-photon interactions with surfaces and gases. The processes of interest are desorption and sputtering, as well as the radiolysis and photolysis of surfaces and gases. The motivation for the program’s research is to understand problems in space physics and astronomy.

Surface Science Center provides services on surface analysis, including modifying the surface layers of materials by ion implantation, and surface characterization and depth profiling of sample compositions using a Perkin-Elmer 560 system. Available techniques are Angle-resolved X-Ray Photoelectron Spectroscopy (XPS or ESCA), Scanning Auger Electron Microscopy with sub-micron resolution, and Ion Scattering Spectroscopy. Each technique can be combined with the others and with sputter etching (using a differentially pumped ion gun) to obtain compo-
sition depth profiles.

**Survivable Information Systems Center** studies the survivability of critical information systems-air traffic control, telecommunications, nationwide control of power distribution, and the financial system. Societal dependence on these systems is growing and will continue to do so for the foreseeable future. The Center’s research focuses on designing software which can be tailored to information systems to ensure the intended operation of their existing components.

**Technology and the Environment,** Virginia Institute, develops environmentally sensitive technology and techniques to mitigate the impacts of current technology on the environment. More than 25 participating engineering faculty members support a broad range of research, including environmental engineering, risk management, contaminant hydrogeology, environmentally sensitive chemical manufacturing, hazardous waste management, alternative energy systems, and the interrelationships of society, technology and the environment.

**Center for Transportation Studies** focuses on issues and problems related to the development, operation, and maintenance of a safe, efficient intermodal transportation system for the Commonwealth of Virginia and the nation. The Center’s research program is noted for being responsive to emerging challenges from the transportation sector and for continually probing into new areas of transportation-related research, like intelligent transportation systems, traffic simulation studies, applications of geographic information systems in facilitating transportation planning and management, and decision support systems using artificial intelligence.

**Virginia Artificial Heart Center** is a major research facility for the design, development and testing of a magnetic bearing supported artificial heart for human implantation. Several prototypes have been successfully testing in pumping both water and blood. The current work is on a ventricular assist version of the pump but future work will be on a total heart replacement.

**Wound Prevention and Repair Center** explores the principles governing mechanical and biological events in chronic skin wounds, developing the necessary monitoring and prevention techniques to eradicate chronic wounds in hospital settings. At the same time, the Center applies these principles to accelerating the repair of acute skin wounds caused by trauma, and improving therapies for skin flap procedures, intestinal ulcers, and neurological injuries.

**Facilities and Services**

The School of Engineering and Applied Science is located in a complex of buildings, the main one being Thornton Hall, named after the first dean of engineering. Thornton Hall houses the school’s administrative offices, the Departments of Civil Engineering, and Electrical and Computer Engineering, the Department of Science, Technology and Society and assorted research laboratories. South of Thornton Hall is Olsson Hall, which houses the Departments of Computer Science, and Systems and Information Engineering. Adjacent to these buildings are three buildings housing the Departments of Mechanical and Aerospace Engineering, Materials Science and Engineering, and Chemical Engineering. Wilsdorf Hall, under construction, will link materials science and chemical engineering and will be ready for occupancy by 2006. The Department of Biomedical Engineering is located in Building MR5, which is part of the Health Sciences Center. The Aerospace Research Laboratory is located on Mount Jefferson.

**Computers** The School of Engineering and Applied Science and the Department of Information Technology and Communication (ITC) provide a wide range of modern facilities to support student computing activities. Students use these computing facilities for a variety of applications including, course work, special projects, research, word processing, spreadsheets, and electronic mail. These facilities are open 24-hours a day, seven days a week, and are staffed with student consultants during the afternoons and evenings. Over 500 workstations of various models are housed in these public labs, all of which are connected to the University network and can be used independently, or to access other computers at the University or worldwide. Some facilities house high-performance Unix workstations that can be used for specific courses or research. To supplement the public facilities, many departments and research groups operate their own computing facilities which are used for specific courses and research projects within those departments. Computer facility equipment ranges from PCs and Macintoshes, to general purpose Unix workstations, high-performance graphics workstations and specialized processors for vision and sound research, to highly advanced parallel processing engines.

The **Charles L. Brown Science and Engineering Library** located in Clark Hall, includes more than 240,000 volumes, 1,500 current serial subscriptions, and 1 million technical reports. A full range of information services is available, including an online catalog with remote access, reference assistance, computerized literature searching, and interlibrary loans and document delivery.

The **Office of Career Services** is available to help engineering students establish their career goals and develop strategies to attain those objectives. In addition to individual appointments, the office provides resource material on career fields, job search strategies, interviewing techniques, and employment opportunities. The office also coordinates on-Grounds interviews in conjunction with University Career Services.

The **Office of Minority Programs**, established in the school in 1986, is available to help students by providing academic support, motivational activities, and financial assistance. The office provides counseling, peer counseling, and other special services for both undergraduate and graduate students. The office and student societies sponsor numerous activities to support engineering students.

**Affiliated Agencies**

The **Virginia Transportation Research Council** is sponsored by the Virginia Department of Transportation in cooperation with the University, and its offices and laboratories are located in the Shelburne Building about one-half mile west of Thornton Hall. The council has two primary objectives: providing training in the fundamentals of transportation engineering; and carrying out research programs to improve the economic design, construction, maintenance, and operation of highways. The council operates laboratories that study problems of highway aggregates, geological engineering, concrete, bituminous materials, soils, bridge structures, and traffic and safety.

The Virginia Transportation Research Council also provides financial assistance for graduate students whose thesis or dissertation research is in an area of interest to the council.

The **Virginia Microelectronics Consortium (VMEC)**, a group of colleges and universities including George Mason University, Old Dominion University, the University of Virginia, Virginia Tech, and the College of William and Mary that offer a world-class program in microelectronics education and research. VMEC was created in 1996 to serve the microelectronics industry in the Commonwealth and to exploit our diverse industry and educational microelectronics resources to our mutual benefit.

The **National Institute of Aerospace (NIA)** at Langley Research Center (LaRC) is a world-class research and education institute created to do cutting edge aerospace and atmospheric research, develop new technologies for the nation and help inspire the next generation of scientists and engineers. The NIA consists of six founding universities - Georgia Tech, North Carolina A&T, North Carolina State University, University of Maryland, University of Virginia, and Virginia Tech - as well as Hampton University, Old Dominion University, The College of William & Mary, and the AIAA Foundation.

The NIA acts as a strategic partner working with LaRC to enhance its world-class aerospace and atmospheric research capability. The Institute complements Langley’s research creativity and expands research and technology development opportunities, and represents the creation of a significant new research and education asset for the nation. The Institute will also be a catalyst for economic development by stimulating the commercialization of new intellectual property and facilitating the growth of new business opportunities.

**Degree Programs**

The University of Virginia School of Engi-
neering and Applied Science offers programs leading to the degree of Master of Science and Master of Engineering, as well as Master degrees in several areas of applied science, and the Doctor of Philosophy degree. The School’s 10 curricula are: biomedical engineering; chemical engineering; civil engineering; computer engineering; computer science; electrical engineering; engineering physics; materials science and engineering; mechanical and aerospace engineering; and systems engineering.

The range of studies available within the school is designed to satisfy a variety of objectives. Specific courses leading to a degree are not prescribed; instead, each student prepares an individual program, with the help of a faculty advisor, tailored to particular needs and goals and then submits it for faculty approval.

Two types of master’s degrees are available. Strong emphasis is placed on research for the Master of Science degree. The focal point of the M.S. is a thesis describing research accomplished in close cooperation with the student’s faculty advisor. The degrees of Master of Engineering and Master of Applied Science are professionally oriented and do not require a thesis.

The Doctor of Philosophy degree is regarded by many as a symbol that its bearer has achieved an in-depth understanding of a segment of human knowledge and has contributed significantly to that knowledge. The Ph.D. requires a program of advanced study in courses and research, satisfactory completion of Ph.D. examinations, and submission of a dissertation based on independent, original research.

**Admission Requirements**

The School of Engineering and Applied Science offers an exceptional educational opportunity for qualified students who seek an environment where graduate study is characterized by integrated learning experiences with highly qualified, experienced, and dedicated faculty. Graduate admissions committees are seeking well-rounded individuals who bring exceptional intellectual capabilities along with a passion for their chosen field. The admissions process looks for evidence of competitive academic performance, work and life experiences, and qualities of character such as motivation, maturity, tenacity, integrity, ability to work with others, self-reliance, and leadership. All applicants are considered without regard to race, color, religion, sex, national origin, political affiliation, disability, age, sexual orientation, or veteran status. The Engineering School welcomes applications from men and women from other countries whose diverse perspectives broaden the range of educational experience for all members of the academic community.

An applicant must have a baccalaureate degree from a recognized college or university. While this degree will normally be in the field of engineering or applied science, degrees in other fields may be acceptable. Undergraduate courses that may be required to remedy deficiencies must be taken without credit. An applicant should have a B average for admission into graduate studies.

Each candidate must complete the Application for Admission. The application requires completion of an essay, complete transcripts of all academic work and three letters of recommendation. A non-refundable application fee must accompany the application; an application will not be considered if the fee has not been paid. All applicants are required to take the Graduate Records Exam (GRE) general exam. International students must have an outstanding command of the English language in order to enroll at the University. The TOEFL exam is required of all applicants if the language first learned and spoken in the home is not English. Most students admitted score at least 600 on the paper exam or 250 on the computer exam. Some students may be required to complete the Summer English for Academic Purposes Program (www.virginia.edu/provost/caelec/summer.html) prior to admission.

Applications may be completed and submitted on-line (https://applyonline.virginia.edu/engineering) or application materials may be downloaded from the same site and submitted by mail to: Graduate Studies, Office of the Dean, School of Engineering and Applied Science, Thornton Hall, Room A-108, P.O. Box 400242 Charlottesville, VA 22904-4242. On-line applications are strongly encouraged. Application information, including recommendations, reach the admissions committees much faster if submitted electronically.

For U.S. citizens and permanent residents, deadlines for complete applications for admission are: December 1 for January admission, May 1 for June admission, and August 1 for September admission. Students requesting financial aid, however, should submit a complete application by January 15 for September admission. International students on visas (other than permanent residents) must apply at least five months prior to the term for which admission is sought.

**Financial Assistance**

The School of Engineering and Applied Science offers financial aid to graduate students through fellowships and assistantships. Students must be nominated by their department to be considered for a fellowship or assistantship. Most superior students can expect to receive aid of some kind throughout their graduate careers.

Students receiving financial aid from the School of Engineering and Applied Science must be registered as full-time students, defined as at least 12 credits of lecture-laboratory courses and/or research during the academic year, must maintain a grade point average of 3.0 and must also maintain satisfactory progress toward a degree. Graduate research assistants must register for a minimum of 6 credits of research during the summer term. Students receiving financial aid are not permitted to have other employment without approval of the Office of Assistant Dean for Graduate Programs. Students are awarded financial assistance to enable them to devote maximum effort to graduate studies.

**Fellowships**

Fellowships are intended to allow graduate students to devote full time to learning opportunities in the classroom and laboratory. No work duties, in a pay for service sense, are required, but good academic progress, including research for the thesis or dissertation, is essential. Some programs, during fellowship support, will include research and teaching duties as part of the usual academic requirements for the degree.

**Graduate Research Assistantships**

Graduate Research Assistants are assigned to work with a faculty member on a specific research project which should culminate in a project report, thesis, or dissertation. Full-time graduate research assistants may not carry a load of more than 9 credits of lecture-laboratory courses but must register each semester for enough additional credits of teaching/research to maintain full-time student status.

**Graduate Teaching Assistantships**

Graduate Teaching Assistants are assigned to assist a faculty member teaching a specific lecture/laboratory course. The assigned duties will depend on the course and instructor. Graduate teaching assistants may not carry a load of more than 9 credits of lecture-laboratory courses but must register each semester for enough teaching/research credit to maintain full-time student status.

**Special Fellowships**

The ARCS Fellowship was established in 1984 as an annual gift from the Metropolitan Washington, D.C. Chapter of the Achievement Rewards for College Scientists Foundation. The recipients are chosen from enrolled students nominated by the departments.

The Virginia Engineering Foundation Fellowship is provided through gifts from alumni and friends of the School of Engineering and Applied Science. The recipient is chosen from enrolled students nominated by the departments.

L. William Ballard, Jr., Fellowship is offered to a graduate student who has demonstrated academic excellence, leadership qualities, and financial need.

Carlos and Esther Farrar Fellowship provides fellowships to deserving students at the University of Virginia studying in disciplines and programs pertaining to scientific investigation of the universe (i.e., aerospace engineering, astrophysics, mathematics). This fellowship is awarded on the basis of scholastic merit and financial need.

John H. and Dorothy W. Sidebottom
Fellowship is offered to graduate students majoring in aerospace engineering.

GEM Fellowships The University of Virginia is a member of the National Consortium for Graduate Degrees for Minorities in Engineering, Inc. While attending one of the member universities for graduate study leading to a master’s degree in engineering, a minority student accepted into the GEM program receives a stipend plus full tuition and fees. The School of Engineering and Applied Science supplements the stipend to equal, at a minimum, the total of the fellowships normally awarded to entering students. Application material can be obtained by contacting Executive Director, GEM, Box 537, Notre Dame, IN 46556, (219) 239-7183.

The Dean’s Fellows Award was established in 1984 to recognize outstanding entering graduate students. This award provides a stipend of $2,000 per year for up to three years, in addition to the financial aid offered by the departments.

General Requirements

Grades The letter grade symbols used for grading graduate students in the School of Engineering and Applied Science are: A+, A, A-, B+, B, B-, C+, C, C-, D+, D, D-, F. To obtain a graduate degree in the School of Engineering and Applied Science, an individual must have a minimum cumulative grade point average of 3.0 on all graded graduate course work taken at the University of Virginia while a graduate student, and graduate courses taken as an undergraduate at the University of Virginia if the courses are listed on a program of studies and are used to satisfy requirements for a graduate degree. No grade lower than a C is acceptable toward meeting the requirements for a graduate degree. If a course is repeated, both grades are used in computing the overall grade average. Undergraduate courses and courses taken on a Credit/No Credit basis may not be used to meet requirements for a graduate degree and are not used in computing the grade average. A 10-day period past the end of the semester (end of the examination period) is automatically allowed to remove an incomplete. A maximum extension to the end of the subsequent semester (the following fall for a spring class and spring for a fall class) may be granted upon special request to the dean’s office.

Quality of Work Graduate degrees are not conferred merely upon the basis of the number of courses passed, nor the length of time spent in residence or in research, but primarily on the basis of the quality and scope of the candidate’s knowledge and power of investigation in a chosen field of study. Unsatisfactory work during any semester or investigation in a chosen field of study may be considered sufficient reason for withdrawal of financial assistance, or for enforced withdrawal from the graduate program. Graduate students are considered to be on probation if their cumulative grade point average for graduate work is less than 3.0 and they are notified of this by the dean’s office. Graduate students are subject to dismissal if their cumulative grade point average is not raised to 3.0 within one semester.

Research All graduate students conducting research must register for the appropriate research course. Credits are assigned to this course in such a way that the total number of credits for which the student is registered reflects the fraction of time devoted to progress toward a degree. Students must register for a minimum of six credits of research for the Master of Science (thesis) degree and 24 credits of research for the Ph.D. degree. In many cases, research in excess of these minimum requirements, particularly for the Ph.D. degree, is desirable. Project research for the Master of Engineering or Master of Applied Science (non-thesis) degrees is encouraged and, in some curricula, required.

Time Limit For Graduate Degrees The student must complete all the requirements for a Master of Science degree within five years after admission to the graduate program, and he or she must complete all requirements for a Master of Engineering degree within seven years after admission to the graduate program. All requirements for the Doctor of Philosophy degree must be completed within seven years after admission to the doctoral program. Expired credits may be revalidated with approval from the advisor, the appropriate department graduate committee or department chair, graduate studies committee, and the Office of the Dean.

Residency M.S. and Ph.D. degree programs require a period of residency. A full-time graduate student in residence at the University, whether taking courses or doing research, is expected to be fully engaged in the academic community, to participate in planned and impromptu discussions with faculty, graduate students and undergraduate students, and to actively contribute to intellectual discourse within the School. During the period of residency, a student should have no major conflicts of commitment. Substantial employment obligations, for example, would generally be in conflict with the residency requirement.

Right to Petition In certain cases there may be extenuating circumstances that cause a deviation from the requirements for the master’s or doctoral degrees. A student has the right to petition the Graduate Studies Committee requesting such a deviation from the normal requirements. This petition should be in writing and endorsed by both the student’s advisor and department chair.

Transfer Credit The Graduate School of Engineering and Applied Science grants transfer credit based on an analysis of the content, level and comparability of the course taken, the applicability of the courses to the student’s intended degree program, the quality of the student’s performance in the course, and the institution at which the work was completed. Transfer credit, as described below, will be considered for acceptance toward a degree in the Graduate School of Engineering and Applied Science.

Master of Science Candidates may include a maximum of six credits of graduate course transfer credit on their program of study at the University of Virginia. They cannot have been used to satisfy requirements for another degree, and only courses with a grade of B or better may be transferred. All requests for the inclusion of transfer credit in the University of Virginia program of study are subject to the approval of the candidate’s academic department and the Office of the Dean for Graduate Programs.

Master of Engineering Candidates may include a maximum of 12 credits of graduate course transfer credit in their program of study at the University of Virginia. They cannot have been used to satisfy requirements for another degree, and only courses with a grade of B or better may be transferred. All requests for the inclusion of transfer credit in the University of Virginia program of study are subject to the approval of the candidate’s academic department and the Office of the Dean.

Doctor of Philosophy Candidates transfer of courses must be submitted for approval in the program of study.

Air Force and Army ROTC Graduate students in the School of Engineering and Applied Science are eligible to participate in the Air Force and Army ROTC programs. Inquiries concerning enrollment in the Air Force ROTC should be addressed to the Professor of Air Science, Varsity Hall. Inquiries concerning enrollment in the Army ROTC should be addressed to the Professor of Military Science, Room B-030, New Cabell Hall. Air and Military Science courses are described in the Undergraduate Record.

M.E.-M.B.A. Joint Degree Program The objective of the joint M.E.-M.B.A. degree program is the development of leaders with business administration skills and solid technical expertise. The M.E. degree provides a foundation in engineering or applied science well above the normal undergraduate level. The M.B.A. develops the functional areas of business by teaching the essential behavioral and quantitative sciences that apply to management, as well as the techniques of management decision making. The combined degrees provide the knowledge required for a wide range of business applications. A student must be admitted to both degree programs and satisfy nearly all of the requirements for both degrees. Typically, the overall program length is reduced by one semester compared to the total time for attaining both degrees separately.

In order to obtain this reduction in the number of credits, the student cannot stop after one degree but must finish both degrees.
If the student decides to drop out of the joint degree program, the full requirements of one of the degree programs must be met.

Students in the M.E.-M.B.A. Joint Degree Program are required to complete 24 credits for the Master of Engineering degree in SEAS and 69 credits for the Master of Business Administration degree in the Darden Graduate School of Business Administration. Of the 24 credits in SEAS, 21 credits will be normal course work and 3 credits will be a project course taken in an appropriately numbered course. A minimum of 12 credits of course work must be taken in the major department, with a maximum of 6 credits at the 500 level. None of these credits may include a course taken in the Darden School. The project must have one advisor from SEAS and another from the Darden School.

Master of Science

The Master of Science degree is a graduate research degree that introduces students to research at the graduate level. A full-time student may be able to complete the program in one and one-half calendar years. The School of Engineering and Applied Science offers instruction leading to degrees in biomedical engineering, chemical engineering, civil engineering, computer engineering, computer science, electrical engineering, engineering physics, materials science and engineering, mechanical and aerospace engineering, and systems engineering.

The department chair appoints an advisor to each graduate student for consultation in preparing a program of study. This program should be approved by the advisor and the department chair, and submitted to the Office of the Dean by the end of the first semester of graduate study. Graduate credit is not automatically granted for courses completed before the program of study is approved. Any later change in the program of study must be submitted for approval. Approval of a program of study does not obligate the University to offer the courses listed, as all graduate courses are offered subject to sufficient enrollment. Candidates who complete the degree requirements and are approved by the faculty are presented for degrees at the University's first scheduled graduation exercise following completion of the requirements.

Degree Requirements A candidate for the Master of Science degree must:

1. complete an approved program of study that includes a minimum of 24 graduate-level credits, with at least 12 credits taken in the area of major study. This program may contain no more than a total of nine credits of 500-level courses, and no more than six of those credits may be taken within the department conferring the degree. Classes at the 400-level or below do not count toward the Masters degree. Departmental requirements may be more restrictive. The program may include a maximum of six transfer credits for graduate courses completed at another school of recognized standing; however, those courses must be part of the approved program of study at the University. Only courses with a grade of B or better may be transferred;
2. complete acceptable research, accomplished under the close direction of a faculty advisor. The research is documented in a written thesis. Written instructions for thesis preparation are available in the Office of the Dean;
3. perform satisfactorily in a final examination of the thesis conducted by an examining committee appointed by the Office of the Dean. Depending on the policy of the individual department, at least one examiner may be from outside the applicant's major department. A candidate who does not perform satisfactorily on the examination may, with the recommendation of two-thirds of the examining committee, be granted a further examination after being given adequate time to prepare;
4. submit the approved thesis. Three copies of the final thesis, as approved by the examining committee, must be submitted for binding by the date specified on the academic calendar;
5. apply for the degree, using a standard form, by the date specified on the academic calendar;
6. complete at least one semester in residence at the University of Virginia as a full-time student; and
7. complete a comprehensive examination (if required by the student’s department).

Master of Engineering

The Master of Engineering degree is a graduate professional degree. It enhances the professional instruction of the bachelor’s program in engineering or applied science, providing greater knowledge and deeper understanding in a specific field. A full-time student should be able to complete the degree program in one calendar year. The School of Engineering and Applied Science offers instruction leading to the degree of Master of Engineering in biomedical engineering; chemical engineering; civil engineering; computer engineering; computer science, electrical engineering; mechanical and aerospace engineering; and systems engineering.

The degrees of Master of Computer Science, Master of Engineering Physics, and Master of Materials Science and Engineering are also offered.

The department chair appoints an advisor to each graduate student for consultation in preparing a program of study. This program must be approved by the advisor and the department chair and submitted to the Office of the Dean by the end of the first semester of graduate study.

Degree Requirements A candidate for the Master of Engineering, Computer Science, Engineering Physics, or Materials Science and Engineering must:

1. complete an approved program that includes a minimum of 30 graduate-level credits, with at least 18 credits taken in the area of major study. This program may contain no more than nine credits of 500-level courses; no more than six of those credits may be taken within the department conferring the degree. Classes at the 400-level or below do not count toward the Masters degree. Departmental requirements may be more restrictive. The program may include a maximum of 12 transfer credits for graduate courses completed at another school of recognized standing; however, those courses must be part of the approved program of study at the University. Only courses with a grade of B or better may be transferred;
2. apply for the degree, using a standard form, by the date specified in the academic calendar; and
3. complete a comprehensive exam (if required by the student’s department).

Accelerated Master’s Degree in Systems and Information Engineering

The Accelerated Master’s Degree in Systems and Information Engineering is designed to enable working professionals to become systems thinkers and problem solvers through a unique blend of formal education integrated with personal work experience. Responding to the needs of industry and individuals alike, this one-year Accelerated Master’s Program enables professionals to earn their degrees without career interruption.

The program’s focus is on information proficiency, systems thinking and decision analytics. The curriculum introduces and explores systems methodologies through real-world case studies firmly focused on problem-solving using both analytical and theoretical modeling approaches throughout.

Taught by full-time faculty of the Department of Systems and Information Engineering and the Darden Graduate School of Business Administration, the program format includes one full week in residence in late May, twenty weekends (Fridays and Saturdays) throughout the year, and a final week in residence during the following April. Tuition covers courses, books, software, lodging and meals.

The program has four core courses: Introduction to Systems Engineering (SYS 601), Systems Integration (SYS 602), Enterprise Analysis and Modeling (SYS 603) and Probabilistic Modeling (SYS 605). Additional elective courses include data analysis and forecasting, risk analysis and modeling, information systems architecture and decision analysis among others. Prerequisites include a bachelor’s degree from an accredited college or university, calculus (2 semesters), probability and statistics (calculus-based), linear algebra (or equivalent) and computer programming. Applicants must take the GRE general exam.

Part-time Graduate Students

Those students who wish to pursue a graduate degree in the School of Engineering and Applied Science on a part-time basis must be approved for admission to the degree program by the department or program offering the degree, and they must meet all admission requirements for full-time degree students.
Part-time students taking on-Grounds courses for degree credit must register through the School of Engineering and Applied Science, not through the School of Continuing and Professional Studies. A maximum of six credits of graduate course work taken on-Grounds through continuing and professional studies prior to admission to a graduate degree program may be accepted as credit toward degree requirements.

**Commonwealth Graduate Engineering Program (CGEP)**

In addition to the resident Master of Engineering degree program conducted on the Grounds of the University of Virginia, the School of Engineering and Applied Science offers the following six degrees through the Commonwealth Graduate Engineering Program: Master of Engineering in Chemical Engineering, Civil Engineering, Electrical Engineering, Mechanical and Aerospace Engineering, and Systems Engineering; Master of Engineering Physics, and Master of Materials Science and Engineering.

Regular graduate courses are taught via videoconferencing throughout the Commonwealth and to selected out-of-state locations. This two-way video/two-way audio capability provides professors and students on-Grounds the ability to communicate with off-Grounds students at remote classroom sites. Serving as off-Grounds receive sites are Virginia Polytechnic Institute and State University, George Mason University, Virginia Commonwealth University, Old Dominion University, Mary Washington College, and Shenandoah University, as well as the Centers for Higher Education in Roanoke, Lynchburg, Northern Virginia, Hampton Roads, Abingdon, and Halifax/South Boston. Additionally, certain companies and government agencies have established classrooms at their locations and participate in this graduate engineering program.

Each of the six departments in this program has an appointed advisor who consults with students on curriculum and any special circumstances that might arise with participating working professionals. Students’ programs of study must be approved by their advisors and the associated department chairs and be submitted to the Office of the Dean.

Degree requirements are the same as mentioned in the previous Master of Engineering section, except that an additional three transfer credits from Virginia Commonwealth University, George Mason University, Old Dominion University, or Virginia Polytechnic Institute and State University may be included in the candidate’s program of study. Graduate courses with grades of C or better taken for graduate credit at participating institutions may be transferred toward meeting the requirement of the Master of Engineering degree.

Graduate courses taken for degree credit through the Commonwealth Graduate Engineering Program, including transfer courses from the participating institutions, are included in the student’s grade point average.

**Doctor of Philosophy**

The School of Engineering and Applied Science offers instruction leading to the degree of Doctor of Philosophy in Biomedical Engineering; Chemical Engineering; Civil Engineering; Computer Engineering; Computer Science; Electrical Engineering; Engineering Physics; Materials Science and Engineering; Mechanical and Aerospace Engineering; and Systems Engineering.

An advisory committee for each doctoral student is appointed by the Office of the Dean upon recommendation of the chair of the student’s department or curriculum area. At least one member of the advisory committee is from outside the student’s department and major current research field. The committee meets with the student as soon as possible to assist in planning a detailed program of study and research. The committee recommends a program of formal courses, discusses research objectives and research plans with the student, and advises the student on the areas in which he or she must take Ph.D. examinations. The committee meets with the student as needed to review progress and, if necessary, to assist the student in revising the program of study.

**Degree Requirements**

The degree of Doctor of Philosophy is conferred by the School of Engineering and Applied Science primarily in recognition of breadth of scholarship, depth of research, and ability to investigate problems independently. A candidate for the Doctor of Philosophy degree must:

1. complete at least three sessions (or the equivalent) after the baccalaureate degree, or two sessions (or the equivalent) after the master’s degree. At least one session beyond the master’s degree must be in full residence at the University of Virginia in Charlottesville. For students who enter a Ph.D. program without a master’s degree, at least 1.5 sessions (3 semesters, not including summer sessions) must be spent in full residence at the University of Virginia in Charlottesville. For the purpose of satisfying these requirements, two regular semesters (not including summer sessions) will be considered as one session.
2. satisfactorily complete an approved program of study. Each program is tailored to the individual student in accordance with the departmental requirements approved by SEAS faculty. The program must include a combined minimum of 72 credits of research and graduate level course work beyond the baccalaureate. The program must also include a minimum of 24 credits of formal course work, with no more than nine of those credits from 500-level courses. No more than six credits at the 500-level may be earned within the department granting the degree. Classes at the 400-level or below do not count toward the Ph.D. degree. Departmental requirements may be more restrictive.

Transfer of course credit from other schools of recognized standing may be included in the program of study; however, only courses with a grade of B or better may be transferred. The student must submit the program for approval first to the department faculty and then to the Office of the Dean within one semester after the Ph.D. exam;
3. perform satisfactorily on the departmental Ph.D. examination. The objective of the examination is to determine whether the student has assimilated and is able to integrate a body of advanced knowledge;
4. submit a dissertation based on independent, original research that makes a significant contribution to the student’s field of study. In preparation for conducting research and writing the dissertation, students must prepare a written dissertation proposal. This proposal describes the current state of the art with bibliography, outlines the proposed method of investigation, and discusses the anticipated results. The student then makes a public, oral presentation of the proposal to the advisory committee, with all members of the faculty invited to attend. After the presentation, the student submits the written dissertation proposal for approval to the department faculty (or its designated committee) and the Office of the Dean;
5. be admitted to candidacy for the degree: a student must have satisfactorily completed the Ph.D. examination and have received approval for the dissertation proposal before being admitted to candidacy. Admission to candidacy must be completed at least one semester before the degree is awarded;
6. satisfactorily present and defend the dissertation in a public forum. The dissertation defense is conducted orally and publicly by a committee appointed by the Office of the Dean; this committee must include the candidate’s advisory committee. The defense is held after the candidate has submitted the dissertation to the committee, and it is designed to test the student’s knowledge of a field of research. Candidates who are accepted by the examining committee and approved by the faculty are presented for degrees at the first scheduled graduation exercises of the University following completion of the requirements;
7. apply for a degree on the standard form by the date specified in the academic calendar;
8. submit three copies of the approved final dissertation to the Office of the Dean by the date specified in the academic calendar.

**Virginia Consortium of Engineering and Science Universities (VCES)**

The College of William and Mary, Old Dominion University, Virginia Tech, and the University of Virginia are involved in a cooperative program of graduate engineering and applied science education and research. This effort focuses on the needs of the NASA Langley...
Research Center and Newport News Shipbuilding and is also intended to serve others in the Peninsula region of the state. This consortium is intended to provide a resident graduate program that emphasizes study for the Ph.D. degree in engineering and applied science and a M.S. degree in naval architecture.

The program complements the Virginia Commonwealth Graduate Engineering Program, which already serves the region by providing, via videoconferencing, courses leading to the Master of Engineering degree. VCES offerings include Ph.D.-level courses broadcast to and from the Peninsula region. The program also includes course offerings taught by resident faculty and adjunct faculty experts from NASA and Newport News Shipbuilding at its regional location in Hampton. Course offerings and research are concentrated in the areas of Aerospace and Ocean Engineering, Mechanical Engineering, Engineering Science and Mechanics, Materials Science and Engineering, Electrical Engineering, and Applied Science.

With the consortium agreement, a student may include 50 percent transfer courses in his or her program of study provided those courses are taught by faculty of the member universities. Accordingly, the student then receives his degree from the institution of his major advisor. The Ph.D. degree requirements are the same as mentioned in the Doctor of Philosophy section, with the exception that residency in Charlottesville is not required.

**National Institute of Aerospace**

The University of Maryland, Virginia Tech, North Carolina State University, North Carolina A&T State University, Georgia Tech, and the University of Virginia are participating in a cooperative program of graduate engineering and applied science education and research centered in the Tidewater area of Virginia. This effort focuses upon research and education opportunities found at the NASA Langley Research Center. It is intended to allow students to pursue M.S. and Ph.D. degrees based upon research conducted at the NASA Langley facility. Students in the NIA program must be U.S. citizens, enroll in the graduate program of one of the six participating schools (their “home institution”), reside in the Tidewater area, and work on a research project at NASA Langley under the guidance of a faculty member at their home institution. Using distance learning technology, students in the NIA program are able to take graduate courses from the six participating schools (the “NIA universities”). A student’s program of study may include 50 percent transfer courses provided that those courses are taught by faculty of the NIA universities. Upon successful completion of the program, a student receives a degree from her or his home institution. Other M.S. and Ph.D. degree requirements are the same as mentioned in the Master of Science and Doctor of Philosophy sections, with the exception that residency in Charlottesville is not required.

**Program Descriptions**

**Applied Mathematics**

The program in Applied Mathematics coordinates and administers mathematics instruction through its APMA courses to students in all departments of the School of Engineering and Applied Science. Mathematical tools and expertise developed are essential to the professional development of the future engineer and applied scientist. This instruction forms the core of the analytical-mathematical component of an engineering education and lays the foundation for ongoing professional development.

**Department of Biomedical Engineering**

Biomedical engineering deals with the interface between technology, biology, and medicine. It draws on the life sciences and medicine, as well as all the physical, mathematical, and engineering fields. Students from a variety of undergraduate disciplines, including biomedical engineering, mechanical engineering, chemical engineering, electrical engineering, and computer science, enter this graduate program and work toward its goals of better health care and enhanced understanding of biological systems.

The Department of Biomedical Engineering offers an undergraduate major degree with courses in physiology, biomedical image analysis, cell and molecular biology, biomedical instrumentation, biomechanics, medical imaging, biomaterials, and bioelectricity. These students come from any undergraduate engineering field or from the physical or life sciences. Appropriate background preparation includes calculus, differential equations, circuit analysis, physics, chemistry, computer programming, and biology.

The Biomedical Engineering Graduate Program encompasses a core curriculum of engineering with an emphasis on instrumentation, mathematics, and life sciences with an emphasis on physiology, cell and molecular biology that reinforces and extends the diverse undergraduate bases of entering students.

Students seeking the Master of Engineering degree develop competence in a field of direct application of engineering to health care. Instrumentation, computer applications, biomechanics, cellular engineering, and image processing are the chief areas of such specialization. Each M.E. student develops a practical project in his or her area of specialization. The project is a departmental requirement for the M.E. degree, applying beyond the 30-credit minimum course requirement. The M.E. degree requires from two to four academic semesters plus one summer.

Students planning careers in development and design, or teaching, usually pursue the Master of Science degree that requires a thesis based on an independent research project. Substantial emphasis is placed on the research project that will be the basis of their master’s thesis, which is expected to be of publishable caliber. The final M.S. exam (oral) focuses on the master’s thesis as well as on areas covered by the student’s program of study. The M.S. degree is designed to prepare students for careers in teaching, industry, and government organizations, and for entry into the Doctoral Program in Biomedical Engineering. Course work in the life sciences and engineering disciplines, completion of a research project under the guidance of a faculty advisor, and documentation of the research in a written thesis are required. Interaction with both the academic and professional scientific and engineering community is also encouraged through participation in seminars, scientific meetings, and publication of research results in scientific journals. Areas of research specialization include molecular bioengineering; magnetic resonance imaging and spectroscopy; image processing; ultrasound imaging; instrumentation; genetic engineering; theoretical and experimental study of cellular biomechanics, mechanotransduction, the cardiovascular, pulmonary, and neurological systems, leukocyte adhesion, and vascular remodeling.

Twenty-four credits of graduate courses and a defense of the submitted thesis describing the student’s research are required.

The Ph.D. program is geared to students planning careers in research in either industry or academic institutions. Advanced courses are followed by dissertation research in vascular engineering, medical imaging, neural engineering, genetic engineering, cellular and molecular engineering, orthopedic engineering, biomechanics, biomaterials, or targeted drug delivery. Doctoral students extend the core program with courses in advanced physiology, cell and molecular biology, mathematics, and engineering. The Ph.D. normally requires three years beyond the master’s, or five beyond the baccalaureate, to achieve the necessary interdisciplinary competence. Exceptional students may choose a double-degree program that, after a minimum of six years, leads to a simultaneous Ph.D. and M.D. For this option, students must be formally admitted to both the School of Engineering and Applied Science and the School of Medicine (M.D./Ph.D. program, MSTP). In addition, a specialized and accelerated program is available for medical doctors who want to acquire a Ph.D. degree (M.D. to Ph.D. program).

M.S. and Ph.D. students may choose from a variety of laboratories to conduct their research. Active research projects in the department include engineering of blood vessel assembly and vascular pattern formation; in vivo leukocyte mechanics and molecular mechanisms; biophysics of cell adhesion; T-cell trafficking in chronic inflammation; atherosclerosis research, microvascular indicator transport for assessing exchange characteristics of endothelium; electron microprobe and patch clamp techniques for molecular and cellular transport; neuromuscular transmission in disease states; blood density measurements for blood volume distribution; fluorescence microscopic assessment of the effect of mechanical stresses on living cells; cellular
mechanotransduction; tissue characterization by high-resolution ultrasound imaging and evaluation of ultrasonic contract agents; multidimensional visualization; rapid imaging of tissue metabolism and blood flow by magnetic resonance imaging techniques; magnetic resonance imaging for noninvasive characterization of atherosclerosis and cancer; development of hyperpolarized helium-3 and xenon-129 gas imaging for assessment of pulmonary ventilation and perfusion by magnetic resonance imaging; tissue characterization of neurological diseases by magnetic resonance spectroscopy; neurological planning; mechanics of soft tissue trauma; and gait analysis. Students benefit from the facilities and collaborators in the Schools of Medicine, Engineering and Applied Science, and Graduate Arts and Sciences. These activities and resources bring the student into contact with the problems and methods typical of such diverse fields to achieve the breadth and judgment that are the goals of the Ph.D. program. A University-wide medical imaging program supports studies on picture archiving and communication systems, rapid MRI (magnetic resonance imaging) acquisition, image perception, MRI of atherosclerosis, image segmentation, MRI microscopy, high resolution ultrasound imaging, and ultrasound contrast agents.

Through a recent Development and Special Award from the Whitaker Foundation, the Department moved into 30,000 square feet of a brand new, state-of-the-art Biomedical Engineering and Medical Sciences Building in February 2002. The building is in the heart of the School of Medicine in close proximity to the hospital and basic medical science departments. It includes modern teaching facilities, laboratories for student projects, physiological and biochemical studies, animal surgery, cell culture, molecular biology, instrument development, and shops for instrument maintenance and fabrication. Equipment includes a variety of sensors and recorders, a cluster of IBM RS/6000 computers, UNIX-based systems, PCs, and MACs, some with A/D and D/A conversion facilities; video equipment; lasers, equipment for static and dynamic characterization of transducers; patch-clamp and intracellular recording facilities. The image-processing facility includes a microscope with a digital CCD camera, high-frequency and clinical ultrasound systems, and SGI and Sun Workstations. Electron microscopes, optical and mass spectrometers, flow cytometry, plasmon resonance, confocal and restoration microscopy systems, proteomics, gene array, ultrasolic, and magnetic resonance imaging equipment are available, as are other specialized equipment and consultation from collaborating departments.

**Department of Chemical Engineering**

The graduate programs in chemical engineering prepare men and women for advanced careers in the chemical, energy, environmental, pharmaceutical, and biotechnology industries as well as for careers in university teaching. Graduate study, which may lead to the Master of Science, Master of Engineering, and Doctor of Philosophy degrees, requires course work extending the fundamentals of chemical reactions, mass transfer, mathematics, thermodynamics and transport processes. Additional courses taken can include applied surface chemistry, biochemical engineering, polymer chemistry and engineering and process control and dynamics. The department also offers advanced graduate courses in selected areas. Study is encouraged in related disciplines such as applied mathematics, chemistry, materials science, mechanical engineering, systems engineering, environmental sciences, and life sciences.

The department’s research areas cover bioengineering/biotechnology; computer and molecular simulation; electrochemical engineering; environmental engineering; heterogeneous catalysis and reaction engineering; materials and interfacial phenomena; separations technology; and thermodynamic properties and phase equilibria. Collaborative research currently involves faculty in the Departments of Biomedical Engineering, Civil Engineering, Chemistry, Environmental Sciences, and Materials Science and Engineering, as well as in the School of Medicine. Students entering the graduate program are invited to discuss research projects with all faculty.

The chemical engineering research laboratories are located in the Chemical Engineering Building and in a renovated wing of Thornton Hall. Laboratories are grouped by specialty, but are open to all graduate students in order to encourage cooperation and the exchange of ideas and experiences among students. The University and the department provide extensive computing facilities in support of education and research.

In addition to the standard full-time programs designed for students entering with chemical engineering degrees, individualized programs can be developed for persons with prior degrees in other disciplines, such as chemistry, or in engineering fields other than chemical engineering.

The Master of Engineering degree can be obtained through part-time, off-grounds study of graduate courses offered in the Commonwealth Graduate Engineering Program (CGEP). Qualified doctoral students are admitted to doctoral study after completing the basic courses, passing the preliminary examination, beginning research and passing the research examination—usually within 12 months of entrance. Doctoral candidates in chemical engineering serve as teaching assistants for at least one semester. Doctoral dissertations are proposed in a proposal examination and defended in a final examination.

**Department of Civil Engineering**

The Department of Civil Engineering offers graduate degree programs in civil engineering. Civil engineering is one of the broadest engineering professions, encompassing such diverse areas as aerospace; construction; environmental, geotechnical, structural, and transportation engineering. Civil engineers are the fabricators of modern society and the protectors of our environment. They deal with people and their management, materials and their use, designs and their application, and the problems of interweaving these factors to serve society.

Graduate study provides opportunities for the development of professional engineering competence and scholarly achievement. Students are prepared for careers leading to management positions in research, development, and design that require creative abilities in solving engineering problems.

A variety of fellowships and assistantships provide financial assistance to qualified graduate students in civil engineering. Research assistantships are available through grants or contracts that support research projects conducted by the faculty. A number of research assistantships are also available through the Virginia Transportation Research Council, a research division of the Virginia Department of Transportation, located on the University Grounds. A limited number of teaching assistantships are available each year to provide tutorial assistance to faculty in several lecture and laboratory courses. In addition, a number of graduate engineering fellowships and tuition scholarships are sponsored by the School of Engineering and Applied Science. Students are also encouraged to apply for various national fellowship awards, including those offered through NSF, NASA, AFOSR, ONR, and DOT, among others.

Degrees offered in civil engineering include the Master of Engineering in Civil Engineering, the Master of Science in Civil Engineering, and the Doctor of Philosophy. The department also participates in the Virginia Cooperative Graduate Engineering Program and provides televised graduate-level courses leading to the Master of Engineering degree. These courses are broadcast live to a variety of locations within Virginia and to selected sites throughout the country.

The requirements for the conferring of the degrees of Master of Engineering in Civil Engineering, Master of Science in Civil Engineering, are the same as those for the School of Engineering and Applied Science given under ‘Degree Requirements.’

The requirements for the conferring of the Doctor of Philosophy in Civil Engineering include the requirements stipulated for the School of Engineering and Applied Science as indicated under ‘Degree Requirements’ with the following additional requirement: The program must include a minimum of 12 credits of formal course work beyond the minimum of 24 credits required for the M.S. degree by the School of Engineering and Applied Science.

Within the Department of Civil Engineering, the principal programs of graduate study are environmental engineering, structural and solid mechanics, transportation engineering, and applied mechanics.

Detailed requirements for Civil Engineering
ing degrees are posted on the department’s web site, www.ce.virginia.edu.

Environmental Engineering emphasizes environmental hydraulics, surface and ground water hydrology, water quality control, and water quality modeling. Research areas include dam safety management, urban hydrology, fate and transport modeling of contaminants in estuaries and coastal waters, sediment-water interactions of contaminants, remediation of contaminated ground water, and sorption of organic pollutants to soil.

Structural and Solid Mechanics utilizes the fundamental principles of structural and solid mechanics, properties and uses of engineering materials toward the multiscale analysis and design of materials, structural components and systems. Research activities include analytical and computational mechanics, linear and nonlinear mechanics of advanced materials, including heterogeneous and functionally graded materials, thermo-mechanical response of nanostructured polymeric systems, dynamic response of structures, field testing of structures, random vibration, and structural reliability.

Transportation Engineering and Planning Transportation interests in the department are concerned with the planning and operation of urban, rural, and intercity facilities; the need to improve the mobility and safety of existing systems; and the design and analysis of advanced transportation pavements. Research areas include decision support systems for intelligent transportation systems, highway safety, geographic information systems, applications of artificial intelligence, public transportation operations; transportation demand management, infrastructure management, and transportation pavement analysis.

Computer Engineering Program
Computer engineering is an exciting field that spans topics across electrical engineering and computer science. Students learn, practice, and perform research related to the design and analysis of computer systems, including both hardware and software aspects and their integration. Careers in computer engineering are wide and varied, ranging from embedded computer systems found in consumer products or medical devices, to control systems for automobiles, aircraft and trains, to more wide-ranging applications in telecommunications, financial transactions and information systems.

Computer Engineering graduate degree programs, Master of Engineering, Master of Science, and Doctor of Philosophy, are jointly administered by the Department of Computer Science and the Department of Electrical and Computer Engineering. For details on facilities and resources available for these degree programs, please consult the sections corresponding to these departments in this graduate record. Students can choose advisors from either one of the departments. Also, students may receive financial assistance in the form of a teaching or research assistantship from either one of these departments.

Computer engineers design, produce, operate, program, and maintain computer and digital systems. They generally apply the theories and principles of science and mathematics to the design of hardware, software, networks, and processes to solve technical problems. Hence research in Computer Engineering covers a broad spectrum of topics, such as computer architecture, embedded systems, integrated circuit design, Very Large Scale Integration (VLSI) systems, Field Programmable Gate Arrays (FPGAs), design automation, hardware/software codesign, software development and systems, software engineering, digital and computer systems design, computer networks, computer and network security, testing, fault-tolerant computing, dependable computing, real-time systems, algorithms, operating systems, middleware, compilers, database management, parallel computing and distributed systems, and computer graphics and vision.

Detailed requirements for these degrees are posted on the web site www.cpe.virginia.edu.

Department of Computer Science
Computer science is that body of knowledge and research associated with the development and utilization of digital computers. It includes material associated with pure and applied mathematics as well as the more technological aspects of engineering subjects. However, the existence and proliferation of computer systems has led to the development of programming languages, operating systems, and other areas of study that have no counterpart in more classical disciplines. For this reason, the department’s instructional and research programs are kept flexible in order to accommodate new areas of importance as they develop.

Programs of study and research through the doctoral level are offered by the department. A suitable background for admission to the graduate program is a bachelor’s degree in computer science or a minor in computer science with a major in physics, engineering, or mathematics. Applicants for this program should have a strong interest in empirical research.

Research in computer science includes algorithms, parallel processing, computer vision, operating systems, system security, performance evaluation, programming languages and environments, software engineering, distributed computing, real-time systems, critical systems and survivability, computer networks and electronic commerce, computer graphics and human-computer interfaces, and databases. A major emphasis is in the development of parallel and distributed computing systems.

The department’s computer core infrastructure is run primarily on Sun Solaris systems, while the desktop computing is dominated by Linux and Windows XP. The infrastructure is linked within the department and to the University’s backbone on Gigabit Ethernet, with 100MB switched Ethernet to the desktop. The department file servers provide over 3 Terabytes of RAID 5 storage available transparently across all systems. The central infrastructure provides support for distributed, parallel and compute intensive jobs on both Sun E280 (UltraSpance-III/8GB RAM) and on dual-cpu AMD (XP2400/2GB RAM) Linux compute servers. On the desktop the department provides the full suite of Microsoft software, including Visual Studio and the .NET compilers and Microsoft Office; most desktop systems are configured to dual-boot RedHat Linux as well. The department also provides a number of high-quality software engineering tools, including commercial development, debugging and version control tools for both the Windows and the Solaris environments.

The department has a number of highly visible research projects that are building innovative, cutting-edge systems. Virginia Embedded Systems Toolkit (VEST) is an integrated environment for constructing and analyzing component-based embedded and real-time systems. Other major projects with national exposure include LEGION, a worldwide virtual computer linking major supercomputer centers across the country; Chromium, a system for scalable interactive graphics on clusters of workstations; POP, or package-oriented programming, for large-scale software reuse and integration; NEST, Networked Embedded Systems Technology for Wireless Sensor Networks; ZEPHYR, a major component of the National Compiler Infrastructure; and SURVIVE, which addresses the vulnerabilities of the information systems embedded in our national infrastructures.

The department offers the Bachelor of Science, Master of Science, Master of Computer Science, and Doctor of Philosophy degrees. Regardless of the degree track all graduate students are expected to engage in serious research. To this end, the department keeps its graduate classes small and fosters a one-to-one relationship with the faculty.

All graduate students are expected to demonstrate breadth of knowledge equivalent to that found in the department’s core courses: Computer Organization (CS 654), Operating Systems (CS 656), and Theory of Computation (CS 660). In addition, they must take at least one graduate-level mathematics course.

Graduate students are also expected to master one area of computer science in depth. To this end, each new student should choose a research advisor within the first semester, take several advanced seminars, and should submit at least one academic publication during their tenure here. Participation in professional conferences is expected.

Although specific course requirements are minimal for the Ph.D. degree, students in the program are expected to develop the mathematical skills necessary for serious scientific research and to participate in the ongoing intellectual life of the department by regular attendance at colloquia and seminars.
Charles L. Brown Department of Electrical and Computer Engineering

The Charles L. Brown Department of Electrical and Computer Engineering offers the Master of Engineering, Master of Science, and Doctor of Philosophy degrees in electrical engineering. Graduate programs of study and research opportunities are available in the areas of automatic controls, digital systems, design automation, solid state devices, microsystems, microfabrication, nanotechnology, communications, network analysis and synthesis, microwave systems, computer engineering, signal processing, and reliable system design and analysis. The selection of a degree program depends upon the interest and background of each individual. The Electrical Engineering Graduate Handbook, describing requirements of the graduate program, is available from the department or online at www.ece.virginia.edu. Financial aid is available to qualified graduate students in the form of graduate research or teaching assistships and fellowships.

The department, in conjunction with the Computer Science Department, offers the Master of Engineering, Master of Science, and Doctor of Philosophy degrees in computer engineering. See the specific section in this catalog that describes these programs.

The department also offers a part-time program in which an employed engineer is able to work toward a masters degree in electrical engineering with a minimum of absence from work. A minimum of two-thirds (and possibly all) of the master’s degree requirements can be completed through courses offered by the University of Virginia Commonwealth Graduate Engineering Program (CGEP). These courses are also available to those who wish to increase their knowledge of electrical engineering but do not wish to enroll in a formal degree program.

Research within the Department of Electrical and Computer Engineering is conducted primarily in the areas of applied electromagnetics (solid state, microsystems, nanotechnology, and microwave systems); communications; controls; signal processing; and computer engineering.

Research in computer engineering within the department is being conducted primarily by a collection of faculty and professional staff conducting research on the design and implementation of complex electronic systems. The research activities within computer engineering are highly interdisciplinary and includes expertise in the areas of analog and digital integrated circuit design, fault tolerance, safety-critical systems, reliability engineering, embedded systems (design, applications, and security) test technology, distributed processing, computer architecture, simulation, design automation, and networks. The disciplines currently represented within the computer engineering research efforts include electrical engineering, mechanical engineering, computer science, and systems engineering.

Research in computer engineering typically includes the development of computer-based systems. Dedicated equipment available for the hardware and software development efforts includes Sun and PC-based workstations, and special purpose hardware for designing and testing full-custom integrated circuits as well as programmable logic devices and field programmable gate arrays. State-of-the-art bench equipment is also available for printed circuit board development and evaluation, including high-speed logic analysis, signal analysis, and microprocessor development. Numerous software systems are available for design description, simulation, test pattern generation, reliability analysis, and system analysis. Examples of such software include the Cadence and Mentor Graphics EDA software. Faculty includes: Professors Aylor, Blalock, Dugan, Johnson, Lach, Stan, Veeraraghavan, and Williams.

A multidisciplinary center called the Center for Safety-Critical Systems is the home for numerous research projects. The overall goal of the center is to create new knowledge that can be used by industry to create safer systems, by regulators to write regulations, for evaluators to compare the safety aspects of complex systems, and by labor to educate the workforce. Although the center grew out of the needs of the railway industry, the general area of systems where safety is a matter of life and death will be addressed. The Center currently receives generous support from the Nuclear Regulatory Commission, Federal Railroad Administration, New York City Transit System, Maglev, Inc., and Lockheed-Martin. In addition, the results of the work conducted for the Federal Railroad Administration was a part of the FRA report to Congress on safety. Finally, representation on the center’s advisory board consists of most of the significant players in the safety field, including the National Transportation Safety Board, the Federal Railroad Administration, the Federal Transit Authority, the American Association of Railroads, the Nuclear Regulatory Commission, and the Intermodal Passenger Transportation Institute.

Communications and signal processing continue to provide exciting research opportunities. New developments in communications and signal processing science and engineering, as well as advances in device technologies, continue to take place especially in the areas of wireless and optical communications and medical imaging. The faculty brings expertise spanning the full range of communication and signal processing theory and engineering to the next generation of communications challenges. Areas of expertise include digital modulation and error control coding; wireless communication, including smart antenna technology; statistical signal processing; optical communications, including fiber and wireless infrared systems; multi-user spread spectrum system analysis; detection and estimation; resource-efficient multiuser communication; and medical imaging. Faculty includes Professors Acton, Brandt-Pearce, Guess, Silverstein, Wilson, and Zheng.

Research in control systems includes several areas in systems and control theory and their applications. The theoretical work spans the areas of adaptive control, nonlinear control, and robust control. Specific topics of interest include control design for systems with nonlinearities, such as backlash, deadzone, failures, hysteresis and saturation, stabilization of nonlinear systems, feedback linearization, sliding mode control, and multivariable adaptive control. Some of the applications of this theoretical work are artificial heart pumps, flight control systems, robotics, high speed rotors suspended on magnetic bearings, unmanned combat aerial vehicles (UCAV). Faculty includes Professors Lin and Tao.

The focus of research in the area of applied electrophysics is in novel solid-state electronic materials, devices, and circuits for microelectronic, optoelectronic, and millimeter-wave applications. Much of the research in this area includes the development of novel devices and systems and is conducted in the Semiconductor Device Laboratories. These laboratories share major fabrication, test, and computing resources, including a 3,500 square foot clean room facility for microelectronic fabrication equipped with molecular beam epitaxy systems for epitaxial growth, lithography with nanometer capability, reactive ion etching, evaporation and sputter deposition of metals, insulators, and superconducting films. Equipment available for material and device evaluation includes a field emission scanning electron microscope with one nanometer resolution, a photoluminescence system, a semiconductor parameter analyzer, a surface profiler, and a variety of optical microscopes, curve tracers, and other equipment. Microwave equipment includes network analyzers, sweep oscillators, and a variety of waveguide components, sources, and detectors for millimeter- and submillimeter-wave applications. Faculty includes: Professors Barker, Bean, Crowe, Gelmont, Globus, Harriott, Hleser, Lichtenberger, Reed, and Weikle, as well as Professor Hull from Materials Science.

The department and the University provide a wide range of computing facilities that support both research and education. The Unix Lab provides Sun Solaris workstations, X terminals, and access to Unix computer-servers, including a high performance parallel processing cluster of IBM/RS6000's. In addition, our facilities provide access to the Web, email, printers, and Engineering software packages, such as Mentor Graphics, Cadence, LabVIEW, Matlab, PSpice, as well as advanced circuit and device simulation packages. Various software development tools and programming languages are also available.

Engineering Physics Program

The graduate program in engineering physics was the first Ph.D. granting program in the School of Engineering and Applied Science. It is a research-oriented program in which students apply the principles of physics to the solution of technical problems. The student prepares for research in a chosen field by...
selecting appropriate courses in mathematics, engineering, physics, and other sciences. Other than the requirement of a minimum of 2 courses in graduate physics courses, 2 courses in graduate engineering courses, and 1 course in graduate mathematics, the master’s student has a wide range of courses from which to select. The Master’s of Science degree requires a total of 8 courses and a Master’s Thesis and the Master’s of Engineering degree requires 10 courses with one course in engineering design. The ME degree is also offered remotely as part of the distance learning program (www.cgep.virginia.edu).

The Ph.D. student must satisfy these same course requirements, with an additional 2 courses in physics, 2 in engineering and 1 in mathematics. If the student by-passes the Master’s degree, then the total course requirement for the Ph.D. is 4 courses in physics, 4 in engineering and 2 in mathematics. Thus, the Engineering Physics Program is extremely flexible, offering students the opportunity to formulate a program of study that closely supports their research activity.

Faculty research advisors for engineering physics students reside in a variety of departments within the University, depending on the student’s research area. Engineering physics research has been directed by faculty members from the Departments of Materials Science and Engineering, Electrical Engineering, Mechanical and Aerospace Engineering, Biomedical Engineering, Physics, Chemistry and the School of Medicine.

Current research areas include nano-technology; photonics; materials properties; planetary science; atomic collisions; surface science; electronic devices; medical physics; computational fluid mechanics; space plasma physics; and nonlinear dynamical systems and chaos. Students oriented towards experimental research may work in a number of facilities, such as the Laboratory for Nanotechnology Institute; Laser Interactions Institute; Atomic and Surface Physics Laboratory, the Semiconductor Device Laboratory, the Medical Imaging Laboratory, the Aerospace Research Laboratory, and the Jefferson National Laboratory.

Financial assistance to qualified engineering physics graduate students is available in several forms. Numerous graduate research assistantships are available in sponsored research programs. Furthermore, a number of graduate engineering fellowships and teaching assistantships are sponsored by the School of Engineering and Applied Science. Students should also apply for National Science Foundation (NSF), Department of Energy, and U.S. National Aeronautics and Space Administration (NASA) fellowships.

Visit the online site at www.virginia.edu/ep for more information.

**Department of Materials Science and Engineering**

The Department of Materials Science and Engineering (MSE) at UVa offers graduate education and research programs in the structure, properties, processing, and performance of materials. The study of materials may be pursued according to their technical importance, as in ceramic or metallurgical engineering, or by considering the general principles that govern their properties. At the University of Virginia, the latter course has been adopted, leading to an understanding of materials through the study of both macroscopic and microscopic viewpoints.

The department provides a broad-based graduate education in materials, one component of which emphasizes the commonality among the various classes of engineering solids. Thus thermodynamics, kinetics, structural analysis and crystallography, defect theory, and principles of the solid state are strong features of the program. In addition, other courses relative to the application of materials and the relationships among materials properties, structure, and the manner in which materials have been processed are also offered. Extensive research programs complement formal course work. Active recent programs on metallurgy, environmental effects on material behavior, electronic materials, fatigue and fracture, tribology, composite materials, and materials processing reflect the diversity of the faculty’s research interests. In addition, the department houses the Center for Light Metals, which oversees a variety of research on Al, Mg, and Ti alloys and composites containing these metals. The Center for Electrochemical Sciences and Engineering conducts interdisciplinary research involving five departments. The Surface Science Laboratory conducts fundamental studies of the surfaces of materials and provides surface analysis services. The Electron Microscope and Image Processing Facility contains a number of electron and ion microscopes used for materials analysis by researchers throughout the Department and School. The newly established NSF-sponsored MRSEC for Nanoscale Materials Design spearheads department efforts in the emerging field of nanotechnology.

The department offers the degrees of Master of Science (M.S.E.) in the Engineering (M.M.S.E.), Master of Science (M.S.) and Doctor of Philosophy (Ph.D.) in Materials Science and Engineering. (M.S.E.), Master of Science (M.S.) and Doctor of Philosophy (Ph.D.). The M.S. and Ph.D. degrees involve extensive-advanced research, leading to a thesis or dissertation, respectively. The M.M.S.E. degree does not include a thesis and is most often achieved by graduate students enrolled in the SEAS distance-learning program. The program of study for each of these degrees has been developed consistent with the principles of academic excellence as a foundation for cutting-edge research and cross-disciplinary learning. Several courses are considered fundamental and constitute a required core for all graduate degrees in MSE. There is, however, great flexibility that enables the graduate student to adapt his or her choice of classes to particular fields of interest and specialization. The graduate program is structured to emphasize acquisition of knowledge and development of critical thinking skills.

**M.S. Degree** The M.S. degree in MSE intends for the successful student to demonstrate both academic achievement and the ability to do independent research in engineering-science, with close faculty guidance. This degree program requires 25-course credits beyond the BS level. All entering M.S. graduate students are enrolled in a 4-course, 12-credit core that includes:

1. Thermodynamics of Materials
2. Materials Structures and Defects
3. One Prescribed Elective selected from:
   - Materials Characterization
   - Deformation and Fracture of Materials
   - During Processing and Service
   - Chemical and Electrochemical Properties of Solid Materials
   - Electronic, Optical and Magnetic Properties of Materials
4. Kinetics of Solid-state Reactions

The M.S. program of study includes 1 credit of MSE seminar, as well as 4 electives beyond the MSE core. These electives are at the 5xx, 6xx and 7xx levels, approved by the graduate student’s advisor and the MSE Curriculum Committee, and selected from all SEAS-course offerings or other UVa Science/Mathematics courses. Up to 6 credits of 5xx MSE courses, and up to 9 credits of 5xx SEAS or UVa courses are permitted. No more than 6 elective credits may be earned in faculty-supervised independent study or advanced-topics courses. One of these 4 electives should be math intensive, consistent with a list established by the MSE faculty. The M.S. degree requires at least 6 credits of research, under the supervision of a faculty advisor, and culminating in a written thesis that is presented and defended in a public forum.

**M.M.S.E. Degree** The M.M.S.E. degree in MSE emphasizes classroom and perhaps laboratory learning, and requires that the student achieve satisfactorily 30 course credits beyond the BS level. The M.M.S.E. program follows the M.S. degree requirements except that the 1-credit seminar course is not required for students enrolled in the distance learning program. This program of study includes 2 additional electives at the 5xx, 6xx and 7xx level, selected from all SEAS-course offerings or other UVa Science/Mathematics courses and subject to approval. Up to 6 credits of electives may be earned in faculty-supervised independent study or advanced topics courses.

**Ph.D. Degree** The Ph.D. degree program in MSE aims to produce tangible-intellectual achievements from independent research at a frontier in the engineering-science of materials. This degree requires that the student achieve satisfactorily 47 course credits, beyond the BS level and beginning with a required 7-course, 21 credit core that includes:

1. Thermodynamics of Materials
2. Materials Structures and Defects
3. Materials Characterization
4. Kinetics of Solid-state Reactions
5. Deformation and Fracture of Materials
   - During Processing and Service
6. Chemical and Electrochemical Properties of Solid Materials

**Course Topics**

1. Thermodynamics of Materials
2. Materials Structures and Defects
3. One Prescribed Elective selected from:
   - Materials Characterization
   - Deformation and Fracture of Materials
   - During Processing and Service
   - Chemical and Electrochemical Properties of Solid Materials
   - Electronic, Optical and Magnetic Properties of Materials
4. Kinetics of Solid-state Reactions

The M.S. program of study includes 1 credit of MSE seminar, as well as 4 electives beyond the MSE core. These electives are at the 5xx, 6xx and 7xx levels, approved by the graduate student’s advisor and the MSE Curriculum Committee, and selected from all SEAS-course offerings or other UVa Science/Mathematics courses. Up to 6 credits of 5xx MSE courses, and up to 9 credits of 5xx SEAS or UVa courses are permitted. No more than 6 elective credits may be earned in faculty-supervised independent study or advanced-topics courses. One of these 4 electives should be math intensive, consistent with a list established by the MSE faculty. The M.S. degree requires at least 6 credits of research, under the supervision of a faculty advisor, and culminating in a written thesis that is presented and defended in a public forum.

**M.M.S.E. Degree** The M.M.S.E. degree in MSE emphasizes classroom and perhaps laboratory learning, and requires that the student achieve satisfactorily 30 course credits beyond the BS level. The M.M.S.E. program follows the M.S. degree requirements except that the 1-credit seminar course is not required for students enrolled in the distance learning program. This program of study includes 2 additional electives at the 5xx, 6xx and 7xx level, selected from all SEAS-course offerings or other UVa Science/Mathematics courses and subject to approval. Up to 6 credits of electives may be earned in faculty-supervised independent study or advanced topics courses.

**Ph.D. Degree** The Ph.D. degree program in MSE aims to produce tangible-intellectual achievements from independent research at a frontier in the engineering-science of materials. This degree requires that the student achieve satisfactorily 47 course credits, beyond the BS level and beginning with a required 7-course, 21 credit core that includes:

1. Thermodynamics of Materials
2. Materials Structures and Defects
3. Materials Characterization
4. Kinetics of Solid-state Reactions
5. Deformation and Fracture of Materials
   - During Processing and Service
6. Chemical and Electrochemical Properties of Solid Materials

**Course Topics**

1. Thermodynamics of Materials
2. Materials Structures and Defects
3. One Prescribed Elective selected from:
   - Materials Characterization
   - Deformation and Fracture of Materials
   - During Processing and Service
   - Chemical and Electrochemical Properties of Solid Materials
   - Electronic, Optical and Magnetic Properties of Materials
4. Kinetics of Solid-state Reactions

The M.S. program of study includes 1 credit of MSE seminar, as well as 4 electives beyond the MSE core. These electives are at the 5xx, 6xx and 7xx levels, approved by the graduate student’s advisor and the MSE Curriculum Committee, and selected from all SEAS-course offerings or other UVa Science/Mathematics courses. Up to 6 credits of 5xx MSE courses, and up to 9 credits of 5xx SEAS or UVa courses are permitted. No more than 6 elective credits may be earned in faculty-supervised independent study or advanced-topics courses. One of these 4 electives should be math intensive, consistent with a list established by the MSE faculty. The M.S. degree requires at least 6 credits of research, under the supervision of a faculty advisor, and culminating in a written thesis that is presented and defended in a public forum.

**M.M.S.E. Degree** The M.M.S.E. degree in MSE emphasizes classroom and perhaps laboratory learning, and requires that the student achieve satisfactorily 30 course credits beyond the BS level. The M.M.S.E. program follows the M.S. degree requirements except that the 1-credit seminar course is not required for students enrolled in the distance learning program. This program of study includes 2 additional electives at the 5xx, 6xx and 7xx level, selected from all SEAS-course offerings or other UVa Science/Mathematics courses and subject to approval. Up to 6 credits of electives may be earned in faculty-supervised independent study or advanced topics courses.

**Ph.D. Degree** The Ph.D. degree program in MSE aims to produce tangible-intellectual achievements from independent research at a frontier in the engineering-science of materials. This degree requires that the student achieve satisfactorily 47 course credits, beyond the BS level and beginning with a required 7-course, 21 credit core that includes:

1. Thermodynamics of Materials
2. Materials Structures and Defects
3. Materials Characterization
4. Kinetics of Solid-state Reactions
5. Deformation and Fracture of Materials
   - During Processing and Service
6. Chemical and Electrochemical Properties of Solid Materials
7. Electronic, Optical and Magnetic Properties of Materials

The Ph.D. program includes 2 credits of MSE seminar and eight 3-credit electives beyond the core. These electives are at the 5xx, 6xx and 7xx levels, approved by the graduate student's advisory Ph.D.-Advisory Committee as well as the MSE Curriculum Committee, and selected from all SEAS-course offerings or other UVa Science/Mathematics courses. One of these 8 elective courses must be math intensive, consistent with a list established by the MSE faculty. At least 15 credits of electives must be at the 7xx or 8xx level. No more than 6 elective credits may be earned in faculty-supervised independent study or advanced-topics courses. Independent study credits will not count as the 15 credits of electives at the 7xx or 8xx level. A maximum of 24 credits may be applied from an M.S. program in another department, school or university, as approved by the MSE Curriculum Committee, and to achieve any part of the core requirement. The Ph.D. candidate's advisory committee will tailor the program of courses to reflect the importance of both depth and breadth in MSE. Breadth may be cross-disciplinary.

The Ph.D. candidate must pass written and oral examinations that include both general and comprehensive elements. These examinations are taken concurrently and within 8-12 months after achieving the M.S. degree. The Ph.D. candidate must write and defend publicly a proposed research plan that is the foundation for his/her dissertation. This proposal must be completed 12 months or more before the defense of the Ph.D. dissertation. The Ph.D. degree requires at least 24 credits of research, under the supervision of a faculty advisor, culminating in a written dissertation that is presented and defended in a public forum. The exceptional graduate student may petition the MSE faculty to bypass the M.S. degree and to follow this Ph.D. program of study. This petition may only be submitted after the core courses for the Ph.D. degree are completed.

The Department of Materials Science and Engineering also participates in the Virginia Cooperative Graduate Engineering Program by presenting televised graduate-level courses that lead to the Master of Materials Science and Engineering degree. These courses are broadcast via satellite to locations both in- and out-of-state in the late afternoon and early evening hours. In addition, the department participates in the Virginia Consortium of Engineering and Science universities program which can lead to the Ph.D. degree.

Department laboratories are well equipped with extensive instrumentation for the investigation of all aspects of materials structure and properties. A modern electron microscope facility includes a 200 kV field-emission gun (FEG) high-resolution transmission electron microscope (HRTEM) equipped with a Gatan imaging filter (GIF) and energy-dispersive X-ray spectrometer (EDXS); a 400 kV dedicated HRTEM with a point-to-point resolution of 0.17 nm; a 200 kV scanning transmission electron microscope (STEM) with EDXS and heating, cooling, and straining specimen holders; two scanning electron microscopes with EDXS, electron-beam lithography, cathodoluminescence and electron backscattered pattern (EBSP) attachments; and a focused ion beam (FIB) microscope equipped with a secondary ion mass spectrometer (SIMS). All microscopes are connected to computers for digital imaging and analysis. X-ray diffraction units provide facilities for a wide variety of single-crystal and powder techniques. The polymer science laboratory offers facilities for infrared spectroscopy, viscosity, differential thermal analysis, automatic osmometry, and for the measurement of thermal, electrical, and optical properties of polymers and other macromolecules. Chemical vapor deposition facilities include equipment for the preparation of electronic materials from metal-organic compounds. The ion beam laboratory has a 110 kV heavy ion accelerator and a 900 kV ion implanter with multiple ultrahigh vacuum experimental chambers. Additional research is conducted in the area of advanced laser processing for nano-scale materials. The facilities include high-power pulsed ultra violet excimer and solid state lasers, time resolved mass spectrometry and imaging, and in-situ diagnostics. Material research areas range from deposition of thin films (electronic, metallic, polymer) and surface modification to biological thin film processing and particular coatings.

Other laboratories are equipped for research in physical metallurgy, fatigue and fracture, electrochemistry, surface studies, thin film properties, and materials processing. Their facilities include mass spectrometers; ultra-high vacuum deposition units; electron beam and vacuum furnaces; heat treating equipment; a rolling mill; numerous mechanical testing machines; a hot isostatic press; an X-ray texture goniometer; optical metallographs; interferometry, and hot stage microscopes; and sophisticated image analysis and processing facilities. A fully equipped machine shop and instrument shop are adjacent to the research laboratories.

Computational facilities within the department include a variety of workstations (SUN, DEC, SGI, and IBM) and personal computers. High performance computing is available through the University’s affiliations with National Computing Centers, and on the University’s 14-node IBM SP2 system housed in the Department of Information Technology and Communication (ITC).

Department of Mechanical and Aerospace Engineering

The department offers graduate programs in mechanical and aerospace engineering. In addition to approximately 80 part-time students, about 65 full-time graduate students are currently enrolled in the department, with approximately 50 percent pursuing the Ph.D.

Financial assistance to qualified mechanical and aerospace engineering graduate students is available in several forms. Graduate research assistantships are available for work on sponsored research. In addition, a number of graduate engineering fellowships and teaching assistantships are sponsored by the School of Engineering and Applied Science. Research and teaching assistantships often are supplemented by department or school fellowship awards.

Mechanical and Aerospace Engineering This combined graduate program offers the degrees of Master of Science, Master of Engineering, and Doctor of Philosophy in Mechanical and Aerospace Engineering. Graduate students in this program may specialize in either (1) continuum and fluid mechanics, (2) thermomechanics, or (3) dynamical systems and control. The particular focus areas range in scales from macro to micro and nano, and in scope from highly theoretical to quite applied, and utilize state-of-the-art analytical, computational, and experimental tools. A large selection of courses is offered covering the above areas. These courses deal with fundamental principles, analytical methods, computational techniques, design methodologies, and practical applications.

Research in the continuum mechanics area includes studies in fluid mechanics and nano mechanics. Current research in fluid mechanics addresses low speed unsteady aerodynamic flows, atmospheric re-entry flows, supersonic mixing, flows in liquid centrifuges, flow in centrifugal pumps, turbomachinery flows, bio-fluid mechanics, hydrodynamic stability, microgravity fluid mechanics, multi-free-surface flows, non-Newtonian fluid mechanics, flow/structure interactions, flows transporting fibers, compressional behavior of fiber assemblies, and free and forced convection. Work on transportation safety includes studies of collision/injury mechanics, complex nonlinear simulation, and restraint optimization. This work is primarily applied to injury mitigation/prevention in automobiles and light aircraft as well as specific work directed at the transportation needs of the disabled. Significant new research thrusts are in morphing structures and polymer electromechanical devices (PEMs).

Research in dynamical systems and control covers a wide range of problems of practical interest including control of machining chatter, vibration control, mechatronics, fluid control, neurodynamic control mechanisms for autonomous mobile robots and biological information processing, intelligent control, and the use of periodicity to enhance the achievable performance of controlled systems. Further, there is substantial work in development and application of modern synthesis techniques to the control of industrial machinery, especially rotating machines with magnetic bearings. Finally, the department hosts a strong activity in rotordynamics research which includes interest in hydrodynamic bearings and seals, turbomachinery, axial and radial flow pumps, model identification techniques, and experimental stability margin assessment.

Research in the thermomechanics
includes topics from micro-scale and non-Fourier heat transfer, combustion (including supersonic), reduced-order chemical kinetics, thermoacoustics, aerogels, remote chemical agents sensing, remote biological agents sensing.

The department’s mechanical and aerospace research facilities include a rotating machinery and control industrial laboratory; a turbomachinery flows laboratory; several subsonic wind tunnel laboratories; a supersonic combustion laboratory; a supersonic wind tunnel laboratory; a structural dynamics laboratory, including an auto crash worthiness laboratory; a nano-scale mechanics and materials laboratory; an atomic-force-microscopy laboratory; a bio thermo fluids laboratory; a micro-scale heat transfer laboratory; a control systems laboratory; and an aerogel laboratory. Several of these laboratories are unique among all universities in the world. For more detailed, up-to-date information about the department’s research programs, and degree requirements, visit the Web site at www.mae.virginia.edu.

**Department of Systems and Information Engineering**

Systems engineers design and implement process, product, and operational improvements in large-scale, complex collections of humans and machines. These collections are systems organized around a central purpose, such as communication, transportation, manufacturing, and environmental protection. The improvements to these systems can target any phase of the life-cycle, from requirements analysis through forecasting, design, development, testing, operation, maintenance, to retirement or replacement.

The central insight in systems engineering is that the analytical techniques for process and product improvement extend across applications. For example, the techniques used to improve communications routing also apply to transportation routing and material handling in manufacturing. The formal disciplines that underlie these techniques constitute the basis for education and training in systems engineering.

The Department of Systems and Information Engineering provides instruction and conducts research in two domains: methodologies for systems analysis, design, and integration; and analytical techniques for making decisions and turning data into information.

**Degree Programs**

The department offers three graduate degrees: Master of Engineering, Master of Science, and Doctor of Philosophy. The plan of study is always tailored to the individual needs and interests of the student; however, each student must gain the knowledge of the fundamental methodologies and techniques of systems engineering.

The M.E. student first learns the fundamentals of systems analysis, design, and integration; and next studies either additional techniques or an application area.

The M.S. student first learns the fundamentals of systems, decision, and information sciences, and next applies this knowledge to a more focused research project leading to a master’s thesis.

Both the M.E. and M.S. students have opportunities for specializing in one of several areas: intelligent decision systems, communication systems, control systems, manufacturing systems, transportation systems, environmental systems, urban systems, health care systems, energy systems, economic systems, financial systems, management systems, risk assessment and management, and information technology.

The Ph.D. student first acquires the advanced knowledge in one area of systems, decision, and information sciences, and next contributes to the research leading to a doctoral dissertation.

Current basic research in the department explores theoretical and methodological issues in the following areas: systems performance evaluation, capacity assurance, and resource allocation; multivariate systems monitoring, discrete event simulation; probabilistic modeling, empirical model building, data fusion, and data mining; risk assessment and management; financial engineering; learning algorithms and dynamic games; optimization, dynamic programming, and Markov decision processes; Bayesian forecasting and decision theories; cognitive systems engineering, human-computer interaction and decision support.

**Research Projects**

Both M.S. and Ph.D. students typically associate with an ongoing research project in the department. These projects involve both theoretical and applied elements and allow students to work closely with faculty on challenging, contemporary problems. Examples of current research projects include complex networks optimization, intelligent transportation system, air traffic prediction system, probabilistic forecasting of weather, flood warning system, semiconduc
tor operational modeling, spatial knowledge discovery, regional crime data analysis, clinical and biological data integration, critical safety data analysis, mitigation of risk to cyber and physical infrastructure, credit scoring and credit portfolio management, valuation of intellectual property.

**Televisioned M.E. Program**

A part-time degree program is available through the Commonwealth Graduate Engineering Program. Regular courses are televised, which offers employed engineers the opportunity to earn credits toward the M.E. degree while requiring a minimum of absences from work. The program is designed so that over a three-year period all of the M.E. degree requirements may be completed through courses taken in the late afternoon or early evening. These courses are also available to those who wish to increase their knowledge of systems engineering but do not wish to enroll in a degree program.

For more detailed information about the department, degree programs, and research areas, visit the website at www.sys.virginia.edu.

**Course Descriptions**

The course descriptions listed below are arranged alphabetically under the heading of the department or program offering the instruction. Courses offered jointly by two or more programs are described under each program involved and cross referenced.

Most graduate study programs include courses offered by departments other than the student’s major department. Students are urged to consider the complete list of course offerings in planning their programs of study.

Courses with 500 numbers are intermediate-level courses that may be taken by both undergraduate and graduate students. Courses with numbers between 600 and 699 are introductory graduate courses recommended for beginning graduate students or non-majors. Courses with numbers of 700 and above are recommended for advanced graduate and doctoral students.

All courses are offered subject to adequate enrollment; thus, any course may be cancelled if enrollment is insufficient.

Unless otherwise indicated, courses meet for three hours of lecture each week. Each semester course in the School of Engineering and Applied Science carries separate credit, whether described separately or not. The number set in brackets following a course title indicates the number of credits granted for that course. Enrollment in courses for which there are no prerequisites listed, or for which prerequisites are not met require the instructor’s permission.

**Aerospace Engineering**

See Mechanical and Aerospace Engineering.

**Applied Mathematics**

**APMA 507 - (3) (SI)**

**Numerical Methods**

*Prerequisite:* Two years of college mathematics, including some linear algebra and differential equations, and the ability to write computer programs.

Introduces techniques used to obtain numerical solutions, emphasizing error estimation. Areas of application include approximation and integration of functions, and solution of algebraic and differential equations.

**APMA 602 - (3) (Y)**

**Continuum Mechanics with Applications**

*Prerequisite:* Instructor permission.

Introduces continuum mechanics and mechanics of deformable solids. Vectors and Cartesian tensors, stress, strain, deformation, equations of motion, constitutive laws, introduction to elasticity, thermal elasticity, viscoelasticity, plasticity, and fluids. Cross-listed as AM 602, CE 602, and MAE 602.

**APMA 613 - (3) (SI)**

**Mathematical Foundations of Continuum Mechanics**

*Prerequisite:* Linear Algebra, Vector Calculus, Elementary PDE (may be taken concurrently).

Describes the mathematical foundations of continuum mechanics from a unified viewpoint. Review of relevant concepts from linear algebra, vector calculus, and Cartesian tensors; kinematics of finite deformations and motions; finite strain measures; lin-
APMA 615 - (3) (SI)  
Linear Algebra  
Prerequisite: Three years of college mathematics or instructor permission.  
Analyzes systems of linear equations; least squares procedures for solving over-determined systems; finite dimensional vector spaces; linear transformations and their representation by matrices; determinants; Jordan canonical form; unitary reduction of symmetric and Hermitian forms; eigenvalues; and invariant subspaces.

APMA 642 - (3) (O)  
Nonlinear Dynamics and Waves  
Prerequisite: Undergraduate ordinary differential equations or instructor permission.  
Introduces phase-space methods, elementary bifurcation theory and perturbation theory, and applies them to the study of stability in the contexts of nonlinear dynamical systems and nonlinear waves, including free and forced nonlinear vibrations and wave motions. Examples are drawn from mechanics and fluid dynamics, and include transitions to periodic oscillations and chaotic oscillations. Also cross-listed as MAE 624.

APMA 634 - (3) (SI)  
Numerical Analysis  
Prerequisite: Two years of college mathematics, including some linear algebra, and the ability to write computer programs.  
Topics include the solution of systems of linear and nonlinear equations, calculations of matrix eigenvalues, least squares problems, and boundary value problems in ordinary and partial differential equations.

APMA 637 - (3) (O)  
Singular Perturbation Theory  
Prerequisite: Familiarity with complex analysis.  
Analyzes of regular perturbations; roots of polynomials; singular perturbations in ODE's; periodic solutions of simple nonlinear differential equations; multiple-Scales method; WKBJ approximation; turning-point problems; Langer's method of uniform approximation; asymptotic behavior of integrals; Laplace Integrals; stationary phase; and steepest descents. Examples are drawn from physical systems. Cross-listed as MAE 637.

APMA 641 - (3) (Y)  
Engineering Mathematics I  
Prerequisite: Graduate standing.  
Review of ordinary differential equations. Initial value problems, boundary value problems, and various physical applications. Linear algebra, including systems of linear equations, matrices, eigenvalues, eigenvectors, diagonalization, and various applications. Scalar and vector field theory, including the divergence theorem, Green's theorem, Stokes theorem, and various applications. Partial differential equations that govern physical phenomena in science and engineering. Solution of partial differential equations by separation of variables, superposition, Fourier series, variation of parameters, d'Alembert's solution. Eigenfunction expansion techniques for nonhomogeneous initial-value, boundary-value problems. Particular focus on various physical applications of the heat equation, the potential (Laplace) equation, and the wave equation in rectangular, cylindrical, and spherical coordinates. Cross-listed as MAE 641.

APMA 642 - (3) (O)  
Engineering Mathematics II  
Prerequisite: Graduate standing and APMA 641 or equivalent.  

APMA 643 - (3) (Y)  
Statistics for Engineers and Scientists  
Prerequisite: Admission to graduate studies.  
Analyzes the role of statistics in science; hypothesis tests of significance; confidence intervals; design of experiments; regression; correlation analysis; analysis of variance; and introduction to statistical computing with statistical software libraries.

APMA 644 - (3) (O)  
Applied Partial Differential Equations  
Prerequisite: APMA 642 or equivalent.  
Includes first order partial differential equations (linear, quasilinear, nonlinear); classification of equations and characteristics; and well-posedness of initial and boundary value problems. Cross-listed as MAE 644.

APMA 648 - (3) (SI)  
Special Topics in Applied Mathematics  
Prerequisite: Instructor permission.  
Topics vary from year to year and are selected to fill special needs of graduate students.

APMA 672 - (3) (Y)  
Computational Fluid Dynamics I  
Prerequisite: MAE 631 or instructor permission.  
Topics include the solution of flow and heat transfer problems involving steady and transient convective and diffusive transport; superposition and panel methods for inviscid flow; finite-difference methods for elliptic, parabolic, and hyperbolic partial differential equations; elementary grid generation for odd geometries; and primitive variable and vorticity-steam function algorithms for incompressible, multidimensional flows. Extensive use of personal computers/workstations including graphics. Cross-listed as MAE 672.

APMA 693 - (Credit as arranged) (SI)  
Independent Study  
Detailed study of graduate-level material on an independent basis under the guidance of a faculty member.

APMA 695 - (Credit as arranged) (Y)  
Supervised Project Research  
Formal record of student commitment to project research under the guidance of a faculty advisor. May be repeated as necessary.

APMA 708 - (3) (SI)  
Inelastic Solid Mechanics  
Prerequisite: AM/MAE 602.  
Emphasizes the formulation of a variety of nonlinear models. Specific topics include nonlinear elasticity, creep, visco-elasticity, and elastoo-plasticity. Solutions to boundary value problems of practical interest are presented in the context of these various theories in order to illustrate the differences in stress distributions caused by different types of material nonlinearities. Cross-listed as AM 708.

APMA 714 - (3) (SI)  
Nonlinear Elasticity Theory  
Prerequisite: AM/APMA 602.  
This course describes the theory of finite (nonlinear) elasticity governing large deformations of highly deformable elastic solids. Both incompressible and compressible materials are considered. Also emphasized are instabilities (both material and geometric), normal stress effects, non-uniqueness, bifurcations and stress singularities. A variety of illustrative boundary-value problems are discussed which exhibit some of the foregoing features. Both physical and mathematical implications are considered. The results are applicable to rubber-like and biological materials and the theory serves as a prototype for more elaborate nonlinear theories of mechanics of continuous media. Cross-listed as AM 714.

APMA 734 - (3) (SI)  
Numerical Solution of Partial Differential Equations  
Prerequisite: One or more graduate courses in mathematics or applied mathematics.  
Topics include the numerical solution of elliptic equations by finite element methods; solution of time dependent problems by finite element and finite difference methods; and stability and convergence results for the methods presented.

APMA 747, 748 - (3) (SI)  
Selected Topics in Applied Mathematics  
Prerequisite: Instructor permission.  
Content varies annually; topics may include wave propagation theory, shell theory, control theory, or advanced numerical analysis.
APMA 767 - (3) (SI)
Micromechanics of Heterogeneous Media
Prerequisite: APMA 602.
Includes averaging principles; equivalent homogeneity; effective moduli; bounding principles; self-consistent schemes; composite spheres; concentric cylinders; three phase model; repeating cell models; inelastic and nonlinear effects; thermal effects; isotropic and anisotropic media; and strength and fracture. Cross-listed as AM 767, and CE 767.

APMA 772 - (3) (Y)
Computational Fluid Dynamics II
Prerequisite: APMA 672 or equivalent.

APMA 792 - (Credit as arranged) (SI)
Independent Study
Detailed study of advanced graduate-level material on an independent basis under the guidance of a faculty member.

APMA 847, 848 - (3) (SI)
Advanced Topics in Applied Mathematics
Prerequisite: Instructor permission.
Course content varies from year to year and depends on students' interests and needs. See APMA 747 for possible topics.

APMA 895 - (Credit as arranged) (S-SS)
Supervised Project Research
Formal record of student commitment to project research for Master of Applied Mathematics degree under the guidance of a faculty advisor. Registration may be repeated as necessary.

APMA 897 - (Credit as arranged) (S)
Graduate Teaching Instruction
For master's students.

APMA 898 - (Credit as arranged) (S-SS)
Thesis
Formal record of student commitment to master's thesis research under the guidance of a faculty advisor. Registration may be repeated as necessary.

APMA 997 - (Credit as arranged) (S)
Graduate Teaching Instruction
For doctoral students.

APMA 999 - (Credit as arranged) (S-SS)
Dissertation
Formal record of student commitment to doctoral research under the guidance of a faculty advisor. May be repeated as necessary.

Applied Mechanics
AM 601 - (3) (Y)
Advanced Mechanics of Materials
Prerequisite: Undergraduate mechanics and mathematics.
Reviews basic stress-strain concepts and constitutive relations. Studies unsymmetrical bending, shear center, and shear flow. Analyzes of curved flexural members, torsion, bending, and twisting of thin walled sections. Cross-listed as CE 601.

AM 602 - (3) (Y)
Continuum Mechanics With Applications
Introduces continuum mechanics and mechanics of deformable solids. Topics include vectors and cartesian tensors, stress, strain, deformation, equations of motion, constitutive laws, introduction to elasticity, thermal elasticity, viscoelasticity, plasticity, and fluids. Cross-listed as APMA 602, CE 602, and MAE 602.

AM 603 - (3) (Y)
Computational Solid Mechanics
Analyzes of variational and computational mechanics of solids, potential energy, complementary energy, virtual work, Reissner's principle, Ritz and Galerkin methods; displacement, force and mixed methods of analysis; finite element analysis, including shape functions, convergence and integration; and applications in solid mechanics. Cross-listed as CE 603 and MAE 603.

AM 604 - (3) (E)
Plates and Shells
Prerequisite: APMA 641 and AM 601 or 602.
Topics include the classical analysis of plates and shells; plates of various shapes (rectangular, circular, skew) and shells of various shape (cylindrical, conical, spherical, hyperbolic, paraboloid); closed-form numerical and approximate methods of solution governing partial differential equations; and advanced topics (large deflection theory; thermal stresses, orthotropic plates). Cross-listed as CE 604 and MAE 604.

AM 606 - (3) (Y)
Applied Boundary Element Analysis
Prerequisite: AM 671 or 603.
Analyzes the fundamental concepts of Green's functions, integral equations, and potential problems; weighted residual techniques and boundary element methods; poisson type problems, including cross-sectional analysis of beams and flow analyses; elastostatics; and other applications.

AM 607 - (3) (E)
Theory of Elasticity
Prerequisite: AM 602 or instructor permission.
Review of the concepts of stress, strain, equilibrium, compatibility; Hooke's law (isotropic materials); displacement and stress formulations of elasticity problems; plane stress and strain problems in rectangular coordinates (Airy's stress function approach); plane stress and strain problems in polar coordinates, axisymmetric problems; torsion of prismatic bars (semi-inverse method using real function approach); thermal stress; and energy methods. Cross-listed as CE 607 and MAE 607.

AM 613 - (3) (Y)
Mathematical Foundations of Continuum Mechanics
Prerequisite: Linear algebra, vector calculus, elementary PDE (may be taken concurrently).
Describes the mathematical foundations of continuum mechanics from a unified viewpoint. The relevant concepts from linear algebra, vector calculus, and Cartesian tensors; the kinematics of finite deformations and motions leading to the definition of finite strain measures; the process of linearization; and the concept of stress. Conservation laws of mechanics yield the equations of motion and equilibrium and description of constitutive theory leading to the constitutive laws for nonlinear elasticity, from which the more familiar generalized Hooke's law for linearly elastic solid is derived. Constitutive laws for a Newtonian and non-Newtonian fluid are also discussed. The basic problems of continuum mechanics are formulated as boundary value problems for partial differential equations. Cross-listed as APMA 613.

AM 620 - (3) (Y)
Energy Principles in Mechanics
Prerequisite: Instructor permission.
Analyzes the derivation, interpretation, and application of the principles of virtual work and complementary virtual work to engineering problems; related theorems, such as the principles of the stationary value of the total potential and complementary energy, Castiglione's Theorems, theorem of least work, and unit force and displacement theorems. Introduces generalized, extended, mixed, and hybrid principles; variational methods of approximation, Hamilton's principle, and Lagrange's equations of motion. Uses variational theorems to approximate solutions to problems in structural mechanics. Cross-listed as CE 620 and MAE 620.

AM 621 - (3) (Y)
Analytical Dynamics
Prerequisite: Differential equations, undergraduate dynamics course.
Topics include the kinematics of rigid body motion; Eulerian angles; Lagrangian equations of motion; moment of inertia; rigid ellipsoid; rigid body equations of motion, Euler's equation, force-free motion; polhode and herpolhode; theory of tops and gyroscopes; variational principles; Hamiltonian equations of motion, Poinsot representation. Cross-listed as MAE 621.

AM 622 - (3) (O)
Waves
Prerequisite: MAE/AM 602 Continuum Mechanics and Applications, or equivalent.
The topics covered are: plane waves; d'Alembert solution; method of characteristics; dispersive systems; wavepackets; group velocity; fully-dispersed waves; Laplace, Stokes, and steepest descents integrals; membranes, plates and plane-stress waves; evanescent waves; Kirchhoff's solution; Fresnel's principle; elementary diffraction; reflection and transmission at interfaces; waveguides and ducted waves; waves in elastic half-spaces; P, S, and Rayleigh waves; layered media and
Love waves; slowly-varying media and WKBJ method; Time-dependent response using Fourier-Laplace transforms; some nonlinear water waves. Also cross-listed as MAE 622.

**AM 623 - (3) (SI)**

**Vibrations**

**Prerequisite:** Instructor permission. 
Topics include free and forced vibrations of undamped and damped single-degree-of-freedom systems and undamped multidegree-of-freedom systems; use of Lagrange’s equations; Laplace transform, matrix formulation, and other solution methods; normal mode theory; introduction to vibration of continuous systems. Cross-listed as CE 623 and MAE 623.

**AM 628 - (3) (SI)**

**Motion Biomechanics**

**Prerequisite:** BIOM 603 or instructor permission. 
Focuses on the study of forces (and their effects) which act on the musculoskeletal structures of the human body. Based on the foundations of functional anatomy and engineering mechanics (rigid body and deformable approaches); students are exposed to clinical problems in orthopaedics and rehabilitation. Cross-listed as BIOM 628.

**AM 631 - (3) (Y)**

**Fluid Mechanics I**

**Prerequisite:** Instructor permission. 
Analyzes of hydrostatics, including surface tension; kinematics; non-inertial reference frames; rigorous formulation of conservation equations for mass, momentum, and energy; Euler and Bernoulli equations; vorticity dynamics; two-dimensional potential flow theory, complex potentials; applications to airfoils; the Navier-Stokes equations: selected exact and approximate solutions. Cross-listed as MAE 631.

**AM 632 - (3) (Y)**

**Fluid Mechanics II**

**Prerequisite:** AM 631. 
Topics include the laminar boundary layer equations, differential and integral; elementary similar and integral solutions; introduction to and modeling of turbulent flows; surface waves; quasi-one-dimensional compressible, perfect gas dynamic analysis; practical applications. Cross-listed as MAE 632.

**AM 665 - (3) (Y)**

**Mechanics of Composite Materials**

**Prerequisite:** ECE 206 and APMA 213. 
Analyzes the properties and mechanics of fibrous, laminated composites; 2-D and 3-D anisotropic constitutive equations; classical lamination theory; thermal stresses; material response and test methods; edge effects; design considerations; and computerized implementation. Cross-listed as CE 665.

**AM 666 - (3) (Y)**

**Stress Analysis of Composites**

**Prerequisite:** AM 665. 
Analyzes 3-D anisotropic constitutive theory, interlaminar stresses, failure criteria, micromechanics, cylindrical bending, laminated tubes, laminated plates, damage mechanics, and hygro-thermal effects. Cross-listed as CE 666.

**AM 671 - (3) (Y)**

**Finite-Element Analysis**

**Prerequisite:** Instructor permission. 
Introduces finite element methods for solving problems in heat transfer, fluid mechanics, solid mechanics, and electrical fields. Emphasizes the basics of one, two, and three-dimensional elements; applications to bars, electrical networks, trusses, conduction and convection heat transfer, ideal and viscous flow, electrical current flow, plane stress, plane strain, and elasticity; development of computer codes to implement finite element techniques. Cross-listed as MAE 671.

**AM 675 - (3) (SI)**

**Theory of Structural Stability**

**Prerequisite:** Instructor permission.
Introduces the elastic stability of structural and mechanical systems. Topics include classical stability theory and buckling of beams, trusses, frames, arches, rings and thin plates and shells; derivation of design formulas; computational formulation and implementation. Cross-listed as CE 675.

**AM 691, 692 - (3) (IR)**

**Special Problems in Applied Mechanics**

Detailed study of special topics in mechanics.

**AM 693 - (Credit as arranged) (Y)**

**Independent Study**

Detailed study of graduate course material on an independent basis under the guidance of a faculty member.

**AM 695 - (Credit as arranged) (Y)**

**Supervised Project Research**

Formal record of student commitment to project research under guidance of a faculty advisor. Registration may be repeated if necessary.

**AM 703 - (3) (Y)**

**Thermal Structures**

**Prerequisite:** AM 602 or instructor permission; corequisite: AM 607.
Topics include the fundamentals of thermal structural analysis; mechanical and thermo-dynamic foundations; formulation of heat transfer and thermal-structural problems; heat transfer in structures; thermal stresses in rods, beams, and plates; thermally induced vibrations; thermoelastic stability; and computational methods.

**AM 704 - (3) (SI)**

**Theory of Shells**

**Prerequisite:** AM 602 and 604. 
Introduces the nonlinear, thermoelastic theory of shells. Governing equations are derived by a mixed approach in which those equations of three-dimensional continuum mechanics that are independent of material properties are used to derive the corresponding shell equations, whereas the constitutive equations of shell theory which, unavoidably, depend on experiments, are postulated. Emphasizes efficient, alternative formulations of initial/boundary value problems, suitable for asymptotic or numerical solution, and discusses variational principles. Some comparisons made with exact, three-dimensional solutions.

**AM 708 - (3) (SI)**

**Inelastic Solid Mechanics**

**Prerequisite:** AM 602. 
Emphasizes the formulation of a variety of nonlinear models. Specific topics include nonlinear elasticity, creep, visco-elasticity, and elasto-plasticity. Solutions to boundary value problems of practical interest are presented in the context of these various theories in order to illustrate the differences in stress distributions caused by different types of material nonlinearities. Cross-listed as APMA 708.

**AM 712 - (3) (SI)**

**Advanced Theory of Elasticity**

**Prerequisite:** AM 602 or instructor permission and AM 607. 
Topics include generalized Hooke’s law, strain-energy density, uniqueness; classes of boundary value problems (Navier’s and Beltrami-Mitchell equations); torsion (Dirichlet and Neumann problems); flexure; complex variable formulation of torsional (Dirichlet and Neumann problems) and two-dimensional problems; general solution methodologies based on complex variable techniques and elements of potential theory for torsional and two-dimensional problems; three-dimensional problems; wave propagation; and energy methods.

**AM 714 - (3) (SI)**

**Nonlinear Elasticity Theory**

**Prerequisite:** AM 602. 
Describes the theory of finite (nonlinear) elasticity governing large deformations of highly deformable elastic solids. New features not present in the linear theory are emphasized. These include instabilities (both material and geometric), normal stress effects, non-uniqueness, bifurcations and stress singularities. A variety of illustrative boundary value problems will be discussed which exhibit some of the foregoing features. Both physical and mathematical implications considered. The results are applicable to rubber-like and biological materials and the theory serves as a prototype for more elaborate nonlinear theories of mechanics of continuous media. Cross-listed as APMA 714.

**AM 725 - (3) (SI)**

**Random Vibrations**

**Prerequisite:** Background in probability theory and vibration analysis. 
Topics include a review of probability theory; stochastic processes, with an emphasis on continuous, continuously parameterized processes; mean square calculus, Markov processes, diffusion equations, Gaussian processes, and Poisson processes; response of SDOF, MDOF, and continuous linear and nonlinear models to random excitation; upcrossings, first passage problems, fatigue and stability the considerations; Monte Carlo simulation, analysis of digital time series data, and filtered excitation models. Cross-listed as CE 725.

**AM 729 - (3) (IR)**

**Selected Topics in Applied Mechanics**

**Prerequisite:** instructor permission. 
Subject matter varies from year to year.
depending on students' interest and needs. Typical topics may include geophysics, astrodynamics, water waves, or nonlinear methods.

**AM 732 - (3) (Y)**
Fracture Mechanics of Engineering Materials
*Prerequisite:* MSE 731 or instructor permission.
Develops the tools necessary for fatigue and fracture control in structural materials. Continuum fracture mechanics principles are presented. Fracture modes are discussed from the interdisciplinary perspectives of continuum mechanics and microscopic plastic deformation/fracture mechanisms. Cleavage, ductile fracture, fatigue, and environmental cracking are included, with emphasis on micromechanical modeling. Cross-listed as MSE 732.

**AM 767 - (3) (SI)**
Micromechanics of Heterogeneous Media
*Prerequisite:* AM 602.
Analyzes averaging principles, equivalent homogeneity, effective moduli, bounding principles, self-consistent schemes, composite spheres, concentric cylinders, three phase model, repeating cell models, inelastic and nonlinear effects, thermal effects, isotropic and anisotropic media, strength and fracture. Cross-listed as APMA 767 and CE 767.

**AM 793 - (Credit as arranged) (Y)**
Independent Study
Detailed study of graduate course material on an independent basis under the guidance of a faculty member.

**AM 822 - (3) (SI)**
Biomechanics
*Prerequisite:* Instructor permission.
Topics include the rheological properties of biological tissues and fluids, with emphasis on methods of measurement and data organization; basic principles of continuum mechanics and their application to mechanical problems of the heart, lung, and peripheral circulation; criteria for selecting either lumped or continuous models to simulate mechanical interaction of biological systems (and mechanical prostheses) and application of such models under static and dynamic loading conditions. Cross-listed as BIOM 822.

**AM 895 - (Credit as arranged) (Y)**
Supervised Project Research
Formal record of student commitment to project research for Master of Engineering degree under the guidance of a faculty advisor. May be repeated as necessary.

**AM 897 - (Credit as arranged) (S)**
Graduate Teaching Instruction
For master’s students.

**AM 997 - (Credit as arranged) (S)**
Graduate Teaching Instruction
For doctoral students.

**Biomedical Engineering**

**BIOM 601 - (3) (Y)**
Engineering Physiology

**BIOM 603 - (3) (Y)**
**Physiology I**
*Prerequisite:* Instructor permission. Suggested preparation: physics, chemistry, cell biology, and calculus.
The integration of biological subsystems into a coherent, functional organism is presented, in a course designed for students with either an engineering or life science background. Topics covered include major aspects of mammalian physiology, with an emphasis on mechanisms. The structure and function of each system is treated, as well as the interrelations and integration of their hormonal and neural control mechanisms. Studies how excitable tissue, nerves, and muscle, and the cardiovascular and respiratory systems work.

**BIOM 604 - (3) (Y)**
**Physiology and Pathophysiology**
*Prerequisite:* BIOM 603 or instructor permission.
This course will emphasize a fundamental understanding of physiology with a focus on mechanisms, and continues the coverage of major systems from BIOM 603. Studies the renal, gastrointestinal, endocrine, and central nervous systems. Integration of function from molecule to cell to organ to body. Includes some functional anatomy. Quantitative understanding of problems like salt and water balance through class work and homework sets. Five lectures on specific diseases and their pathophysiology.

**BIOM 610 - (4) (Y)**
**Instrumentation and Measurement in Medicine I**
*Prerequisite:* Instructor permission. Suggested preparation: physics and mathematics through differential equations.
Presentation of the fundamental circuit concepts and signal and system analysis methods used in the design and analysis of medical instrumentation. Circuit concepts include passive electronic circuits, operational amplifier circuits, circuit solution methods, and filter design methods. Special emphasis is placed on circuits commonly employed in medical devices, such as, differential amplifiers and filtering networks used in electrocardiograph systems. Signal and system analysis topics include linear system definitions, convolution, Fourier transforms, and Laplace transforms. Students perform a project using the signal and systems analysis methods to model and analyze biomedical problems. A laboratory, equivalent to one of the four course credits, provides experience in electronic circuit construction and testing, and numerical modeling and analysis of signals and systems.

**BIOM 611 - (4) (Y)**
**Instrumentation and Measurement in Medicine II**
*Prerequisite:* Instructor permission, and EE 203 or MAE 202.
Preparation: Mathematics through differential equations. Undergraduate Physics, Chemistry, Electronic Circuit Analysis. Review of basic sensor classes (resistive, piezoelectric, etc.). Principles of measurement of various biomedical parameters and effects that limit accuracy. Interfacing and loading issues. Discussion of electronic circuits for pre-amplification and signal conditioning. Noise, signal averaging, A/D conversion and sampling effects. Origin and measurement of biopotentials. Biostimulation techniques used for various physiological signal monitoring methods (blood flow, ECG, respiratory, etc.). Discussion of magnetic resonance and ultrasound imaging principles and basic image quality metrics. Laboratory experiments involve construction and characterization of simple transducers and signal conditioning equipment for measuring such biomedical parameters as force, displacement, pressure, flow and biopotentials.

**BIOM 628 - (3) (Y)**
Motion Biomechanics
*Prerequisite:* BIOM 603.
Focuses on the study of forces (and their effects) that act on the musculoskeletal structures of the human body. Based on the foundations of functional anatomy and engineering mechanics (rigid body and deformable approaches); students are exposed to clinical problems in orthopedics and rehabilitation. Cross-listed as AM 628.

**BIOM 695 - (3) (Y)**
Special Topics in Biomedical Engineering

**BIOM 701 - (3) (E)**
Fundamentals of Biophysical Sciences
*Prerequisite:* Undergraduate fluid mechanics or transport phenomena.
The major focus of the course is an analysis of the fundamental transport properties relevant to biologic systems: diffusion, momentum and mass transport, hydrodynamics of macromolecules and cells, suspension stability (colloidal) and rheology of concentrated suspensions, and flow through permeable and semi-permeable media. Transport models will be developed to analyze processes such as blood coagulation, biomolecular transport in tissue, hemodialysis, protein-surface interactions, and forces underlying physical organization of cell membranes, which will then be extended to appropriate design problems relevant to the biomedical engineering industry.

**BIOM 702 - (3) (Y)**
Fundamentals of Biophysical Sciences
*Prerequisite:* BIOM 603, graduate mechanics. Review basics of mechanics and their application to problems in circulatory transport. Indicator dilution methods to quantify blood flows, blood volume and mass transport in the circulation are examined. Imaging methods to assess regional perfusion and the hemodynamic abnormalities of tumor circulation are presented.

**BIOM 703, 704 - (0) (S)**
Biomedical Engineering Seminar
A seminar course in which selected topics in biomedical engineering are presented by students, faculty and guest investigators.

**BIOM 706 - (3) (SI)**
Biomedical Applications of Genetic
Engineering

Prerequisite: BIOM 603, undergraduate-level cell and/or molecular biology course. (e.g., BIOM 304) or instructor permission. Suggested preparation: biochemistry, cell biology, genetics, and physiology.

Provides biomedical engineers with a grounding in molecular biology and a working knowledge of recombinant DNA technology, thus establishing a basis for the evaluation and application of genetic engineering in whole animal systems. Beginning with the basic principles of genetics, this course examines the use of molecular methods to study gene expression and its critical role in health and disease. Topics include DNA replication, transcription, translation, recombinant DNA methodology, methods for analyzing gene expression (including microarray and genechip analysis), methods for creating genetically-engineered mice, and methods for accomplishing gene therapy by direct in vivo gene transfer.

BIOM 731 - (4) (Y)
Quantitative Techniques in Biomedical Engineering I

Prerequisite: APMA 641 or equivalent.

A study of mathematical techniques useful in biomedical engineering. Topics cover linear and nonlinear ordinary differential equations, partial differential equations, vector analysis, matrices, and optimization. Applications include diffusion in biological tissues, biochemical kinetics, and optimization of physiological systems.

BIOM 741 - (3) (SI)
Bioelectricity

Prerequisite: Instructor permission.

Comprehensive overview of the biophysical mechanisms governing production and transmission of bioelectric signals in living systems, biopotential measurement and analysis techniques in clinical electrophysiology (ECG, EEG, and EMG), and the principles of operations for therapeutic medical devices that aid bioelectrical function of the cardiac and nervous systems. Lectures are supplemented by a computer project simulating the action potential generation, review of papers published in professional journals, and field trips to clinical laboratories at the University of Virginia Hospital.

BIOM 783 - (3) (SI)
Medical Image Modalities

Corequisite: BIOM 610 or instructor permission.

Studies engineering and physical principles underlying the major imaging modalities such as X-ray, ultrasound CT, MRI, and PET. A comprehensive overview of modern medical imaging modalities with regard to the physical basis of image acquisition and methods of image reconstruction. Students learn about the tradeoffs, which have been made in current implementations of these modalities. Considers both primarily structural modalities (magnetic-resonance imaging, electrical-impedance tomography, ultrasound, and computer tomography) and primarily functional modalities (nuclear medicine, single-photon-emission computed tomography, positron-emission tomography, magnetic-resonance spectroscopy, and magnetic-source imaging).

BIOM 784 - (3) (SI)
Medical Image Analysis

Prerequisite: BIOM 610 and ECE 682/CS 682, or instructor permission.

Comprehensive overview of medical image analysis and visualization. Focuses on the processing and analysis of these images for the purpose of quantitation and visualization to increase the usefulness of modern medical image data. Topics covered involve image formation and perception, enhancement and artifact reduction, tissue and structure segmentation, and 3-D visualization techniques as well as pictures archiving, communication and storage systems. Involves "hands-on" experience with homework programming assignments.

BIOM 822 - (3) (SI)
Advanced Biomechanics

Prerequisite: BIOM 603 and instructor permission.


BIOM 891 - (3) (SI)
Diagnostic Ultrasound Imaging

Prerequisite: Instructor permission, BIOM 610 and BIOM 611. Preparation: Undergraduate Physics, Electronic circuit analysis, Differential Equations, Fourier and Laplace Transforms, Sampling Theorems. Underlying principles of array based ultrasound imaging. Physics and modeling techniques used in ultrasound transducers. Brief review of ID circuit transducer models. Use of Finite Element techniques in transducer design. Design considerations for 1.5D and 2D arrays will be reviewed. Diffraction and beamforming will be introduced starting from Huygen's principle. FIELD propagation model will form an important part of the class. In depth discussion of various beamforming and imaging issues such as sidelobes, apodization, grating lobes, resolution, contrast, etc. The course addresses attenuation, time-gain-compensation and refraction. Finally, speckle statistics and K-Space techniques will be introduced. Laboratories will involve measuring ultrasound image metrics, examining the effect of various beamforming parameters and simulating these on a computer using Matlab.

BIOM 892 - (3) (SI)
Biomicolecular Engineering

Using a problem-based approach, a number of current bioengineering technologies applicable to tissue engineering, wound healing, drug delivery, and gene delivery are examined. Special topics include microfluidics and low Reynolds number hydrodynamics, molecular mechanics related to cell and microparticle sorting, and micropatterning surfaces for cell and tissue engineering.

BIOM 895 - (3) (SI)
Research: Biomedical Engineering Entrepreneurship

Prerequisite: Instructor permission.

The goal of this course is to give students insight into and experience in utilizing the opportunities available to biomedical engineers as they become successful entrepreneurs. The lectures will cover topics including Small Business Innovative Research (SBIR) grants, business plans for the development of medical devices, and patent and 510 k applications. Students will form teams of five and draft an SBIR grant and a business plan for a pacemaker, cardiac defibrillator, vascular stent, hemodialysis machine, tissue replacement, or a medical device of students’ own interests.

BIOM 897 - (Credit as arranged) (S)
Graduate Teaching Instruction

For master's students.

BIOM 898 - (Credit as arranged) (S)
Master's Research

BIOM 997 - (Credit as arranged) (S)
Graduate Teaching Instruction

For doctoral students.

BIOM 999 - (Credit as arranged) (S-SS)
Dissertation

Formal record of student commitment to doc-
toral research under the guidance of a faculty advisor. May be repeated as necessary.

**Chemical Engineering**

**CHE 615 - (3) (Y)**

Advanced Thermodynamics  
*Prerequisite:* Undergraduate-level thermodynamics or instructor permission.  
Development of the thermodynamic laws and derived relations. Application of relations to properties of pure and multicomponent systems at equilibrium in the gaseous, liquid, and solid phases. Prediction and calculation of phase and reaction equilibria in practical systems.

**CHE 618 - (3) (Y)**

Chemical Reaction Engineering  
*Prerequisite:* CHE 625 and 665.  
Fundamentals of chemical reaction kinetics and mechanisms; experimental methods of determining reaction rates; introduction to heterogeneous catalysis; application of chemical kinetics, along with mass-transfer theory, fluid mechanics, and thermodynamics, to the design and operation of chemical reactors.

**CHE 625 - (3) (Y)**

Transport Processes  
*Prerequisite:* Undergraduate transport processes; corequisite: CHE 665.  
Integrated introduction to fluid mechanics, heat transfer, and mass transfer. Development of the basic equations of change for transport of momentum, energy, and mass in continuous media. Applications with exact solutions, consistent approaches to limiting cases and approximate solutions to formulate the relations to be solved in more complicated problems.

**CHE 630 - (3) (Y)**

Mass Transfer  
*Prerequisite:* CHE 625 and 665.  
Fundamental principles common to mass transfer phenomena, with emphasis on mass transfer in diverse chemical engineering situations. Detailed consideration of fluxes, diffusion with and without convection, interphase mass transfer with chemical reaction, and applications.

**CHE 635 - (3) (Y)**

Process Control and Dynamics  
*Prerequisite:* Instructor permission.  
Introduction to dynamics and control of process systems, controllers, sensors, and final control elements. Development and application of time- and frequency-domain characterizations of subsystems for stability analyses of closed control loops. State-space models, principles of sampled-data analysis and digital control techniques. Elementary systems identification with emphasis on dead time, distributed parameters, and nonlinearities.

**CHE 642 - (3) (Y)**

Applied Surface Chemistry  
*Prerequisite:* Instructor permission.  
Factors underlying interfacial phenomena, with emphasis on thermodynamics of surfaces, structural aspects, and electrical phenomena; applications such as emulsification, foaming, detergency, sedimentation, flow through porous media, fluidization, nucleation, wetting, adsorption, flotation, electrocapillarity.

**CHE 647 - (3) (Y)**

Biochemical Engineering  
*Prerequisite:* Instructor permission.  
Introduction to properties, production, and use of biological molecules of importance to medicine and industry, such as proteins, enzymes, and antibodies. Topics may include fermentation and cell culture processes, biological mass transfer, enzyme engineering, and implications of recent advances in molecular biology, genomics, and proteomics.

**CHE 648 - (3) (Y)**

Bioseparations Engineering  
*Prerequisite:* Instructor permission.  
Principles of bioseparations engineering including specialized unit operations not normally covered in regular chemical engineering courses. Processing operations downstream of the initial manufacture of biotechnology products, including product recovery, separations, purification, and ancillary operations such as sterile processing, clean-in-place and regulatory aspects. Bioprocess integration and design aspects.

**CHE 649 - (3) (Y)**

Polymer Chemistry and Engineering  
*Prerequisite:* CHE 321 or instructor permission.  
Analyses the mechanisms and kinetics of various polymerization reactions; relations between the molecular structure and polymer properties, and how these properties can be influenced by the polymerization process; fundamental concepts of polymer solution and melt rheology. Applications to polymer processing operations, such as extrusion, molding, and fiber spinning. Three lecture hours.

**CHE 665 - (3) (Y)**

Techniques for Chemical Engineering Analysis and Design  
*Prerequisite:* Undergraduate differential equations, transport processes, and chemical reaction engineering.  
Methods for analysis of steady state and transient chemical engineering problems arising in fluid mechanics, heat transfer, mass transfer, kinetics, and reactor design.

**CHE 674 - (4) (Y)**

Process Design and Economics  
*Prerequisite:* Instructor permission.  
Factors that determine the genesis and evolution of a process. Principles of marketing and technical economics and modern process design principles and techniques, including computer simulation with optimization.

**CHE 716 - (3) (SI)**

Applied Statistical Mechanics  
*Prerequisite:* CHE 615, or other graduate-level thermodynamics course, and instructor permission.  
Introduction to statistical mechanics and its methodologies such as integral equations, computer simulation and perturbation theory. Applications such as phase equilibria, adsorption, transport properties, electrolyte solutions.

**CHE 744 - (3) (SI)**

Electrochemical Engineering  
*Prerequisite:* Graduate-level transport phenomena (e.g., CHE 625 and graduate-level mathematical techniques (e.g., CHE 665), or instructor permission.  
Electrochemical phenomena and processes from a chemical engineering viewpoint. Application of thermodynamics, electrode kinetics, interfacial phenomena, and transport processes to electrochemical systems such as batteries, rotating disk electrodes, corrosion of metals, and semiconductors. Influence of coupled kinetics, interfacial, and transport phenomena on current distribution and mass transfer in a variety of electrochemical systems.

**CHE 793 - (Credit as arranged) (S)**

Independent Study  
Detailed study of graduate course material on an independent basis under the guidance of a faculty member.

**CHE 795 - (Credit as arranged) (S)**

Supervised Project Research  
Formal record of student commitment to project research for Master of Engineering degree under the guidance of a faculty advisor. May be repeated as necessary.

**CHE 796 - (1) (S)**

Graduate Seminar  
Weekly meetings of graduate students and faculty for presentations and discussion of research in academic and industrial organizations. May be repeated.

**CHE 819 - (3) (SI)**

Advanced Chemical Engineering Kinetics and Reaction Engineering  
*Prerequisite:* CHE 618 or instructor permission.  
Advanced study of reacting systems, such as experimental methods, heterogeneous catalysis, polymerization kinetics, kinetics of complex reactions, reactor stability, and optimization.

**CHE 820 - (3) (SI)**

Modeling of Biological Processes in Environmental Systems  
*Prerequisite:* Instructor permission.  
Use of mathematical models to describe processes such as biological treatment of chemical waste, including contaminant degradation and bacterial growth, contaminant and bacterial transport, and adsorption. Engineering analyses of treatment processes such as biofilm reactors, sequenced batch reactors, biofilters and in situ bioremediation. May include introduction to hydrogeology, microbiology, transport phenomena and reaction kinetics relevant to environmental systems; application of material and energy balances in the analysis of environmental systems; and dimensional analysis and scaling. Guest lectures by experts from industry, consulting firms and government agencies to discuss applications of these bioremediation technologies.

**CHE 833 - (3) (SI)**

Specialized Separation Processes
Prerequisite: Instructor permission. Less conventional separation processes, such as chromatography, ion-exchange, membranes, and crystallization using in-depth and modern chemical engineering methods. Student creativity and participation through development and presentation of individual course projects.

CHE 881, 882 - (3) (SI)
Special Topics in Chemical Engineering
Prerequisite: Permission of the staff. Special subjects at an advanced level under the direction of staff members.

CHE 893 - (Credit as arranged) (S)
Independent Study
Detailed study of graduate course material on an independent basis under the guidance of a faculty member.

CHE 897 - (Credit as arranged) (S)
Graduate Teaching Instruction
For master’s students.

CHE 898 - (Credit as arranged) (S)
Master’s Research
Formal record of student commitment to master’s thesis research under the guidance of a faculty advisor. Registration may be repeated as necessary.

CHE 997 - (Credit as arranged) (S)
Graduate Teaching Instruction
For doctoral students.

CHE 999 - (Credit as arranged) (S)
Dissertation
Formal record of student commitment to doctoral research under the guidance of a faculty advisor. Registration may be repeated as necessary.

Civil Engineering

CE 601 - (3) (Y)
Advanced Mechanics of Materials
Prerequisite: Undergraduate mechanics and mathematics. Reviews basic stress-strain concepts; constitutive relations. Studies unsymmetrical bending, shear center, and shear flow. Analyzes curved flexural members, beams on elastic foundation, torsion, bending, and twisting of thin walled sections. Cross-listed as AM 601.

CE 602 - (3) (Y)
Continuum Mechanics with Applications
Prerequisite: Instructor permission. Introduces continuum mechanics and mechanics of deformable solids. Vectors and cartesian tensors, stress, strain, deformation, equations of motion, constitutive laws, introduction to elasticity, thermal elasticity, viscoelasticity, plasticity, and fluids. Cross-listed as APMA 602, AM 602, MAE 602.

CE 603 - (3) (Y)
Computational Solid Mechanics
Corequisite: CE 602. Analyzes the variational and computational mechanics of solids, potential energy, complementary energy, virtual work, Reissner’s principle, Ritz and Galerkin methods; displacement, force and mixed methods of analysis; finite element analysis, including shape functions, convergence and integration; and applications in solid mechanics. Cross-listed as AM 603, MAE 603.

CE 604 - (3) (E)
Plates and Shells
Prerequisite: APMA 641 and CE 601 or 602. Includes the classical analysis of plates and shells of various shapes; closed-form numerical and approximate methods of solution of governing partial differential equations; and advanced topics (large deflection theory, thermal stresses, orthotropic plates). Cross-listed as AM 604, MAE 604.

CE 607 - (3) (SI)
Theory of Elasticity
Prerequisite: AM/CE/MAE 602 or instructor permission. Review of the concepts of stress, strain, equilibrium, compatibility; Hooke’s law (isotropic materials); displacement and stress formulations of elasticity problems; plane stress and strain problems in rectangular coordinates (Airy’s stress function approach); plane stress and strain problems in polar coordinates, axisymmetric problems; torsion of prismatic bars (semi-inverse method using real function approach); thermal stress; and energy methods. Cross-listed as AM 607 and MAE 607.

CE 610 - (3) (Y)
Concrete Materials
Prerequisite: Graduate standing or instructor permission. This course covers basic properties of hydraulic cements and mineral aggregates and their interactions in concrete as well as properties of plastic and hardened concrete. Modifications through admixtures; concrete test methods and behavior under various loads and durability of concrete as well as performance of concrete are also covered. Production, handling, and placement problems; lightweight, heavyweight, and other special concretes topics are discussed.

CE 611 - (3) (Y)
Asphalt Materials
Prerequisite: Graduate standing or instructor permission. This course will cover the major types of bituminous materials: asphalt cements, cutback asphalts, asphalt emulsions, and tars. The influence of chemical composition upon physical properties, desirableaggregate characteristics for bituminous mixtures, and asphalt mixtures and construction techniques are also covered. Furthermore, characteristics of constitutive materials, mix design methodology (including current practices for determining optimum asphalt contents), test methods, behavior under various loads, durability, and performance are discussed.

CE 613 - (3) (Y)
Infrastructure Management
Prerequisite: Graduate standing or instructor permission. Studies the tools required to formulate a prioritization procedure that leads to a realistic and rational way of establishing candidate projects for priority programming at both the network and project level infrastructure management systems. Topics include methods for obtaining distress measurements and pavement condition ratings for flexible and rigid pavements, and prioritizing procedures for establishing priority listings for rehabilitation and maintenance activities.

CE 614 - (3) (Y)
Pavement Analysis and Design
Prerequisite: Graduate standing or instructor permission. This course covers historical developments of pavement structures and different types of pavements. Additionally, it covers basic stresses, strains, and deflections in rigid and flexible pavements; traffic loading; and material characterization. Drainage design, pavement performance, and reliability concepts are discussed. Current design methodologies (i.e., empirical design methodologies) for both rigid and flexible pavements and design of overlays are covered, discussed and practiced. This course also discusses the influence of climatic and traffic loading on pavement performance and life-cycle cost analysis concepts.

CE 615 - (3) (Y)
Advanced Geotechnical Engineering
Prerequisite: CE 316. This course covers the engineering properties of typical soils and aggregates found in Virginia. Various soil classification systems used in the U.S., the effects of loading on the performance of soils, and the effects of compaction and moisture on the engineering properties of soils are also covered. Various stabilization techniques that may be used to transform weak soils such that they can be used for road construction applications are discussed.

CE 616 - (3) (Y)
Advanced Foundations
Prerequisite: CE 316 and 326. Topics include subsurface investigation, control of groundwater, analysis of sheeting and bracing systems, shallow foundations, pile foundations, retaining walls, bridge abutments, caissons and cofferdams.

CE 617 - (3) (Y)
Advanced Geometric Design
Prerequisite: CE 344. This course covers advanced topics in geometric design of highways. Topics include highway functions and classification, characteristics, design control and criteria, and cross section elements. Other material covered includes local collectors, rural and urban arterials, freeways, at-grade intersections, grade separations, and interchanges. The topics covered parallel the AASHTO geometric design book, “The Green Book.”

CE 620 - (3) (Y)
Energy Principles in Mechanics
Prerequisite: Instructor permission. Derivation, interpretation, and application to engineering problems of the principles of virtual work and complementary virtual work. Related theorems such as the principles of the stationary value of the total potential and complementary energy, Castigliano’s Theo-

CE 623 - (3) (Y)

**Vibrations**  
*Prerequisite:* Instructor permission.  
Topics include free and forced vibration of undamped and damped single-degree-of-freedom systems and undamped multi-degree-of-freedom systems; use of Lagrange's equations, Laplace transform, matrix formulation, and other solution methods; normal mode theory; introduction to vibration of continuous systems. Cross-listed as AM 623, MAE 623.

CE 631 - (3) (E)

**Intelligent Transportation Systems**  
*Prerequisite:* Graduate standing or instructor permission.  
Intelligent transportation systems (ITS) can best be defined as the application of information technology to the surface transportation system. This technology, which includes communications, sensors, and computer hardware and software, supports both travelers and transportation providers in making effective decisions. This course provides an introduction to the concepts of intelligent transportation systems (ITS), explores the technology that serves as the foundation for ITS, and includes case-studies to allow students to explore ITS analysis and design.

CE 632 - (3) (Y)

**Introduction to Integrated Transportation Systems Models**  
*Prerequisite:* Graduate standing or instructor permission.  
The purpose of this course is to introduce students to core models that support transportation engineering. In addition, the course provides a background on fundamental mathematical and heuristic search methods, optimization theories, stochastic optimizations and graph theory that underpin the transportation models. At the completion of this course, students will be able to apply mathematical search and optimization techniques and graph theory for transportation system control and management problems and understand the importance of stochastic optimization and its applications.

CE 633 - (3) (Y)

**Introduction to Transportation Planning**  
*Prerequisite:* Graduate standing or instructor permission.  
Introduces the legal requirements, framework, and principles of urban and statewide planning. Focuses on describing and applying the methodology of the forecasting system of the transportation planning process, including inventory (data collection and information systems), forecasts of population and economic activity, network analysis, and travel demand analysis. Also introduces computerized models for transportation planning.

CE 634 - (3) (Y)

**Geographic Information Systems**  
*Prerequisite:* Graduate standing or instructor permission.  
Introduces fundamentals of spatial analysis through reading, lecture, discussion, research, and hands-on experience gained through laboratory work using the ArcGIS package. The primary objective of this course is to investigate the GIS application process.

CE 635 - (3) (Y)

**Intermodal Transportation**  
*Prerequisite:* Graduate standing or instructor permission.  
Studies the structure of domestic freight and passenger transportation in the United States. Focuses on the integration of modes, economic impacts, national transportation policy and advanced technology. Case studies of contemporary examples of intermodal integration are explored.

CE 636 - (3) (Y)

**Traffic Operations**  
*Prerequisite:* Graduate standing or instructor permission.  
Covers the methods for evaluating the impact on the quality of traffic operations due to the interaction of the three main components of the highway mode: the driver, the vehicles, and the road. Includes the collection and analysis of traffic operations data, fundamentals of traffic flow theory, analysis of capacity and level of service and accident analysis.

CE 637 - (3) (IR)

**Transportation Safety Engineering**  
*Prerequisite:* CE 344 and 444 or instructor permission.  
A study of different transportation systems management strategies, with specific emphasis on their impact on safety, including methods of obtaining and analyzing crash data. Emphasis is also placed on the interaction of human and vehicle characteristics and the road environment on safety.

CE 638 - (3) (Y)

**Public Transportation**  
*Prerequisite:* Graduate standing or instructor permission.  
Study of the application of transportation systems and technologies in an urban context. Focuses on the management and operation of public transit systems, and comparative costs and capabilities of transit modes.

CE 639 - (3) (IR)

**Financing Transportation Infrastructure**  
*Prerequisite:* CE 635.  
The financing of transportation systems and services is an important element in the process of developing new or renovated facilities. This course develops familiarity with financing techniques that have been proposed or used by localities and state agencies. Consideration is given to advantages and disadvantages and the conditions appropriate to their application.

CE 640 - (3) (Y)

**Wastewater Treatment**  
*Prerequisite:* CE 430 or instructor permission.  
A first course in surface water quality modeling. Emphasizes the basic understanding of the mechanisms and interactions to various types of water quality behavior. Designed to meet a very simple need—dissemination of the fundamentals and principles underlying the mathematical modeling techniques used to analyze the quality of surface waters. Students practice wasteload allocations using a variety of water quality models on microcomputer systems.

CE 644 - (3) (Y)

**Water Chemistry for Environmental Engineering**  
*Prerequisite:* CHEM 151 and 151L, and graduate standing.  
Teaches the basic principles of inorganic and organic chemistry as applied to problems in environmental engineering, including water and wastewater treatment, contaminant hydrology, and hazardous-waste management. Specific topics include analytical instrumentation, acid-base chemistry, reaction kinetics, precipitation and dissolution, organic and surface chemistry, and chlorine chemistry for water disinfection.

CE 653 - (3) (Y)

**Hydrology**  
*Prerequisite:* CE 336 or instructor permission.  
Stresses the quantitative description and the physical basis of hydrology. Both deterministic and stochastic methodology are applied to the analysis of the hydrologic cycle, namely, precipitation, evaporation, overland flow and stream flow, infiltration, and groundwater. The use of computer simulation models, especially microcomputer based models, is emphasized.

CE 655 - (3) (Y)

**Ground-Water Hydrology**  
*Prerequisite:* CS 101, CE 315, CE 336, or equivalent.  
Topics include Darcy's Law, fluid potential, hydraulic conductivity, heterogeneity and anisotropy, the unsaturated zone, compressibility, transmissivity and storativity, the 3-D equation of ground-water flow, steady-state and transient regional ground-water flow, and well hydraulics, including discussions involving Theis' Inverse Method, Jacob's
Method, slug test analyses, and the principle of superposition. Students solve transient, one-dimensional and steady-state, two-dimensional ground-water flow problems by solving the governing partial differential equations by the finite-difference technique. Also includes numerical solution of tridiagonal systems of linear equations, truncation errors, and stability analysis. Requires writing computer programs using Fortran, C++, or an equivalent.

**CE 656 - (3) (Y)**

**Environmental Systems Management**  
**Prerequisite:** Graduate standing or instructor permission.  
Emphasizes the formulation of environmental management issues as optimization problems. Simulation models are presented and then combined with optimization algorithms. Environmental systems to be addressed include stream quality, air quality, water supply, waste management, groundwater remediation, and reservoir operations. Optimization techniques presented include linear, integer, and separable programming, dynamic programming and nonlinear programming.

**CE 665 - (3) (Y)**

**Mechanics of Composite Materials**  
**Prerequisite:** Knowledge of strength of materials and a computer language.  
Analyzes the properties and mechanics of fibrous, laminated composites; stress, strain, equilibrium, and tensor notation; micromechanics, lamina, laminates, anisotropic materials, classical lamination theory, stiffness and strength, interlaminar stresses, fabrication, and test methods; thermal stresses, analysis, design and computerized implementation. Cross-listed as AM 665.

**CE 666 - (3) (Y)**

**Stress Analysis of Composites**  
**Prerequisite:** CE 665 or AM 665.  
Focuses on 3-D anisotropic constitutive theory, edge effects and interlaminar stresses, failure criteria, fracture, anisotropic elasticity, micromechanics, laminated plates, hygrothermal effects, conduction and diffusion. Cross-listed as AM 666.

**CE 671 - (3) (Y)**

**Introduction to Finite Element Methods**  
**Prerequisite:** CE 471 or equivalent.  
Focuses on the fundamentals and basic concepts of the finite element method; modeling and discretization; application to one-dimensional problems; direct stiffness method; element characteristics; interpolation functions; extension to plane stress problems.

**CE 672 - (3) (Y)**

**Numerical Methods in Structural Mechanics**  
**Prerequisite:** CE 471.  
Focuses on solutions to the static, dynamic, and buckling behavior of determinate and indeterminate structures by numerical procedures, including finite difference and numerical integration techniques.

**CE 675 - (3) (SI)**

**Theory of Structural Stability**  
**Prerequisite:** Instructor permission.  
Introduces the elastic stability of structural and mechanical systems. Studies classical stability theory and buckling of beams, trusses, frames, arches, rings and thin plates and shells. Also covers the determination of design formulas, computational formulation and implementation. Cross-listed as AM 675.

**CE 677 - (3) (SI)**

**Risk and Reliability in Structural Engineering**  
**Prerequisite:** Background in probability and statistics.  
Studies the fundamental concepts of structural reliability; definitions of performance and safety, uncertainty in loadings, materials and modeling. Analysis of loadings and resistance. Evaluation of existing design codes. Development of member design criteria, including stability, fatigue and fracture criteria; and the reliability of structural systems.

**CE 681 - (3) (Y)**

**Advanced Design of Metal Structures**  
**Prerequisite:** CE 401 or equivalent.  
Analyzes the behavior and design of structural elements and systems, including continuous beams, plate girders, composite steel-concrete members, members in combined bending and compression. Structural frames, framing systems, eccentric connections, and torsion and torsional stability are also studied.

**CE 683 - (3) (O)**

** Prestressed Concrete Design**  
**Prerequisite:** CE 326 or equivalent.  
Analyzes prestressing materials and concepts, working stress analysis and design for flexure, strength analysis and design for flexure, prestress losses, design for shear, composite prestressed beams, continuous prestressed beams, prestressed concrete systems concepts, load balancing, slab design.

**CE 684 - (3) (E)**

**Advanced Reinforced Concrete Design**  
**Prerequisite:** CE 326.  
Study of advanced topics in reinforced concrete design, including design of slender columns, deflections, torsion in reinforced concrete, design of continuous frames, and two-way floor systems. Introduction to design of tall structures in reinforced concrete, and design of shear walls.

**CE 685 - (3) (SI)**

**Experimental Mechanics**  
**Prerequisite:** CE 323.  
Analyzes the theories and techniques for the determination of static and dynamic stresses, strains, and deformations. Studies include photoelastic, electrical, mechanical, and optical methods and instruments. Both models and full-scale specimens will be used in experimental testing.

**CE 691 - (3) (IR)**

**Special Topics in Civil Engineering**  
Detailed study of special topics in civil engineering. Master’s-level graduate students.

**CE 693 - (Credit as arranged) (Y)**

**Independent Study**  
Detailed study of graduate course material on an independent basis under the guidance of a faculty member. Master’s-level graduate students.

**CE 695 - (Credit as arranged) (Y)**

**Supervised Project Research**  
Formal record of student commitment to project research under the guidance of a faculty advisor. Registration may be repeated as necessary. Master’s-level graduate students.

**CE 696 - (1) (Y)**

**Graduate Seminar**  
Weekly meeting of master’s-level graduate students and faculty for presentation and discussion of contemporary research and practice in civil engineering. This seminar is offered for credit every spring semester and should be taken by all students in the master’s program.

**CE 700 - (0) (Y)**

**Graduate Seminar**  
For students who have established resident credit.  
Weekly meeting of graduate students and faculty for presentation and discussion of contemporary research and practice in civil engineering. This seminar is offered every spring semester.

**CE 714 - (3) (Y)**

**Advanced Pavement Analysis and Design**  
**Prerequisite:** CE 614.  
This course covers advanced topics in the design and analysis of pavement structures for all types of pavements. Mechanistic-empirical design procedures are covered, and drainage layer design is discussed in detail. Actual pavement design programs are used and advanced design checks and analysis topics covered in detail. Stress, strain, deflection calculation, and back calculation procedures are also discussed.

**CE 724 - (3) (Y)**

**Dynamics of Structures**  
**Prerequisite:** Concrete and metal structure design and CE 623.  
Study of the dynamic behavior of such structures as beams, rigid frames, floors, bridges, and multi-story buildings under the action of various disturbing forces such as wind, blasts, earthquakes, vehicles, machinery, etc.

**CE 725 - (3) (Y)**

**Random Vibrations**  
**Prerequisite:** A background in probability theory and vibration analysis.  
Topics include a review of probability theory; stochastic processes, with an emphasis on continuous, continuously parameterized processes; mean square calculus, Markov processes, diffusion equations, Gaussian processes, and Poisson processes; response of SDOF, MDOF, and continuous linear and nonlinear models to random excitation; upcrossings, first passage problems, fatigue and stability considerations; Monte Carlo simulation, analysis of digital time series data, and filtered excitation models. Cross-listed as AM 725.

**CE 731 - (3) (IR)**
Project Planning
Prerequisite: CE 632 and 633.
Analyzes the planning of public facilities in contemporary society; review of common social, economic, and environmental impact considerations in the location and design of corridor or point facilities; cost parameters; comprehensive methods of evaluating and combining tangible and intangible factors including cost benefit, cost effectiveness, goals, achievement, planning balance sheet, risk profiles, preference theories, mapping, and factor analysis methods; case studies.

CE 732 - (3) (E)
Transportation Impact Analysis
Prerequisite: CE 633, 634, and 636.
Introduces the non-travel impacts of transportation systems and the methodologies used to capture them for project evaluation; to develop and illustrate methodologies used for evaluating the effectiveness of transportation systems/projects including benefit-cost analysis and multi-objective decision models, and to illustrate the analysis of different alternatives.

CE 734 - (3) (IR)
Traffic Flow Theory
Prerequisite: CE 636.
Analyzes theoretical and computer applications of mathematical models of traffic flow; deterministic and stochastic traffic flow models; queuing theory and its application including cases where arrival rates exceed service rates; acceleration noise and traffic simulation.

CE 735 - (3) (IR)
Transportation Logistics
Prerequisite: CE 652.
This course covers logistics systems, with emphasis on the design and analysis of transportation and supply chain systems, such as the activities of transportation and supply chain systems, including transportation network design, scheduling, routing, contracting and pricing; interactions and trade-offs of these activities; and models and techniques for the analysis of logistics systems and the development of decision support systems.

CE 738 - (3) (O)
Advanced Integrated Transportation Systems Models
Prerequisite: CE 632 and 636.
Introduces the current and advanced optimization and simulation computer models used in traffic operations. Increased familiarity with the concepts and methodologies associated with selecting an appropriate model for a given situation. Covers the advantages and disadvantages of the models considered and is project-oriented, with students spending a significant amount of time in selecting and using these models to solve "real world" problems.

CE 739 - (3) (IR)
Advanced Topics in Transportation
Focuses on selected contemporary problems in transportation that are of interest to the students and faculty. Seminars, guest lecturers, projects.

CE 742 - (3) (SI)
Modeling Environmental Fate and Effects of Contaminants
Prerequisite: CE 641 or instructor permission.
Designed as a follow-up course for Water Quality Modeling, this course covers a number of modeling applications. Designed to apply water quality models to regulatory oriented water quality problems. Emphasis on reading water quality data using models, the results of which serve as a rational basis for making water quality control decisions. Each student conducts an individual water quality modeling study using actual data.

CE 743 - (3) (E)
Theory of Groundwater Flow and Contaminant Transport
Prerequisite: CE 655 or equivalent.
Provides a theoretical framework for understanding fluid flow and contaminant transport in porous media. Topics include the properties of a porous medium, including types of phases, soil and clay mineralogy, surface tension and capillarity, soil surface area, and soil organic matter composition; the derivation of the general equations for multi-phase fluid flow and multi-species solute transport; and the fundamentals of the fate and transport processes of organic pollutants in ground-water systems, including advection, dispersion, diffusion, sorption, hydrolysis, and volatilization.

CE 746 - (3) (Y)
Groundwater Modeling
Prerequisite: CE 655 or instructor permission.
Introduces the fundamentals of modeling groundwater systems. Emphasizes the evaluation, development, and application of computer models. Modeling techniques include analytical solutions, finite difference and finite element methods, particle tracking, and inverse modeling. Models are applied to flow and transport in saturated and unsaturated groundwater systems.

CE 748 - (3) (SI)
Design of Waste Containment Facilities
Corequisite: CE 644 and 655.
Covers concepts important to the design and construction of new waste disposal facilities, and to the closure of existing disposal facilities. Emphasizes the fundamentals of contaminant behavior in a porous media, engineering designs to reduce contaminant migration, and issues related to the operation, monitoring, and closure of waste disposal facilities.

CE 750 - (3) (SI)
Hazardous Waste Site Characterization and Remediation
Corequisite: CE 644 and 655.
Covers concepts important to the characterization and remediation of hazardous contamination of soil and groundwater. Theoretical concepts of contaminant behavior in the subsurface, methods of contaminant detection, and remedial systems are combined with issues of practical implementation at the field scale.

CE 754 - (3) (SI)
Stormwater Management and Nonpoint Source Pollution Control
Prerequisite: CE 653 or instructor permission.
Discusses nonpoint source pollution in general, and stormwater-induced pollution in particular. Emphasizes stormwater management planning and design in an urban setting. An integrated watershed management approach in nonpoint source pollution control is described. Topics include sources and impact of nonpoint pollution; stormwater regulations; combined sewer overflow problems; best management practices; such as detention ponds and constructed wetlands; design methodologies; and institutional considerations.

CE 776 - (3) (Y)
Non-Linear Structural Systems
Prerequisite: CE 671, 672, or instructor permission.
Discussion of deflection theory. Analysis of arches, suspension bridges, cable supported roof systems, guyed towers, lattice domes and space trusses. Focuses on wind-induced vibration, creep effects, and the visco-elastic behavior of structures.

CE 780 - (3) (SI)
Optimum Structural Design
Prerequisite: Instructor permission.
Introduces the basic concepts, numerical methods, and applications of optimum design to civil engineering structures; formulation of the optimum design problems; development of analysis techniques including linear and nonlinear programming and optimality criteria; examples illustrating application to steel and concrete structures.
stiffening beams and edge stress are studied. Considers erection, economy and aesthetics.

CE 791 - (3) (IR)
Special Topics in Civil Engineering
Detailed study of special topics in civil engineering. Doctoral-level graduate students.

CE 793 - (Credit as arranged) (Y)
Independent Study
Detailed independent study of graduate course material under the guidance of a faculty member. Doctoral-level graduate students.

CE 795 - (Credit as arranged) (Y)
Supervised Project Research
Formal record of student commitment to project research under the guidance of a faculty advisor. Registration may be repeated as necessary. Doctoral-level graduate student.

CE 796 - (1) (Y)
Graduate Seminar
Weekly meeting of doctoral-level graduate students and faculty for presentation and discussion of contemporary research and practice in civil engineering. This seminar is offered for credit every spring semester and should be taken by all students in the Ph.D. program.

CE 897 - (Credit as arranged) (S)
Graduate Teaching Instruction
For master's students.

CE 898 - (Credit as arranged) (Y)
Thesis
Formal record of student commitment to master's thesis research under the guidance of a faculty advisor. Registration may be repeated as necessary.

CE 997 - (Credit as arranged) (S)
Graduate Teaching Instruction
For doctoral students.

CE 999 - (Credit as arranged) (Y)
Dissertation
Formal record of student commitment to doctoral research under the guidance of a faculty advisor.

Computer Science

CS 551 - (3) (SI)
Special Topics in Computer Science
Prerequisite: Instructor permission.
Course content varies by section and is selected to fill timely and special interests and needs of students. See CS 751 for example topics. May be repeated for credit when topic varies.

CS 571 - (3) (Y)
Translation Systems
Prerequisite: CS 333 or instructor permission.
Study of the theory, design, and specification of translation systems. Translation systems are the tools used to translate a source language program to a form that can be executed. Using rigorous specification techniques to describe the inputs and outputs of the translators and applying classical translation theory, working implementations of various translators are designed, specified, and implemented.

CS 586 - (3) (Y)
Real-Time Systems
Prerequisite: CS 333 and CS 414, knowledge of C or C++, or instructor permission.
This course presents the underlying theory, concepts, and practice for real-time systems, such as avionics, process control, space travel, mobile computing and ubiquitous computing. The goals of the course include: introducing the unique problems that arise when time constraints are imposed on systems, identifying basic theory and the boundary between what is known today and what is still research, stressing a systems integration viewpoint in the sense of showing how everything fits together rather than presenting a collection of isolated solutions, and addressing multiprocessor and distributed systems. This course also presents some of the basic results from what might be called the classical technology of real-time computing and presents these results in the context of new applications of this technology in ubiquitous/pervasive computer systems.

CS 587 - (3) (Y)
Security in Information Systems
Prerequisite: CS 340 and either CS 457 or CS 414 or instructor permission.
This course focuses on security as an aspect of a variety of software systems. We will consider software implementations of security related policies in the context of operating systems, networks, and data bases. Topics include: operating system protection mechanisms, intrusion detection systems, formal models of security, cryptography and associated security protocols, database security, worms, viruses, network and distributed systems security, and policies of privacy and confidentiality.

CS 588 - (3) (Y)
Cryptography: Principles and Applications
Prerequisite: CS 302 or instructor permission.
Introduces the basic principles and mathematical ideas of cryptography including information theory, classical ciphers, symmetric key cryptosystems and public-key cryptosystems. Develops applications of cryptography such as anonymous email, digital cash and code signing.

CS 616 - (3) (Y)
Knowledge-Based Systems
Prerequisite: Graduate standing.
Introduces the fundamental concepts for research, design, and development of knowledge-based systems. Emphasizes theoretical foundations of artificial intelligence, problem solving, search, and decision making with a view toward applications. Students develop a working knowledge-based system in a realistic application domain. Cross-listed as SYS 616.

CS 644 - (3) (Y)
Introduction to Parallel Computing
Prerequisite: CS 308, 414, and 415, or instructor permission.
Introduces the basics of parallel computing. Covers parallel computation models, systems, languages, compilers, architectures, and algorithms. Provides a solid foundation on which advanced seminars on different aspects of parallel computation can be based. Emphasizes the practical application of parallel systems. There are several programming assignments.

CS 645 - (3) (Y)
Computer Graphics
Prerequisite: Knowledge of C/C++.
Analyzes display devices, line and circle generators; clipping and windowing; data structures; 2-D picture transformations; hidden line and surface algorithms; shading algorithms; free form surfaces; color graphics; 3-D picture transformation. Cross-listed as ECE 635.

CS 650 - (3) (Y)
Building Complex Software Systems
Prerequisite: First-year standing as a CS graduate, good programming skills, undergraduate mastery of operating systems and programming languages, or instructor permission.
This course requires actual implementation of a complex, challenging system such as those encountered in today's world. Most systems undertaken involve an external interface implementation, such as a real-time controller, robotic management, requiring sophisticated sensor input. Available implementation tools, such a CORBA, distributed RPC calls, and GUI interface systems are mastered as appropriate to the project. Similarly, relevant software engineering concepts, such as system specification and documenta tion methodologies are developed as appropriate to the project.

CS 651 - (3) (SI)
Special Topics in Computer Science
Prerequisite: Instructor permission.
Course content varies by section and is selected to fill timely and special interests and needs of students. See CS 751 for example topics. May be repeated for credit when topic varies.

CS 654 - (3) (Y)
Computer Architecture
Prerequisite: CS 333 or proficiency in assembly language programming.
Study of representative digital computer organization with emphasis on control unit logic, input/output processors and devices, asynchronous processing, concurrency, and parallelism. Memory hierarchies.

CS 655 - (3) (Y)
Programming Languages
Prerequisite: CS 415 or equivalent.
Examines modern and non-imperative languages, the theoretical techniques used to design and understand them, and the implementation techniques used to make them run. Topics include functional languages, object-oriented languages, language safety and classification of errors, type systems, formal semantics, abstraction mechanisms, memory management, and unusual control-flow mechanisms. Example languages include Standard ML, Modula-3, CLU, Scheme, Prolog, and Icon.
CS 656 - (3) (Y)
Operating Systems
Prerequisite: Undergraduate course in OS; CS 654 or instructor permission.
Covers advanced principles of operating systems. Technical topics include support for distributed O/Ss; microkernels and OS architectures; processes and threads; IPC; files servers; distributed shared memory; object-oriented O/Ss; reflection in O/Ss; real-time kernels; multiprocessing; multimedia and quality of service; mobile computing; and parallelism in I/O.

CS 660 - (3) (Y)
Theory of Computation
Prerequisite: CS 302 or equivalent.
Analyzes formal languages, the Chomsky hierarchy, formal computation and machine models, finite automata, pushdown automata, Turing machines, Church's thesis, reductions, decidability and undecidability, and NP-completeness.

CS 661 - (3) (Y)
Design and Analysis of Algorithms
Prerequisite: CS 432 or equivalent.
Analyzes concepts in algorithm design, problem solving strategies, proof techniques, complexity analysis, upper and lower bounds, sorting and searching, graph algorithms, geometric algorithms, probabilistic algorithms, intractability and NP-completeness, transformations, and approximation algorithms.

CS 662 - (3) (Y)
Database Systems
Prerequisite: CS 462 or equivalent.
Studies new database systems, emphasizing database design and related system issues. Explores advanced topics such as object-oriented and real-time database systems, data warehousing, data mining, and workflow. Makes use of either commercial or research database systems for in-class projects.

CS 682 - (3) (Y)
Digital Picture Processing
Prerequisite: Graduate standing.
Explores basic concepts of image formation and image analysis: imaging geometries, sampling, filtering, edge detection, Hough transforms, region extraction and representation, extracting and modeling three-dimensional objects. Cross-listed as ECE 682.

CS 685 - (3) (Y)
Software Engineering
Prerequisite: CS 340 or equivalent.
Analyzes project management, software tools, requirements and specification methods; top-down, bottom-up, and data-flow design; structured programming, information hiding, programming language issues, and coding standards; software development environments, fault tolerance principles, and testing.

CS 693 - (Credit as arranged) (SI)
Independent Study
Detailed study of graduate course material on an independent basis under the guidance of a faculty member.

CS 696 - (1) (Y)
Computer Science Perspectives
Prerequisite: CS graduate student or instructor permission.
This "acclimation" seminar helps new graduate students become productive researchers. Faculty and visitors speak on a wide variety of research topics, as well as on tools available to researchers, including library resources, various operating systems, UNIX power tools, programming languages, software development and version control systems, debugging tools, user interface kits, word processors, publishing systems, HTML, JAVA, browsers, Web tools, and personal time management.

CS 715 - (3) (SI)
Performance Analysis of Communication Networks
Prerequisite: CE/ECE 457, APMA 310, or instructor permission.
Analyzes the topologies arising in communication networks; queuing theory; Markov Chains and ergodicity conditions; theory of regenerative processes; routing algorithms; multi-access and random-access transmission algorithms; mathematical methodologies for throughput and delay analyses and evaluation; performance monitoring; local area networks (LANs); interactive LANs. Cross-listed as ECE 715.

CS 716 - (3) (Y)
Artificial Intelligence
Prerequisite: CS 616 or SYS 616.
In-depth study of a few major areas historically considered to be part of artificial intelligence. Emphasizes the design considerations involved in automatic theorem proving, natural language understanding, and machine learning. Cross-listed as SYS 716.

CS 751 - (3) (SI)
Selected Topics in Computer Science
Prerequisite: Instructor permission.
Content varies based on the interest and needs of students. Topics may include safety critical systems, parallel processing, information retrieval, data communications, computer networks, real-time computing, distributed multimedia systems, electronic commerce, and advanced combinatorics and graph theory. May be repeated for credit when topic varies.

CS 756 - (3) (O)
Models of Computing Systems
Prerequisite: CS 656 and either SYS 605 or ECE 611.
Explores studies of user behavior, program behavior, and selected aspects of computer systems such as scheduling, resource allocation, memory sharing, paging, or deadlock. Analyzes mathematical models and simulation, the use of measurements in the formulation and validation of models, and performance evaluation and prediction.

CS 757 - (3) (Y)
Computer Networks
Prerequisite: CS 656 or instructor permission.
Introduction: switching methods, network services, layered protocol architectures, OSI reference model; Physical Layer: transmission media, modulation, encoding; Data Link Layer: framing, error detection and correction, ARQ protocols, data link layer protocols, multiplexing; Local Area Networks: multiple access protocols, local network topologies, CSMA/CD, token bus, token ring, FDDI, DQDB; Network Layer: packet switching, routing algorithms, traffic control, internetworking, network protocols; Transport Layer: transport services, connection management, transport protocols; Special topics such multimedia, ATM, and protocol design and verification.

CS 771 - (3) (Y)
Compilers
Prerequisite: CS 660 and 655, or equivalent.
Study of techniques used in the implementation of assemblers, compilers, and other translator systems. Analyzes the relationship of available techniques to the syntactic and semantic specification of languages.

CS 782 - (3) (Y)
Advanced Computer Vision
Prerequisite: CS 682.
Analyzes advanced topics in automated reconstruction of imaged objects and computer interpretation of imaged scenes; techniques for three-dimensional object reconstruction; computing motion parameters from sequences of images; computational frameworks for vision tasks such as regularization, and stochastic relaxation; approaches for autonomous navigation. Depth image analysis; novel imaging techniques and applications; and parallel architectures for computer vision. Cross-listed as ECE 782.

CS 793 - (Credit as arranged) (SI)
Independent Study
Detailed study of graduate course material on an independent basis under the guidance of a faculty member.

CS 851 - (3) (SI)
Advanced Topics in Computer Science
Prerequisite: Instructor permission.
The exact syllabus for the seminar depends on the interests of the participants. Recent publications are read and analyzed. Student presentations followed by intense discussion. Original work and submission to conferences may be required. May be repeated for credit when the topics vary.

CS 854 - (3) (Y)
Topics in Computer Architecture
Prerequisite: CS 654 or instructor permission.
Studies selected advances in the architecture of computer systems. May include distribution processor systems, memory hierarchies, and secondary storage management schemes.

CS 855 - (3) (Y)
Topics in Programming Languages
Prerequisite: CS 655 or instructor permission.
Studies selected advanced topics in design, definition, and implementation of programming languages. Typical recent topics: parallel language design; formal semantics of programs. May be repeated for credit when the
topics vary.

CS 856 - (3) (Y)
Topics in Operating Systems
Prerequisite: CS 656 or instructor permission.
Topics covered are generally chosen from one or more of the following operating system research areas: detailed case studies, distributed systems, global computing, distributed shared memory, real-time systems, object-oriented systems, security, multimedia, and mobile computing.

CS 860 - (3) (O)
Topics in Theoretical Computer Science
Prerequisite: CS 660 or instructor permission.
Study of selected formal topics in computer science, including computational geometry, advanced searching techniques, proximity and intersection problems, interconnection problems, VLSI CAD, amortized complexity analysis, approximation algorithms, zero-knowledge proofs, biological computing, and quantum computing.

CS 862 - (3) (Y)
Topics in Database Systems
Prerequisite: CS 662 or instructor permission.
Analyzes the implementation of database systems, concurrent and distributed access, backup, and security; query languages and optimization of query access; multi-attribute dependencies and retrieval. Data warehousing and web-based data systems are explored.

CS 882 - (3) (Y)
Special Topics in Computer Vision/Image Processing
Prerequisite: Instructor permission.
For M.S. and Ph.D. students conducting research in computer vision/image processing. Readings from recently published articles in journals and conference proceedings are assigned. Cross-listed as ECE 882.

CS 885 - (3) (O)
Topics in Software Engineering
Prerequisite: CS 685 or instructor permission.
A special topics course in software engineering. Topics are determined by the individual instructor, but might include software reliability; engineering real-time systems; managing large software projects; resource estimation; validation and verification; or advanced programming environments.

CS 895 - (3) (S)
Supervised Project Research
Formal record of student commitment to project research for the Master of Computer Science degree under the guidance of a faculty advisor.

CS 897 - (Credit as arranged) (S)
Graduate Teaching Instruction
For master's students who are teaching assistants.

CS 898 - (Credit as arranged) (SI)
Thesis
Formal record of student commitment to thesis research for the Master of Science degree under the guidance of a faculty advisor. May be repeated as necessary.

CS 997 - (Credit as arranged) (S)
Dissertation
Formal record of student commitment to doctoral research under the guidance of a faculty advisor. May be repeated as necessary.

Electrical and Computer Engineering

ECE 525 - (3) (SI)
Introduction to Robotics
Prerequisite: ECE 402 or 621, or equivalent.
Analyzes kinematics, dynamics and control of robot manipulators, and sensor and actuator technologies (including machine vision) relevant to robotics. Includes a robotics system design project in which students completely design a robotic system for a particular application and present it in class. Includes literature related to emerging technologies and Internet resources relevant to robotics.

ECE 541 - (3) (SI)
Optics and Lasers
Prerequisite: ECE 203, 309, 323.
Reviews the electromagnetic principles of optics; Maxwell’s equations; reflection and transmission of electromagnetic fields at dielectric interfaces; Gaussian beams; interference and diffraction; laser theory with illustrations chosen from atomic, gas and semiconductor laser systems; detectors including photomultipliers and semiconductor-based detectors; and noise theory and noise sources in optical detection.

ECE 556 - (3) (Y)
Microwave Engineering I
Prerequisite: ECE 309 or instructor permission.
Design and analysis of passive microwave circuits. Topics include transmission lines, electromagnetic field theory, waveguides, microwave network analysis and signal flow graphs, impedance matching and tuning, resonators, power dividers and directional couplers, and microwave filters.

ECE 563 - (3) (Y)
Introduction to VLSI
Prerequisite: ECE 203, ECE 230.

ECE 564 - (3) (Y)
Microelectronic Integrated Circuit Fabrication
Prerequisite: ECE 303 or equivalent.
Explores fabrication technologies for the manufacture of integrated circuits and microsystems. Emphasizes processes used for monolithic silicon-based systems and basic technologies for compound material devices. Topics include crystal properties and growth, Miller indices, Czochralski growth, impurity diffusion, concentration profiles, silicon oxidation, oxide growth kinetics, local oxidation, ion implantation, crystal annealing, photolithography and pattern transfer, wet and dry etching processes, anisotropic etches, plasma etching, reactive ion etching, plasma ashing, chemical vapor deposition and epitaxy; evaporation, sputtering, thin film evaluation, chemical-mechanical polishing, multilevel metal, device contacts, rapid thermal annealing, trench isolation, process integration, and wafer yield.

ECE 576 - (3) (Y)
Digital Signal Processing
Prerequisite: ECE 323 and 324, or equivalent.
Fundamentals of discrete time signal processing are presented. Topics include discrete-time linear systems, continuous time signal sampling and reconstruction, Discrete Fourier Transform (DFT), Fast Fourier Transform (FFT), Spectral analysis, Z-transform, FIR and IIR digital filter design, and digital filter implementations. Problem solving using MATLAB is required.

ECE 578 - (1.5) (Y)
Digital Signal Processing Laboratory
Prerequisite: ECE 323 and 324; corequisite: ECE 576.
This course provides hands-on exposure to real-time digital signal sampling (DSP) using general-purpose DSP processors. The laboratory sequence explores sampling/reconstruction, aliasing, quantization errors, fast Fourier transform, spectral analysis, and FIR/IIR digital filter design and implementation. Programming is primarily in C++, with exposure to assembly coding.

ECE 586, 587 - (1-3) (SI)
Special Topics in Electrical and Computer Engineering
Prerequisite: Instructor permission.
A first-level graduate/advanced undergraduate course covering a topic not normally covered in the course offerings. The topic usually reflects new developments in the electrical and computer engineering field. Offering is based on student and faculty interests.

ECE 601 - (3) (SI)
Network Analysis and Synthesis
Prerequisite: ECE 204 and 324, or equivalent.
Design with active and passive elements is introduced from an immitance realization standpoint. Initially, the course deepens the student's circuit theory to include general passive and active elements and their characterization and manipulation using matrix methods. Passive synthesis is then used as a
foundation for active synthesis employing imittance-conversion devices The course also introduces some of the software packages available for approximation, network function extraction, circuit synthesis and tolerance analysis. This material provides a good background for continuing studies in signal processing, communications, passive or active circuit design.

ECE 602 - (3) (SI)
Electronic Systems
Prerequisite: ECE 204/307 or equivalent. Explores frequency response and stability of feedback electronic circuits. Analysis and design of analog integrated circuits, such as operational amplifiers, multipliers, phase locked loops, A/D and D/A converters and their application to instrumentation, and control.

ECE 611 - (3) (Y)
Probability and Stochastic Processes
Prerequisite: APMA 310, MATH 310, or equivalent. Topics include probability spaces (sample spaces, event spaces, probability measures); random variables and vectors (distribution functions, expectation, generating functions); and random sequences and processes; especially specification and classification. Includes detailed discussion of second-order stationary processes and Markov processes; inequalities, convergence, laws of large numbers, central limit theorem, ergodic, theorems; and MS estimation, Linear MS estimation, and the Orthogonality Principle.

ECE 613 - (3) (Y)
Communication Systems Engineering
Prerequisite: Undergraduate course in probability. A first graduate course in principles of communications engineering. Topics include a brief review of random process theory, principles of optimum receiver design for discrete and continuous messages, matched filters and correlation receivers, signal design, error performance for various signal geometries, Mary signaling, linear and nonlinear analog modulation, and quantization. The course also treats aspects of system design such as propagation, link power calculations, noise models, RF components, and antennas.

ECE 614 - (3) (Y)
Estimation Theory
Prerequisite: ECE 611 or instructor permission. Presents estimation theory from a discrete-time viewpoint. One-half of the course is devoted to parameter estimation, and the other half to state estimation using Kalman filtering. The presentation blends theory with applications and provides the fundamental properties of, and interrelationships among, basic estimation theory algorithms. Although the algorithms are presented as a neutral adjunct to signal processing, the material is also appropriate for students with interests in pattern recognition, communications, controls, and related engineering fields.

ECE 621 - (3) (Y)
Linear Automatic Control Systems
Prerequisite: ECE 323 or instructor permission. Provides a working knowledge of the analysis and design of linear automatic control systems using classical methods. Introduces state space techniques; dynamic models of mechanical, electrical, hydraulic and other systems; transfer functions; block diagrams; stability of linear systems, and Nyquist criterion; frequency response methods of feedback systems design and Bode diagram; Root locus method; System design to satisfy specifications; PID controllers; compensation using Bode plots and the root locus. Powerful software is used for system design. Cross-listed as MAE 651.

ECE 622 - (3) (Y)
Linear State Space Control Systems
Prerequisite: ECE 621, or instructor permission. Studies linear dynamical systems emphasizing canonical representation and decomposition, state representation, controllability, observability, stability normal systems, state feedbacks and the decoupling problem. Representative physical examples. Cross-listed as MAE 652.

ECE 631 - (3) (Y)
Advanced Switching Theory
Prerequisite: ECE 230 or equivalent. Review of Boolean Algebra; synchronous and asynchronous machine synthesis; functional decomposition; fault location and detection; design for testability techniques.

ECE 634 - (3) (Y)
Fault-Tolerant Computing
Examines techniques for designing and analyzing dependable computer-based systems. Topics include fault models and effects, fault avoidance techniques, hardware redundancy, error detecting and correcting codes, time redundancy, software redundancy, combinatorial reliability modeling, Markov reliability modeling, availability modeling, maintainability modeling, safety modeling, trade-off analysis, design for testability, and the testing of redundant digital systems. Includes a research project and investigation of current topics. Cross listed as CS 634.

ECE 635 - (3) (Y)
Computer Graphics in Engineering Design
Prerequisite: Knowledge of C. Analyzes display devices, line and circle generators; clipping and windowing; data structures; 2-D picture transformations; hidden line and surface algorithm; shading algorithms; free form surfaces; color graphics; 3-D picture transformation. Cross-listed as CS 645.

ECE 642 - (3) (Y)
Optics for Optoelectronics
Prerequisite: ECE 541 or instructor permission. Covers the electromagnetic applications of Maxwell’s equations in photonic devices such as the dielectric waveguide, fiber optic waveguide and Bragg optical scattering devices. Includes the discussion of the exchange of electromagnetic energy between adjacent guides, (i.e., mode coupling). Ends with an introduction to nonlinear optics. Examples of optical nonlinearity include second harmonic generation and soliton waves.

ECE 652 - (1.5) (Y)
Microwave Engineering Laboratory
Corequisite: ECE 556 or instructor permission. Explores measurement and behavior of high-frequency circuits and components. Equivalent circuit models for lumped elements. Measurement of standing waves, power, and frequency. Use of vector network analyzers and spectrum analyzers. Computer-aided design, fabrication, and characterization of microstrip circuits.

ECE 655 - (3) (O)
Microwave Engineering II
Prerequisite: ECE 556 or instructor permission. Explores theory and design of active microwave circuits. Review of transmission line theory, impedance matching networks and scattering matrices. Transistor s-parameters, amplifier stability and gain, and low-noise amplifier design. Other topics include noise in two-port microwave networks, negative resistance oscillators, injection-locked oscillators, video detectors, and microwave mixers.

ECE 663 - (3) (Y)
Solid State Devices
Prerequisite: ECE 303 or equivalent, or solid state materials/physics course. Introduces semiconductor device operation based on energy bands and carrier statistics. Describes operation of p-n junctions and metal-semiconductor junctions. Extends this knowledge to descriptions of bipolar and field effect transistors, and other microelectronic devices. Related courses: ECE 564, 666, and 667.

ECE 666 - (1.5) (Y)
Microelectronic Integrated Circuit Fabrication Laboratory
Corequisite: ECE 564. Topics include the determination of semiconductor material parameters: crystal orientation, type, resistivity, layer thickness, and majority carrier concentration; silicon device fabrication and analysis techniques: thermal oxidation, oxide masking, solid state diffusion of intentional impurities, metal electrode evaporation, layer thickness determination by surface profiling and optical interferometer; MOS transistor design and fabrication using the above techniques, characterization, and verification of design models used.

ECE 667 - (3) (Y)
Semiconductor Materials and Devices
Prerequisite: Some background in solid state materials and elementary quantum principles. Examines the fundamentals, materials, and engineering properties of semiconductors; and the integration of semiconductors with...
other materials to make optoelectronic and microelectronic devices. Includes basic properties of electrons in solids; electronic, optical, thermal and mechanical properties of semiconductors; survey of available semiconductors and materials choice for device design; fundamental principles of important semiconductor devices; sub-micron engineering of semiconductors, metals, insulators and polymers for integrated circuit manufacturing; materials characterization techniques; and other electronic materials. Cross-listed as MSE 667.

ECE 673 - (3) (Y)
Analog Integrated Circuits
Prerequisite: ECE 503 and 307, or equivalent.
Design and analysis of analog integrated circuits. Topics include feedback amplifier analysis and design including stability, compensation, and offset-correction; layout and floor-planning issues associated with mixed-signal IC design; selected applications of analog circuits such as A/D and D/A converters, references, and comparators; and extensive use of CAD tools for design entry, simulation, and layout. Includes an analog integrated circuit design project.

ECE 682 - (3) (Y)
Digital Image Processing
Prerequisite: Graduate standing.
Analyzes the basic concepts of image formation and image analysis: imaging geometries, sampling, filtering, edge detection, Hough transforms, region extraction and representation, extracting and modeling three-dimension objects. Students will be assigned analytical and programming assignments to explore these concepts. Cross-listed as CS 682.

ECE 686, 687 - (3) (SI)
Special Topics in Electrical and Computer Engineering
Prerequisite: Instructor permission.
A first-level graduate course covering a topic not normally covered in the graduate course offerings. The topic will usually reflect new developments in the electrical and computer engineering field. Offering is based on student and faculty interests.

ECE 693 - (3) (S)
Independent Study
Detailed study of graduate course material on an independent basis under the guidance of a faculty member.

ECE 695 - (3-6) (S)
Supervised Project Research
Formal record of student commitment to project research under the guidance of a faculty advisor. A project report is required at the completion of each semester. May be repeated as necessary.

ECE 712 - (3) (Y)
Digital Communications
Prerequisite: ECE 611.
An in-depth treatment of digital communications techniques and performance. Topics include performance of uncoded systems such as Mary, PSK, FSK, and multi-level signaling; orthogonal and bi-orthogonal codes; block and convolutional coding with algebraic and maximum likelihood decoding; burst correcting codes; efficiency and bandwidth; synchronization for carrier reference and bit timing; baseband signaling techniques; intersymbol interference; and equalization.

ECE 715 - (3) (O)
Performance Analysis of Communication Networks
Prerequisite: ECE /CS 457, APMA 310, or instructor permission.
Analyzes topologies arising in communication networks; queuing theory; Markov Chains and ergodicity conditions; theory of regenerative processes; routing algorithms; multiple-access and random-access transmission algorithms; mathematical methodologies for throughput and delay analyses and evaluations; performance evaluation; performance monitoring; local area networks (LANs); interactive LANs; multimedia and ATM networks. Cross-listed as CS 715.

ECE 717 - (3) (Y)
Information Theory and Coding
Prerequisite: ECE 611 or instructor permission.
A comprehensive treatment of information theory and its application to channel coding and source coding. Topics include the nature of information and its mathematical description for discrete and continuous sources; noiseless coding for a discrete source; channel capacity and channel coding theorems of Shannon; error correcting codes; introduction to rate distortion theory and practice of data compression; information and statistical measures.

ECE 722 - (3) (SI)
Robotics
Prerequisite: ECE 525, 621, or instructor permission.
Analyzes kinematics of manipulator robots in terms of homogeneous matrices, solution of the kinematics equations; differential translations and rotations, the Jacobian and the inverse Jacobian; manipulator path control; manipulator dynamics, the Lagrange's and Newton's formulations; manipulator control; principles of machine vision applied to robots, sensors, edge and feature detection, object location and recognition; stereo vision and ranging; programming of robot tasks.

ECE 723 - (3) (O)
Optimal Control Systems
Prerequisite: ECE 622 or instructor permission.
Analyzes the development and utilization of Pontryagin's maximum principle, the calculus of variations, Hamilton-Jacobi theory and dynamic programming in solving optimal control problems; performance criteria including time, fuel, and energy; optimal regulators and trackers for quadratic cost index designed via the Riccati equation; introduction to numerical optimization techniques. Cross-listed as MAE 753.

ECE 725 - (3) (SI)
Multivariable Robust Control Systems
Prerequisite: ECE 622 or equivalent, or instructor permission.
Studies advanced topics in modern multivariable control theory; matrix fraction descriptions, state-space realizations, multivariable poles and zeros; operator norms, singular value analysis; representation of unstructured and structured uncertainty, linear fractional transformation, stability robustness and performance robustness, parametrization of stabilizing controllers; approaches to controller synthesis; H\textsubscript{2}-optimal control and loop transfer recovery; H\textsubscript{\infty}-optimal control and state-space solution methods. Cross-listed as MAE 755.

ECE 726 - (3) (O)
Nonlinear Control Systems
Prerequisite: ECE 621 and 622.
Studies the dynamic response of nonlinear systems; analyzes nonlinear systems using approximate analytical methods; stability analysis using the second method of Liapunov, describing functions, and other methods. May include adaptive, neural, and switched systems. Cross-listed as MAE 756.

ECE 728 - (3) (E)
Digital Control Systems
Prerequisite: ECE 412 and 621, APMA 615, or equivalent.
Includes sampling processes and theorems, z-transforms, modified transforms, transfer functions, and stability criteria; analysis in frequency and time domains; discrete state models of systems containing digital computers; and advanced discrete-time control techniques. Some in-class experiments using small computers to control dynamic processes. Cross-listed as MAE 758.

ECE 735 - (3) (Y)
Digital and Computer System Design
Prerequisite: ECE 435 or equivalent.
Studies the design of the elements of special purpose and large scale digital processors using a hardware description language. Selected topics from the literature.

ECE 736 - (3) (Y)
Advanced VLSI Systems Design
Prerequisite: ECE 563 or instructor permission.
Includes structured VLSI design, special purpose VLSI architectures, and algorithms for VLSI computer-aided design. A major part of the class is devoted to the design and implementation of a large project. Uses papers from current literature as appropriate.

ECE 738 - (3) (Y)
Computer System Reliability Engineering
A mathematical introduction to system reliability theory, emphasizing the analysis of digital computer systems. Includes time-to-failure models and distributions, fault tree analysis, Markov models and counting processes, failure and repair dependencies, sensitivity and importance analysis, hardware and software redundancy management, and dependability measurement.

ECE 741 - (3) (SI)
Fourier Optics  
**Prerequisite:** ECE 324 and 541, or instructor permission. 
Topics include techniques for solving and analyzing engineering electromagnetic systems; relation of fundamental concepts of electromagnetic field theory and circuit theory, including duality, equivalence principles, reciprocity, and Green’s functions; applications of electromagnetic principles to antennas, waveguide discontinuities, and equivalent impedance calculations.

ECE 753 - (3) (O)  
**Electromagnetic Field Theory**  
**Prerequisite:** ECE 409 or instructor permission. 
Topics include techniques for solving and analyzing engineering electromagnetic systems; relation of fundamental concepts of electromagnetic field theory and circuit theory, including duality, equivalence principles, reciprocity, and Green’s functions; applications of electromagnetic principles to antennas, waveguide discontinuities, and equivalent impedance calculations.

ECE 757 - (3) (Y)  
**Computer Networks**  
**Prerequisite:** CS 656 or instructor permission. 
Analyzes network topologies; backbone design; performance and queuing theory; data-grams and virtual circuits; technology issues; layered architectures; standards; survey of commercial networks, local area networks, and contention-based communication protocols; encryption; and security. Cross-listed as CS 757.

ECE 763 - (3) (Y)  
**Physics of Semiconductors**  
**Prerequisite:** ECE 663 or instructor permission. 
Analyzes semiconductor band theory; constant energy surfaces and effective mass concepts; statistics treating normal and degenerate materials; spin degeneracy in impurities; excited impurity states and impurity recombination; carrier transport; scattering mechanisms; and prediction techniques.

ECE 768 - (3) (Y)  
**Semiconductor Materials and Characterization Techniques**  
**Prerequisite:** ECE 663 or instructor permission. 
Analyzes semiconductor growth and characterization methods applicable to III-V heteroepitaxial growth along with etching and contact formation mechanisms; and the physical, structural, and electrical characterization tools including X-ray diffraction, Auger, Hall and C(V).

ECE 774 - (3) (E)  
**Adaptive and Statistical Signal Processing**  
**Prerequisite:** ECE 611, 576, or equivalent; corequisite: ECE 614. 
Topics include a review of probability and stochastic processes, parametric and non-parametric spectral estimation, optimal filtering, linear prediction, methods of steepest descent, LMS filters, methods of least squares, RLS filters, Kalman filters, and array signal processing techniques.

ECE 776 - (3) (O)  
**Multi-Dimensional Signal Processing**  
**Prerequisite:** ECE 576 or instructor permission. 
Provides the background of multi-dimensional digital signal processing, emphasizing the differences and similarities between the one-dimensional and multi-dimensional cases. Includes M-D Fourier transforms, M-D sampling and reconstruction, M-D DFT, M-D filtering, M-D spectral estimation, and inverse problems such as tomography, iterative signal reconstruction, and coherent imaging. Broad applications in radar, sonar, seismic, medical, and astronomical data processing are introduced.

ECE 781 - (3) (Y)  
**Pattern Recognition**  
**Prerequisite:** ECE 611 or equivalent. 
Studies feature extraction and classification concepts: analysis of decision surfaces, discriminant functions, potential functions, deterministic methods, automatic training of classifiers, analysis of training algorithms and classifier performance, statistical classification including optimality and design of optimal decision rules, clustering and non-supervised learning, feature selection and dimensionality reduction. Assignments include programming and analytical problem sets and a final computer project.

ECE 782 - (3) (Y)  
**Advanced Computer Vision**  
**Prerequisite:** ECE 682. 
Studies automated reconstruction of imaged objects and computer interpretation of imaged scenes; techniques for three-dimensional object reconstruction; computing motion parameters from sequences of images; computational frameworks for vision tasks such as regularization, and stochastic relaxation; approaches for autonomous navigation; depth image analysis; novel imaging techniques and applications; parallel architectures for computer vision. Cross-listed as CS 782.

ECE 786, 787 - (3) (SI)  
**Special Topics in Electrical and Computer Engineering**  
**Prerequisite:** Instructor permission. 
A second level graduate course covering a topic not normally covered in the graduate course offerings. Topics usually reflect new developments in electrical and computer engineering and are based on student and faculty interests.

ECE 793 - (3) (S)  
**Independent Study**  
Detailed study of graduate course material on an independent basis under the guidance of a faculty member.

ECE 814 - (3) (Y)  
**Advanced Detection and Estimation**  
**Prerequisite:** ECE 611 or instructor permission. 
Analyzes classical detection theory and hypothesis testing (Bayes, Neyman-Pearson, minimax); robust hypothesis testing; decision criteria; sequential and nonparametric detection; classical estimation theory (Bayes, minimax, maximum likelihood); performance bounds; robust-outlier resistant estimation of location parameters; stochastic distance measures; parametric and robust operations in time series (Prediction, interpolation, filtering). Applications to problems in communications, control, pattern recognition, signal processing.

ECE 825 - (3) (SI)  
**Adaptive Control**  
**Prerequisite:** ECE 621 and 622, or instructor permission. 
Analyzes parametric controlled system models, signal norms, Lyapunov stability, passivity, error models, gradient and least squares algorithms for parameter estimation, adaptive observers, direct adaptive control, indirect adaptive control, certainty equivalence principle, multivariable adaptive control, stability theory of adaptive control, and applications to robot control systems.

ECE 862 - (3) (SII)  
**High Speed Transistors**  
**Prerequisite:** ECE 663 or 768 or instructor permission. 
Includes the principles of operation, device physics, basic technology, and modeling of high speed transistors. A brief review of material properties of most important compound semiconductors and heterostructure systems, followed by the discussion of high speed Bipolar Junction Transistor technology, Heterojunction Bipolar Transistors, and Tunelling Emitter Bipolar Transistors and by the theory and a comparative study of MESFETS, HFETs, and Variable-Threshold and Split-gate Field Effect Transistors. Also includes advanced transistor concepts based on ballistic and hot electron transport in semiconductors such as Ballistic Injection Transistors and Real Space Transfer Transistors (RSTs) concepts.

ECE 863 - (3) (SI)  
**High Frequency Diodes**  
**Prerequisite:** ECE 536, 663, or instructor permission. 
Lectures on the basic two terminal solid state devices that are still extensively used in high frequency microwave and millimeter-wave detector and oscillator circuits. Devices discussed are PIN Diode limiters and phase shifters; Schottky Diode mixers and varactors; Planar-Doped Barrier and Heterostructure Barrier mixer diodes; Superconducting-Insulating- Superconducting mixer devices; Metal-Semiconductor-Metal photodetectors; Transferred Electron Devices; IMPATT Diodes; and Resonant Tunelling Diodes. Basic concepts related to Noise in high frequency circuits, Mixers, Resonators, and
Oscillators are reviewed. Emphasis on basic device theory, and device fabrication.

**ECE 886, 887 - (3) (SI)**
**Special Topics in Electrical and Computer Engineering**
**Prerequisite:** Instructor permission.
A third-level graduate course covering a topic not normally covered in the graduate course offerings. The topic will usually reflect new developments in the electrical and computer engineering field. Offering is based on student and faculty interests.

**ECE 805 - (3-6) (S)**
**Supervised Project Research**
Formal record of student commitment to project research under the guidance of a faculty advisor. Registration may be repeated as necessary.

**ECE 897 - (Credit as arranged) (S)**
**Graduate Teaching Instruction**
For master’s students.

**ECE 898 - (Credit as arranged) (S)**
**Thesis**
Formal record of student commitment to master’s thesis research under the guidance of a faculty advisor. May be repeated as necessary.

**ECE 997 - (Credit as arranged) (S)**
**Graduate Teaching Instruction**
For doctoral students.

**ECE 999 - (Credit as arranged) (S)**
**Dissertation**
Formal record of student commitment to doctoral research under the guidance of a faculty advisor. May be repeated as necessary.

**Engineering Physics**
Opportunities for research project work and special topics are provided through the following courses:

**EP 693 - (Credit as arranged) (S)**
**Independent Study**
Detailed study of graduate course material on an independent basis under the guidance of a faculty member.

**EP 695 - (Credit as arranged) (S)**
**Supervised Project**
Formal record of student commitment to project research under the guidance of a faculty advisor. May be repeated.

**EP 700 - (0) (S)**
**Graduate Seminar**
Weekly seminars for graduate students in Engineering Physics offered every semester. All resident EP graduate students enroll each semester.

**EP 733, 734 - (3) (IR)**
**Special Topics in Engineering Physics**
**Prerequisite:** instructor permission.
Advanced-level study of selected problems in engineering physics.

**EP 793 - (Credit as arranged) (S)**
**Independent Study**
Detailed study of graduate course material on an independent basis under the guidance of a faculty member.

**EP 897 - (Credit as arranged) (S)**
**Graduate Teaching Instruction**
For master’s students.

**EP 898 - (Credit as arranged) (S)**
**Master’s Degree Research**
Formal record of student commitment to master’s thesis research under the guidance of a faculty advisor. May be repeated as necessary.

**EP 997 - (Credit as arranged) (S)**
**Ph.D. Dissertation Research**
Formal record of commitment to doctoral research under the guidance of a faculty advisor. May be repeated as necessary.

**Materials Science and Engineering**

**MSE 512 - (3) (Y)**
**Introduction to Biomaterials**
Provides a multi-disciplinary perspective on the phenomenon and processes which govern material-tissue interactions with the soft tissue, hard tissue, and cardiovascular environments. Emphasizes both sides of the biomaterials interface, examining the events at the interface, and discussing topics on material durability and tissue compatibility.

**MSE 524 - (3) (Y)**
**Modeling in Materials Science**
Computational (primarily classical) methods of atomistic, mesoscopic, continuum, and multiscale modeling are discussed in the context of real materials-related problems (mechanical and thermodynamic properties, phase transformations, microstructure evolution during processing). Success stories and limitations of contemporary computational methods are considered. The emphasis is on getting practical experience in designing and performing computer simulations. Students use and modify pre-written codes and write their own simulation and data analysis codes.

**MSE 532 - (3) (Y)**
**Deformation and Fracture Mechanics of Structural Materials**
**Prerequisite:** MSE 306 or instructor permission.
Deformation and fracture are considered through integration of materials science microstructure and solid mechanics principles, emphasizing the mechanical behavior of metallic alloys and engineering polymers. Metal deformation is understood based on elasticity theory and dislocation concepts. Fracture is understood based on continuum fracture mechanics and microstructural damage mechanisms. Additional topics include fatigue loading, elevated temperature behavior, material embrittlement, time-dependency, experimental design, and damage-tolerant life prediction.

**MSE 567 - (3) (Y)**
**Structure and Properties of Materials**
Explore the fundamental physical laws governing electrons in solids, and show how that knowledge can be applied to understanding electronic, optical and magnetic properties. Students will gain an understanding of how these properties vary between different types of materials, and thus why specific materials are optimal for important technological applications. It will also be shown how processing issues further define materials choices for specific applications.

**MSE 601 - (3) (Y)**
**Materials Structure and Defects**
**Prerequisite:** Instructor permission.
Provides a fundamental understanding of the structure and properties of perfect and defective materials. Topics include: crystallography and crystal structures, point defects in materials, properties of dislocations in f.c.c. metals and other materials, surface structure and energy, structure and properties of interphase boundaries.

**MSE 602 - (3) (Y)**
**Materials Characterization**
**Prerequisite:** MSE 601 and MSE 623.
Develops a broad understanding of the means used to characterize the properties of solids coupled with a fundamental understanding of the underlying mechanisms in the context of material science and engineering. The course is organized according to the type of physical property of interest. The methods used to assess properties are described through integration of the principles of materials science and physics. Methods more amenable to analysis of bulk properties are differentiated from those aimed at measurements of local/surface properties. Breadth is achieved at the expense of depth to provide a foundation for advanced courses.

**MSE 604 - (3) (SS)**
**Scanning Electron Microscopy and Microanalysis**
**Prerequisite:** Instructor permission.
Covers the physical principles of scanning electron microscopy and electron probe microanalysis. Laboratory demonstrations and experiments cover the operation of the SEM and EPMA. Applications of secondary and backscattered electron imaging, energy dispersive x-ray microanalysis, wave- analysis are applied to materials characterization. Laboratory experiments may include either materials science or biological applications, depending on the interests of the student.

**MSE 605 - (3) (Y)**
**Structure and Properties of Materials I**
**Prerequisite:** Instructor permission.
This is the first of a sequence of two basic courses for first-year graduate students or qualified undergraduate students. Topics include atomic bonding, crystal structure, and crystal defects in their relationship to properties and behavior of materials (polymers, metals, and ceramics); phase equilibria and non-equilibrium phase transformation; metastable structures; solidification; and recrystallization.

**MSE 606 - (3) (Y)**
**Structure and Properties of Materials II**
**Prerequisite:** MSE 605 or instructor permission.
permission. This is the second of a two-course sequence for the first-year graduate and qualified undergraduate students. Topics include diffusion in solids; elastic, anelastic, and plastic deformation; and electronic and magnetic properties of materials. Emphasizes the relationships between microscopic mechanisms and macroscopic behavior of materials.

MSE 608 - (3) (Y)
Chemical and Electrochemical Properties
Prerequisite: Physical chemistry course or instructor permission.
Introduces the concepts of electrode potential, double layer theory, surface charge, and electrode kinetics. These concepts are applied to subjects that include corrosion and embrittlement, energy conversion, batteries and fuel cells, electro-catalysis, electroanalysis, electrochemical industrial processes, bio-electrochemistry, and water treatment.

MSE 623 - (3) (Y)
Thermodynamics of Solids
Prerequisite: Instructor permission.
Emphasizes the understanding of thermal properties such as heat capacity, thermal expansion, and transitions in terms of the entropy and the other thermodynamic functions. Develops the relationships of the Gibbs and Helmholtz functions to equilibrium systems, reactions, and phase diagrams. Atomistic and statistical mechanical interpretations of crystalline and non-crystalline solids are linked to the general thermodynamical laws by the partition function. Nonequilibrium and irreversible processes in solids are discussed.

MSE 624 - (3) (Y)
Kinetics of Solid-state Reactions
Prerequisite: MSE 623.
An introduction to basic kinetic processes in materials, develops basic mathematical skills necessary for materials research, and reinforces basic numerical and computer programming skills. Students learn to formulate the partial differential equations and boundary conditions used to describe basic materials phenomena in the solid state including mass and heat diffusion in single- and two-phase systems, the motion of planar phase boundaries, and interfacial reactions. Students develop analytical and numerical techniques for solving these equations and apply them to understanding microstructural evolution.

MSE 635 - (3) (E)
Physical Metallurgy of Light Alloys
Prerequisite: Instructor permission.
Develops the student’s literacy in aluminum and titanium alloys used in the aerospace and automotive industries. Considers performance criteria and property requirements from design perspectives. Emphasizes processing-microstructure development, and structure-property relationships.

MSE 647 - (3) (O)
Physical Metallurgy of Transition-Element Alloys
Prerequisite: MSE 606 or instructor permission.

Reinforces fundamental concepts, introduces advance topics, and develops literacy in the major alloy systems. Emphasizes microstructural evolution by composition and thermo-mechanical process control. Topics include phase diagrams, transformation kinetics, martensitic transformation, precipitation, diffusion, recrystallization, and solidification. Considers both experimental and model-simulation approaches.

MSE 662 - (3) (Y)
Mathematics of Materials Science
Prerequisite: Instructor permission.
Representative problems in materials science are studied in depth with emphasis on understanding the relationship between physical phenomena and their mathematical description. Topics include rate processes, anelasticity, eigenvalue problems, tensor calculus, and elasticity theory.

MSE 667 - (3) (Y)
Semiconductor Materials and Devices
Prerequisite: Some background in solid state and elementary quantum principles.
Provides an understanding of the fundamentals, materials, and engineering properties of semiconductors; and the integration of semiconductors with other materials to make optoelectronic and microelectronic devices. Topics include basic properties of electrons in solids; electronic, optical, thermal and mechanical properties of semiconductors; survey of available semiconductors and materials choice for device design; fundamental principles of important semiconductor devices; sub-micron engineering of semiconductors, metals, insulators and polymers for integrated circuit manufacturing; materials characterization techniques; and other electronic materials. Cross-listed as ECE 667.

MSE 691, 692 - (3) (SI)
Topics in Materials Science
A study of special subjects related to developments in materials science under the direction of members of the staff. Offered as required under the guidance of a faculty member.

MSE 694 - (3) (Y)
Materials Science Laboratory
Introduces student to the specialized experimental techniques used in materials science research. Particular attention is given to the techniques of X-ray diffractions and electron microscopy. Also introduced are several of the latest experimental methods such as field ion microscopy, electron spin resonance, and low voltage electron diffraction. This course builds on MSE 602.

MSE 695 - (Credit as arranged) (S)
Supervised Project Research
Formal record of student commitment to project research for Master of Science or Master of Materials Science degree under the guidance of a faculty advisor. May be repeated as necessary.

MSE 701, 702 - (1) (Y)
Materials Science Seminar
Broad topics and in-depth subject treatments are presented. The course is related to research areas in materials science and involves active student participation.

MSE 703 - (3) (Y)
Electron Microscopy of Crystals
Prerequisite: MSE 601 or instructor permission.
An analysis of the physical principles of microscopy and electron optics, attainment of high resolution; mass-thickness contrast; theory of diffraction contrast; scanning electron microscopy and applications to materials science; and high-voltage electron microscopy.

MSE 706 - (3) (E)
Advanced Electron Microscopy
Prerequisite: MSE 703 or instructor permission.
Emphasis placed on the applications of advanced techniques of transmission and scanning electron microscopy to modern research problems in materials science and engineering. Microdiffraction and microanalysis, lattice imaging, and convergent beam diffraction in TEM and STEM are treated. In SEM, quantitative probe analysis techniques and back scattered electron imaging and channeling are covered.

MSE 712 - (3) (Y)
Diffusional Processes in Materials
Prerequisite: MSE 623, 624.
An introduction to elasticity theory, the thermodynamics of stressed crystals, and diffuse interface theory with application to understanding microstructural evolution in bulk materials and thin films.

MSE 714 - (3) (SI)
Quantization in Solids
Quantization arising from eigenvalue problems is discussed in relation to the classical and quantum wave equations. This theory is applied to lattice vibrations (phonons) and electrons in a solid. Topics studied in detail include cohesion, thermal properties (e.g., specific heat and conductivity), electrical properties (e.g., metallic conductivity and semiconductor junctions) and optical properties (e.g., luminescence and photoconductivity).

MSE 722 - (3) (SI)
Surface Science
Prerequisite: Instructor permission.
Analyses the structure and thermodynamics of surfaces, with particular emphasis on the factors controlling chemical reactivity of surfaces; adsorption, catalysis, oxidation, and corrosion are considered from both theoretical and experimental viewpoints. Modern surface analytical techniques, such as Auger, ESCA, and SIMS are considered.

MSE 731 - (3) (Y)
Mechanical Behavior of Materials
Prerequisite: MSE 532 or instructor permission.
Studies the deformation of solids under stress; emphasizing the role of imperfections, state of stress, temperature and strain rate. Description of stress, strain, strain rate and elastic properties of materials comprise the opening topic. Then considers fundamental
aspects of crystal plasticity, along with the methods for strengthening crystals at low temperatures. Covers deformation at elevated temperatures and deformation maps. Emphasizes the relationships between microscopic mechanisms and macroscopic behavior of materials.

MSE 732 - (3) (SI) Fracture Mechanics of Engineering Materials
Prerequisite: MSE 731 or instructor permission.
Develops the tools necessary for fatigue and fracture control in structural materials. Presents continuum fracture mechanics principles and discusses fracture modes from the interdisciplinary perspectives of continuum mechanics and microscopic plastic deformation/fracture mechanisms. Includes cleavage, ductile fracture, fatigue, and environmental cracking, emphasizing micromechanical modeling. Cross-listed as AM 732.

MSE 741 - (3) (Y) Crystal Defect Theory
Prerequisite: MSE 625 or comparable thermodynamics.
Studies the nature and major effects of crystal defects on the properties of materials, emphasizing metals. The elasticity theory of dislocations is treated in depth.

MSE 751 - (3) (Y) Polymer Science
Prerequisite: Instructor permission.
Emphasizes the nature and types of polymers and methods for studying them. Surveys chemical structures and methods of synthesis, and develops the physics of the special properties of polymers (e.g., rubber elasticity, tactility, glass transitions, crystallization, dielectric and mechanical relaxation, and permeability). Discusses morphology of polymer systems and its influence on properties.

MSE 752 - (3) (SI) Advanced Polymer Science II
Prerequisite: MSE 751 or instructor permission.
Focuses on the experimental methods of polymer science. Develops a picture of polymer structure and properties by examining the use of solutions (viscosity and chromatography), thermal (DSC, DTA, TGA), microscopic (electron and optical), spectroscopic (IR, Raman, NMR, mechanical and dielectric), scattering (neutron, X-ray, and visible light), and diffraction (neutron, electron and X-ray) techniques as they are applied to the characterization and study of polymeric materials.

MSE 757 - (3) (SI) Materials Processing
Prerequisite: MSE 731 or instructor permission.
Discusses scientific and technological bases of material processing. Examines solidification, deformation, particulate and thermomechanical processing from a fundamental point of view and discusses their current technological applications.

MSE 762 - (3) (E) Modern Composite Technology
Prerequisite: Instructor permission.
Discusses the technology of modern composite materials including basic principles, mechanics, reinforcements, mechanical properties and fracture characteristics, fabrication techniques, and applications. Emphasizes high performance filamentary reinforced materials. Discusses the principles of chemical vapor deposition and the application of this technology to the area of composite materials.

MSE 771 - (3) (SI) Advanced Electrochemistry
A highly specialized course detailing specific subject matter in the areas of corrosion of stainless steel, cyclic voltammetry, and the adsorption of hydrogen on and diffusion of hydrogen through Palladium. Associated experimental methods are discussed.

MSE 771, 792 - (3) (SI) Advanced Topics in Materials Science
Prerequisite: Permission of the staff.
An advanced level study of special subjects related to developments in materials science under the direction of members of the staff. Offered as required.

MSE 793 - (Credit as arranged) (S) Independent Study
Detailed study of graduate course material on an independent basis under the guidance of a faculty member.

MSE 795 - (Credit as arranged) (S) Supervised Project Research
Formal record of student commitment to project research for Doctor of Philosophy degree under the guidance of a faculty advisor. May be repeated as necessary.

MSE 897 - (Credit as arranged) (S) Graduate Teaching Instruction
For master's students.

MSE 898 - (Credit as arranged) (S) Thesis
Formal record of student commitment to master's thesis research under the guidance of a faculty advisor. May be repeated as necessary.

MSE 997 - (Credit as arranged) (S) Graduate Teaching Instruction
For doctoral students.

MSE 999 - (Credit as arranged) (S) Dissertation
Formal record of student commitment to doctoral research under the guidance of a faculty advisor. May be repeated as necessary.

Mechanical and Aerospace Engineering
Listed prerequisites represent ordinary and reasonable preparation. Equivalent preparation is acceptable. Enrollment without prerequisites is allowed with instructor's permission.

Graduate students in Mechanical and Aerospace Engineering often take courses in applied mathematics and other engineering and science departments.

MAE 602 - (3) (Y) Continuum Mechanics with Applications
Introduction to continuum mechanics and mechanics of deformable solids. Topics include Vectors and cartesian tensors, stress, strain, deformation, equations of motion, constitutive laws, introduction to elasticity, thermal elasticity, viscoelasticity, plasticity, and fluids. Cross-listed as AM 602, APMA 602, and CE 602.

MAE 603 - (3) (IR) Computational Solid Mechanics
Prerequisite: MAE 602.
Analyzes variational and computational mechanics of solids; potential energy; complementary energy; virtual work; Reissner's principle; Ritz and Galerkin methods; displacement; force and mixed methods of analysis; finite element analysis including shape functions, convergence, and integration. Applications in solid mechanics. Cross-listed as AM 603 and CE 603.

MAE 604 - (3) (O) Plates and Shells
Prerequisite: APMA 641, AM 601 or AM 602.
Topics include the classical analysis of plates and shells; plates of various shapes (cylindrical, conical, spherical, hyperbolic, paraboloid); closed-form numerical and approximate methods of solution governing partial differential equations; and advanced topics (large deflection theory, thermal stresses, orthotropic plates). Cross-listed as AM 604 and CE 604.

MAE 607 - (3) (E) Theory of Elasticity
Prerequisite: AM 602 or instructor permission.
Review of the concepts of stress, strain, equilibrium, compatibility; Hook's law (isotropic materials); displacement and stress formulations of elasticity problems; plane stress and strain problems in rectangular coordinates (Airy's stress function approach); plane stress and strain problems in polar coordinates, axisymmetric problems; torsion of prismatic bars (semi-inverse method using real function approach); thermal stress; and energy
methods. Cross-listed as AM 607 and CE 607.

MAE 608 - (3) (E)
Constitutive Modeling of Biosystems
Prerequisite: Continuum Mechanics.
The course covers state-of-the-art mechanical models to describe the constitutive behavior of hard and soft tissues with emphasis on biological form following physiological function. The course will cover linear and nonlinear elasticity, viscoelasticity, poroelasticity, and biphasic constitutive relations in the context of biological systems and will include the dependence of macroscopic behavior and properties on material microstructure.

MAE 610 - (3) (Y)
Thermomechanics
Prerequisite: Graduate standing.
Review of classical thermodynamics; introduction to kinetic theory; quantum mechanical analysis of atomic and molecular structure; statistical mechanical evaluation of thermodynamic properties; chemical thermodynamics and equilibria.

MAE 611 - (3) (Y)
Heat and Mass Transport Phemonena
Prerequisite: Undergraduate fluid mechanics or instructor permission.

MAE 612 - (3) (E)
Microscale Heat Transfer
Prerequisite: MAE 610.
This course will begin with a study of the fundamental microscopic energy carriers (definitions, properties, energy levels and disruptions of photons, phonons, and electrons.) Transport of energy will then be investigated with an emphasis on microscale effects in space and in time. The approaches used to describe microscale heat transportation differ significantly from the macroscopic phenomenological approaches and include new physical mechanisms. They often involve solution of the Boltzman transport equation and the equation of phonon radiative transfer. These approaches will be introduced with an emphasis on ultra-short time scale heating and ultra-low temperatures.

MAE 613 - (3) (E)
Kinetic Theory and Transport Properties
Prerequisite: MAE 610 or instructor permission.
Derivation of Boltzmann equation; Molecular derivation of Navier-Stokes equations; dynamics of molecular collisions; Chapman-Enskog solution of Boltzmann equation; transport properties of gases; analyses of shock structure, flows with chemical reactions, radiative nonequilibrium, rarefied gases, etc.

MAE 616 - (3) (IR)
Advanced Thermodynamics
Prerequisite: Instructor permission.
Analyses basic concepts, postulates, and relationships of classical thermodynamics; thermodynamics potentials and derivatives; energy minimum and entropy maximum principle; generalized Maxwell relations; stability considerations; phase transitions; application to perfect and imperfect systems; and extension to chemically reacting and solid systems.

MAE 620 - (3) (IR)
Energy Principles in Mechanics
Prerequisite: Instructor permission.
Analyses the derivation, interpretation, and application to engineering problems of the principles of virtual work and complementary virtual work; related theorems, such as the principles of the stationary value of the total potential and complementary energy, Castigiano's Theorem, theorem of least work, and unit force and displacement theorems. Introduces generalized, extended, mixed, and hybrid principles; variational principles: approximation, Hamilton's principle, and Lagrange's equations of motion; and approximate solutions to problems in structural mechanics by use of variational theorems. Cross-listed as AM 620 and CE 620.

MAE 621 - (3) (Y)
Analytical Dynamics
Prerequisite: Undergraduate physics, ordinary differential equations.
Classical analytical dynamics from a modern mathematical viewpoint: Newton's laws, dynamical variables, many particle systems; the Lagrangian formulation, constraints and configuration manifolds, tangent bundles, differential manifolds; variational principles, least action; non-potential forces; constrained problems; linear oscillations; Hamiltonian formulation: canonical equations, Rigid body motion. Cross-listed as AM 621.

MAE 622 - (3) (O)
Waves
Prerequisite: MAE/AM 602 or equivalent.
The topics covered are: plane waves; d'Alembert solution; method of characteristics; dispersive systems; wavepackets; group velocity; fully-dispersed waves; Laplace, Stokes, and steepest descents integrals; membranes, plates and plane-stress waves; evanescent waves; Kirchhoff's solution; Fresnel's principle; elementary diffraction; reflection and transmission at interfaces; waveguides and ducted waves; waves in elastic half-spaces; P, S, and Rayleigh waves; layered media and Love waves; slowly-varying media and WKBJ method; Time-dependent response using Fourier-Laplace transforms; some nonlinear water waves. Cross-listed as AM 622.

MAE 623 - (3) (Y)
Vibrations
Prerequisite: Instructor permission.
Topics include free and forced vibrations of undamped and damped single- and multi-degree-of-freedom systems; modal analyses; continuous systems; matrix formulations; finite element equations; direct integration methods; and eigenvalue solution methods. Cross-listed as AM 623 and CE 623.

MAE 624 - (3) (E)
Nonlinear Dynamics and Waves
Prerequisite: Undergraduate ordinary differential equations or instructor permission.
Introduces phase-space methods, elementary bifurcation theory and computation, and applications to the study of stability in the contexts of nonlinear dynamical systems and nonlinear waves, including free and forced nonlinear vibrations and wave motions. Examples are drawn from mechanics and fluid dynamics, and include transitions to periodic oscillations and chaotic oscillations. Cross-listed as APMA 624.

MAE 625 - (3) (O)
Multibody Mechanical Systems
Prerequisite: Engineering degree and familiarity with a programming language.
Analytical and computational treatment for modeling and simulation of 3-Dimensional multibody mechanical systems. Provide a systematic and consistent basis for analyzing the interactions between motion constraints, kinematics, static, dynamic, and control behavior of multibody mechanical systems. Applications to machinery, robotic devices and mobile robots, biomechanical models for gait analysis and human motion, and motion control. Matrix modeling procedures with symbolic and numerical computational tools will be utilized for demonstrating the methods developed in this course. Focus on the current research and computational tools and examine a broad spectrum of physical systems where multibody behavior is fundamental to their design and control.

MAE 631 - (3) (Y)
Fluid Mechanics I
Prerequisite: MAE 602 and APMA/MAE 641.
The topics covered are: dimensional analysis; physical properties of fluids; kinematic descriptions of flow; streamline, path lines and streak lines; stream functions and vorticity; hydrostatics and thermodynamics; Euler and Bernoulli equations; irrotational potential flow; exact solutions to the Navier-Stokes equation; effects of viscosity - high and low Reynolds numbers; waves in incompressible flow; hydrodynamic stability. Cross-listed as AM 631.

MAE 632 - (3) (E)
Fluid Mechanics II
Prerequisite: MAE 631.
The topics covered are: thin wing theory; slender-body theory; three-dimensional wings in steady subsonic and supersonic flows; drag at supersonic speeds; drag minimization; transonic small-disturbance flow; unsteady flow; properties and modeling of turbulent flows. Cross-listed as AM 632.

MAE 633 - (3) (IR)
Lubrication Theory and Design
Prerequisite: Instructor permission.
Topics include the hydrodynamic theory of lubrication for an incompressible fluid; design principles of bearings: oil flow, load-carrying capacity, temperature rise, stiffness, damping properties; influence of bearing
design upon rotating machinery; computer modeling methods; and applications to specific types.

MAE 634 - (3) (O)
Transport Phenomena in Biological Systems
Prerequisite: Introductory fluid mechanics and/or heat or mass transfer, or instructor permission.
Fundamentals of momentum, energy and mass transport as applied to complex biological systems ranging from the organs to the cells in whole plants and animals and their environments. Derivation of conservation laws (momentum, heat and mass), constitutive equations, and auxiliary relations. Applications of theoretical equations and empirical relations to model and predict the characteristics of diffusion and convection in complex biological systems and their environments. Emphasis placed on the bio-mechanical understanding of these systems through the construction of simplified mathematical models amenable to analytical, numerical or statistical formulations and solutions, including the identification and quantification of model uncertainties.

MAE 636 - (3) (IR)
Gas Dynamics
Prerequisite: MAE 610.
Analyzes the theory and solution methods applicable to multi-dimensional compressible inviscid gas flows at subsonic, supersonic, and hypersonic speeds; similarity and scaling rules from small-perturbation theory, introduction to transonic and hypersonic flows; method-of-characteristics applications to nozzle flows, jet expansions, and flows over bodies one dimensional non-steady flows; properties of gases in thermodynamic equilibrium, including kinetic-theory, chemical-thermodynamics, and statistical-mechanics considerations; dissociation and ionization process; quasi-equilibrium flows; and introduction to non-equilibrium flows.

MAE 637 - (3) (IR)
Singular Perturbation Theory
Prerequisite: Familiarity with complex analysis. Analyzes regular perturbations, roots of polynomials; singular perturbations in ODE's, periodic solutions of simple nonlinear differential equations; multiple-Scales method; WKBJ approximation; turning-point problems; Langer's method of uniform approximation; asymptotic behavior of integrals, Laplace Integrals, stationary phase, steepest descents. Examples are drawn from physical systems. Cross-listed with APMA 637.

MAE 641 - (3) (Y)
Engineering Mathematics I
Prerequisite: Graduate standing.
Review of ordinary differential equations. Initial value problems, boundary value problems, and various physical applications. Linear algebra, including systems of linear equations, matrices, eigenvalues, eigenvectors, diagonalization, and various applications. Scalar and vector field theory, including the divergence theorem, Green's theorem, and Stokes theorem, and various applications. Partial differential equations that govern physical phenomena in science and engineering. Solution of partial differential equations by separation by variables, superposition, Fourier series, variation of parameter, d'Alembert's solution. Eigenfunction expansion techniques for non-homogeneous initial-value, boundary-value problems. Particular focus on various physical applications of the heat equation, the potential (Laplace) equation, and the wave equations in rectangular, cylindrical, and spherical coordinates. Cross-listed as APMA 641.

MAE 642 - (3) (Y)
Engineering Mathematics II
Prerequisite: Graduate standing and APMA/MAE 641 or equivalent.

MAE 643 - (3) (Y)
Statistics for Engineers and Scientists
Prerequisite: Admission to graduate studies or instructor permission.
Role of statistics in science, hypothesis tests of significance, confidence intervals, design of experiments, regression, correlation analysis, analysis of variance, and introduction to statistical computing with statistical software libraries. Cross-listed as APMA 643.

MAE 644 - (3) (IR)
Applied Partial Differential Equations
Prerequisite: APMA/MAE 641 or equivalent.
Includes first order partial differential equations (linear, quasilinear, nonlinear); classification of equations and characteristics; and well-posedness of initial and boundary value problems. Cross-listed as APMA 644.

MAE 651 - (3) (Y)
Linear Automatic Control Systems
Prerequisite: Instructor permission.
Studies the dynamics of linear, closed-loop systems. Analysis of transfer functions; stability theory; time response, frequency response; robustness; and performance limitations. Design of feedback controllers. Cross-listed as ECE 621.

MAE 652 - (3) (Y)
Linear State Space Systems
Prerequisite: Graduate standing.
A comprehensive treatment of the theory of linear state space systems, focusing on general results which provide a conceptual framework as well as analysis tools for investigation in a wide variety of engineering contexts. Topics include vector spaces, linear operators, functions of matrices, state space description, solutions to state equations (time invariant and time varying), state transition matrices, system modes and decomposition, stability, controllability and observability, Kalman decomposition, system realizations, grammians and model reduction, state feedback, and observers. Cross-listed as SYS 612 and ECE 622.

MAE 662 - (3) (IR)
Mechanical Design Analysis
Prerequisite: Undergraduate mechanical design or instructor permission.
Topics include the design analysis of machine elements subject to complex loads and environments; emphasis on modern materials and computer analysis; theory of elasticity, energy methods; failure theories, fracture, fatigue, creep; contact, residual, and thermal stresses; experimental stress analysis; and corrosion.

MAE 668 - (3) (Y)
Advanced Machine Technologies
Prerequisite: MAE 665 and 667.
Studies new technologies for machine automation, including intelligent machines, robotics, machine vision, image processing, and artificial intelligence. Emphasis on computer control of machines; intelligent automatic control systems; and distributed networks. Focuses on research problems in each of these areas.

MAE 671 - (3) (Y)
Finite Element Analysis
Prerequisite: MAE/AM 602 or equivalent.
The topics covered are: review of vectors, matrices, and numerical solution techniques; discrete systems; variational formulation and approximation for continuous systems; linear finite element method in solid mechanics; formulation of isoparametric finite elements; finite element method for field problems, heat transfer, and fluid dynamics. Cross-listed as AM 671.

MAE 672 - (3) (E)
Computational Fluid Dynamics I
Prerequisite: MAE 631 or instructor permission.
Includes the solution of flow and heat transfer problems involving steady and transient convective and diffusive transport; superposition and panel methods for inviscid flow, finite-difference methods for elliptic, parabolic and hyperbolic partial differential equations, elementary grid generation for odd geometries, primitive variable and vorticity-steam function algorithms for incompressible, multidimensional flows. Extensive use of personal computers/workstations, including interactive graphics. Cross-listed as APMA 672.

MAE 685 - (3) (E)
Measurement Theory and Advanced Instrumentation
Prerequisite: Undergraduate electrical science.
Studies the theory and practice of modern measurement and measurement instrumentation; statistical analysis of data; estimation of errors and uncertainties; operating principles and characteristics of fundamental transducers and sensors; common electrical circuits and instruments; and signal processing.
methods.

MAE 687 - (3) (IR)
Applied Engineering Optics
Prerequisite: PHYS 241E.
Analyzes modern engineering optics and methods; fundamentals of coherence, diffraction interference, polarization, and lasing processes; fluid mechanics, heat transfer, stress/strain, vibrations, and manufacturing applications; laboratory practice: interferometry, schlieren/shadowgraph, and laser velocimetry.

MAE 692 - (3) (Y)
Special Topics in Mechanical and Aerospace Science: Intermediate Level
Study of a specialized, advanced, or exploratory topic relating to mechanical or aerospace engineering science, at the first-graduate-level. May be offered on a seminar or a team-taught basis. Subjects selected according to faculty interest. New graduate courses are usually introduced in this form. Specific topics and prerequisites are listed in the Course Offering Directory.

MAE 693 - (3) (Y)
Independent Study in Mechanical or Aerospace Science: Intermediate Level
Prerequisite: Students must petition the department Graduate Studies Committee before enrolling.
Independent study of first-year graduate level material under the supervision of a faculty member.

MAE 694 - (Credit as arranged) (Y)
Special Graduate Project in Mechanical or Aerospace Engineering: First-Year Level
Prerequisite: Students must petition the department Graduate Studies Committee before enrolling.
A design or research project for a first-year graduate student under the supervision of a faculty member. A written report must be submitted and an oral report must be presented. Up to three credits from either this course or MAE 794 may be applied toward the master’s degree.

MAE 703 - (3) (E)
Injury Biomechanics
Prerequisite: MAE 608.
This is an advanced applications course on the biomechanical basis of human injury and injury modeling. The course covers the etiology of human injury and state-of-the-art analytic and synthetic mechanical models of human injury. The course will have a strong focus on modeling the risk of impact injuries to the head, neck, thorax, abdomen and extremities. The course will explore the biomechanical basis of widely used and proposed human injury criteria and will investigate the use of these criteria with simplified dummy surrogates to assess human injury risk. Brief introductions to advanced topics such as human biomechanical variation with age and sex, and the biomechanics of injury prevention will be presented based on current research and the interests of the students.

MAE 715 - (3) (IR)
Combustion
Prerequisite: Undergraduate thermodynamics and MAE 631, or instructor permission.
Reviews chemical thermodynamics, including conservation laws, perfect gas mixtures, combustion chemistry and chemical equilibrium; finite-rate chemical kinetics; conservation equations for multicomponent reacting systems; detonation and deflagration waves in premixed gases; premixed laminar flames; gaseous diffusion flames and droplet evaporation; introduction to turbulent flames; chemically-reacting boundary-layer flows; ignition; applications to practical problems in energy systems, aircraft propulsion systems, and internal combustion engines. Projects selected from topics of interest to the class.

MAE 753 - (3) (O)
Optimal Dynamical Systems
Prerequisite: Two years of college mathematics, including some linear and vector calculus. Classical and state-spaced controls and undergraduate design courses are recommended.
Introduces the concept of performance metrics for dynamical systems and examines the optimization of performances over both parameter and function spaces. Discusses both the existence of optimal solutions to dynamic problems and how these may be found. Such results provide via limits to performance of dynamic systems, which delineate what can and cannot be achieved via engineering. Constitutes a basis for more advanced study in design synthesis and optimal control. Cross-listed as ECE 723.

MAE 755 - (3) (E)
Multivariable Control
Prerequisite: MAE 652.
State space theories for linear control system design have been developed over the last 40 years. Among those, H2 and Hinf control theories are the most established, powerful, and popular in applications. This course focuses on these theories and shows why and how they work. Upon completion of this course, student will be confident in applying the theories and will be equipped with technical machinery that allows them to thoroughly understand these theories and to explore new control design methods if desired in their own research. More importantly, students will learn a fundamental framework for optimal system design from a state perspective. Cross-listed as ECE 725.

MAE 756 - (3) (E)
Nonlinear Control Systems
Prerequisite: ECE 621 or instructor permission.
Studies the dynamic response of nonlinear systems; approximate analytical and graphical analysis methods; stability analysis using the second method of Liapunov, describing functions, and other methods; adaptive, learning, and switched systems; examples from current literature. Cross-listed as ECE 726.

MAE 758 - (3) (O)
Digital Control Systems
Prerequisite: MAE 652 or instructor permission.
Topics include sampling processes and theorems, z-transforms, modified transforms, transfer functions, stability criteria; analysis in both frequency and time domains; discrete-state models for systems containing digital computers; and applications using small computers to control dynamic processes. Cross-listed as ECE 728.

MAE 772 - (3) (IR)
Computational Fluid Dynamics II
Prerequisite: MAE 672 or instructor permission.

MAE 791 - (0-1) (S)
Research Seminar, Mechanical and Aerospace Engineering: Master’s Students
Required one-hour weekly seminar for master’s students in mechanical and aerospace and nuclear engineering. Students enrolled in MAE 898 or 694/794 make formal presentations of their work.

MAE 792 - (3) (Y)
Special Topics in Mechanical or Aerospace Engineering Science: Advanced Level
A specialized, advanced, or exploratory topic relating to mechanical or aerospace engineering science, at the second-year or higher graduate level. May be offered on a seminar or team-taught basis. Subjects selected according to faculty interest. Topics and prerequisites are listed in the Course Offering Directory.

MAE 793 - (Usually three credits) (Y)
Independent Study in Mechanical or Aerospace Engineering Science: Advanced Level
Prerequisite: Students must petition the department Graduate Studies Committee before enrolling.
Independent study of advanced graduate material under the supervision of a faculty member.

MAE 794 - (Credit as arranged) (Y)
Special Graduate Project in Mechanical or Aerospace Engineering Science: Advanced Level
Prerequisite: Students must petition the department Graduate Studies Committee before enrolling.
A design or research project for an advanced graduate student under the supervision of a faculty member. A written report must be submitted and an oral report must be presented. Up to three credits of either this
course or MAE 694 may be applied toward the master’s degree.

MAE 897 - (Credit as arranged) (S)
Graduate Teaching Instruction
For master’s students.

MAE 898 - (1-12) (Y)
Master’s Thesis Research, Mechanical and Aerospace Engineering
Formal documentation of faculty supervision of thesis research. Each full-time, resident Master of Science student in mechanical and aerospace engineering is required to register for this course for the number of credits equal to the difference between his or her regular course load (not counting the one-credit MAE 791 seminar) and 12.

MAE 991 - (0-1) (S)
Research Seminar, Mechanical and Aerospace Engineering: Doctoral Students
Required one-hour weekly seminar for doctoral students in mechanical, aerospace, and nuclear engineering. Students enrolled in MAE 999 may make formal presentations of their work.

MAE 997 - (Credit as arranged) (S)
Graduate Teaching Instruction
For doctoral students.

MAE 999 - (1-12) (Y)
Dissertation Research, Mechanical and Aerospace Engineering
Formal documentation of faculty supervision of dissertation research. Each full-time resident doctoral student in mechanical and aerospace engineering is required to register for this course for the number of credits equal to the difference between his or her regular course load (not counting the one-credit MAE 991 seminar) and 12.

Systems and Information Engineering

SYS 601 - (3) (Y)
Introduction to Systems Engineering
Prerequisite: Admission to the graduate program.
An integrated introduction to systems methodology, design, and management. An overview of systems engineering as a professional and intellectual discipline, and its relation to other disciplines, such as operations research, management science, and economics. An introduction to selected techniques in systems and decision sciences, including mathematical modeling, decision analysis, risk analysis, and simulation modeling. Elements of systems management, including decision styles, human information processing, organizational decision processes, and information system design for planning and decision support. Emphasizes relating theory to practice via written analyses and oral presentations of individual and group case studies.

SYS 602 - (3) (Y)
Systems Integration
Prerequisite: SYS 601 or instructor permission.
Provides an introduction to the problems encountered when integrating large systems, and also presents a selection of specific technologies and methodologies used to address these problems. Includes actual case-studies to demonstrate systems integration problems and solutions. A term project is used to provide students with the opportunity to apply techniques for dealing with systems integration.

SYS 603 - (3) (Y)
Mathematical Programming
Prerequisite: Two years of college mathematics, including linear algebra, and the ability to write computer programs.
Presents the foundations and taxonomy of mathematical modeling and optimization: building blocks of models and the centrality of state variables; optimality conditions in mathematical programming: convexity, Lagrangian function, necessary and sufficient conditions for optimality; nonlinear optimization; necessary and regularity conditions for non-linear systems; Kuhn-Tucker conditions; the epsilon-constrained formulation; the surrogate worth trade-off (SWT) method; linear programming; the complementary slackness theorem; the simplex algorithm; Leontief input-output optimization model; quadratic and dynamic programming; Bayesian dynamic programming; and hierarchical decomposition.

SYS 605 - (3) (Y)
Stochastic Systems
Prerequisite: APMA 310, 312, or equivalent background in applied probability and statistics.
Covers basic stochastic processes with emphasis on model building and probabilistic reasoning. The approach is non-measure theoretic but otherwise rigorous. Topics include a review of elementary probability theory with particular attention to conditional expectations; Markov chains; optimal stopping; renewal theory and the Poisson process; martingales. Applications are considered in reliability theory, inventory theory, and queueing systems.

SYS 606 - (3) (Y)
The Art and Science of Systems Modeling
Prerequisite: SYS 603, 605, or equivalent.
Focuses on learning and practicing the art and science of systems modeling through diverse case studies. Topics span the modeling of discrete and continuous, static and dynamic, linear and non-linear, and deterministic and probabilistic systems. Two major dimensions of systems modeling are discussed and their efficacy is demonstrated: the building blocks of mathematical models and the centrality of state variables in systems modeling, including: state variables, decision variables, random variables, exogenous variables, inputs and outputs, objective functions, and constraints; and effective tools in systems modeling, including multiobjective models, influence diagrams, event trees, systems identification and parameter estimation, hierarchical holographic modeling, and dynamic programming.

Dynamic Systems
Prerequisite: APMA 213 or equivalent.
Introduces modeling, analysis, and control of dynamic systems, using ordinary differential and difference equations. Emphasizes the properties of mathematical representations of systems, the methods used to analyze mathematical models, and the translation of concrete situations into appropriate mathematical forms. Primary coverage includes ordinary linear differential and difference equation models, transform methods and concepts from classical control theory, state-variable methods and concepts from modern control theory, and continuous system simulation. Applications are drawn from social, economic, managerial, and physical systems. Cross-listed as MAE 652.

SYS 613 - (3) (IR)
Applied Multivariate Statistics
Prerequisite: SYS 605, SYS 618, or STAT 512.
This course covers the major methods for multivariate data analysis. Topics include multivariate Gaussian distribution, multivariate regression, MANOVA, principal components, factor analysis, canonical correlation, structure equation models, discriminant analysis, and logistic regression. The course illustrates the use of these methods using modern statistical software. Cross-listed as STAT 513.

SYS 614 - (3) (Y)
Decision Analysis
Prerequisite: SYS 603, 605, or equivalent.
Principles and procedures of decision-making under uncertainty and with multiple objectives. Topics include representation of decision situations as decision trees, influence diagrams, and stochastic dynamic programming models; Bayesian decision analysis, subjective probability, utility theory, optimal decision procedures, value of information, multiobjective decision analysis, and group decision making.

SYS 616 - (3) (Y)
Knowledge-Based Systems
A graduate-level survey of artificial intelligence techniques with emphasis on their application to systems engineering problem-solving. Topics include: informed and uninformed search; propositional and first order logic; and learning techniques such as Bayes nets, reinforcement learning and neural networks. Students are required to have sufficient computational background to complete several substantive programming assignments. Cross-listed as CS 616.

SYS 618 - (3) (Y)
Data Mining
Prerequisite: SYS 605 or STAT 512.
Data mining describes approaches to turning data into information. Rather than the more typical deductive strategy of building models using known principles, data mining uses inductive approaches to discover the appro
prise models. These models describe a relationship between a system's response(s) and a set of factors or predictor variables. Data mining in this context provides a formal basis for machine learning and knowledge discovery. This course investigates the construction of empirical models from data mining for systems with both discrete and continuous valued responses. It covers both estimation and classification, and explores both practical and theoretical aspects of data mining.

SYS 623 - (3) (Y)
Cognitive Systems Engineering
Introduces the field of cognitive systems engineering, which seeks to characterize and support human-systems integration in complex systems environments. Covers key aspects of cognitive human factors in the design of information support systems. Reviews human performance (memory, learning, problem-solving, expertise and human error); characterizes human performance in complex, socio-technical systems, including naturalistic decision making and team performance; reviews different types of decision support systems, with a particular focus on representation aiding systems; and covers the human-centered design process (task analysis, knowledge acquisition methods, product concept, functional requirements, prototype, design, and testing).

SYS 634 - (3) (Y)
Discrete-Event Stochastic Simulation
Prerequisite: A first course in probability and statistics.
A first course on the theory and practice of discrete-event simulation. Coverage includes Monte Carlo methods and spreadsheet applications, generating random numbers and variates, sampling distributions, the dynamics of discrete-event stochastic systems, simulation logic and computational issues, specifying input probability distributions, output analysis, comparing simulated alternatives, model verification and validation, and simulation optimization. Applications in manufacturing, transportation, communication, computer, health-care, and service systems.

SYS 650 - (3) (Y)
Risk Analysis
Prerequisite: APMA 310, SYS 321, or equivalent.
A study of technological systems, where decisions are made under conditions of risk and uncertainty. Topics include conceptualization (the nature, perception, and epistemology of risk, and the process of risk assessment and management) systems engineering tools for risk analysis (basic concepts in probability and decision analysis, event trees, decision trees, and multibjective analysis), and methodologies for risk analysis (hierarchical holographic modeling, uncertainty taxonomy, risk of rare and extreme events, statistics of extremes, partitioned multibjective risk method, multibjective decision trees, fault trees, multibjective impact analysis method, uncertainty sensitivity index method, and filtering, ranking, and management method). Case studies are examined.

SYS 654 - (3) (Y)
Financial Engineering
Prerequisite: SYS 603 or equivalent graduate-level optimization course. Students need not have any background in finance or investment. Provides an introduction to basic topics in finance from an engineering and modeling perspective. Topics include the theory of interest, capital budgeting, valuation of firms, futures and forward contracts, options and other derivatives, and practical elements of investing and securities speculation. Emphasis is placed on the development and solution of mathematical models for problems in finance, such as capital budgeting, portfolio optimization, and options pricing; also predictive modeling as it is applied in credit risk management. One of the unique features of this course is a stock trading competition hosted on www.virtualstockexchange.com or a similar site.

SYS 664 - (3) (Y)
Applied Human Factors Engineering
This topic covers principles of human factors engineering, understanding and designing systems that take into account human capabilities and limitations from cognitive, physical, and social perspectives. Models of human performance and human-machine interaction are covered as well as methods of design and evaluation.

SYS 670 - (3) (Y)
Environmental Systems Analysis
Prerequisite: CHEM 152, PHYS 241.
This course focuses on the infrastructure for the provision of drinking water, wastewater/sewage, and solid waste management services in the context of the environmental systems in which they are embedded and the institutional framework within which they must operate. It begins with coverage of the infrastructure design, operation, and maintenance, proceeds to a treatment of the concept of integrated sanitation systems, and then considers the major environmental issues relevant to these services, including global warming, tropospheric and stratospheric ozone, and hazardous waste. It also includes a study of the common tools in environmental systems analysis: lifecycle assessment, environmental economics, mass and energy balances, benefit-cost analysis, risk analysis, and environmental forecasting.

SYS 674 - (3) (Y)
Total Quality Engineering
Prerequisite: Basic statistics or instructor permission.
Comprehensive study of quality engineering techniques; characterization of Total Quality Management philosophy and continuous improvement tools; statistical monitoring of processes using control charts; and process improvement using experimental design.

SYS 681, 682 - (3) (IR)
Selected Topics in Systems Engineering
Detailed study of a selected topic, determined by the current interest of faculty and students. Offered as required.

SYS 693 - (Credit as arranged) (S)
Independent Study
Detailed study of graduate course material on an independent basis under the guidance of a faculty member.

SYS 695 - (Credit as arranged) (S)
Supervised Project Research
Formal record of student commitment to project research under the guidance of a faculty advisor. Registration may be repeated as necessary.

SYS 701 - (3) (Y)
System and Decision Sciences
Prerequisite: Mathematical analysis and probability theory at an undergraduate level; admission to the graduate program.
Introduction to system and decision science with focus on theoretical foundations and mathematical modeling in four areas: systems (mathematical structures, coupling, decomposition, simulation, control), human inputs (principles from measurement theory and cognitive psychology, subjective probability theory, utility theory), decisions under uncertainty (Bayesian processing of information, Bayes decision procedures, value of information), and decisions with multiple objectives (wholistic ranking, dominance analysis, multibtribute utility theory).

SYS 702 - (3) (SS)
Case Studies in Systems Engineering
Prerequisite: SYS 601, 603, and 605.
Under faculty guidance, students apply the principles of systems methodology, design, and management along with the techniques of systems and decision sciences to systems analysis and design cases. The primary goal is the integration of numerous concepts from systems engineering using real-world cases. Focuses on presenting, defending, and discussing systems engineering projects in a typical professional context. Cases, extracted from actual government, industry, and business problems, span a broad range of applicable technologies and involve the formulation of the issues, modeling of decision problems, analysis of the impact of proposed alternatives, and interpretation of these impacts in terms of the client value system.

SYS 705 - (3) (Y)
Advanced Stochastic Processes
Prerequisite: SYS 605 or equivalent.
Provides a non-measure theoretic treatment of advanced topics in the theory of stochastic processes, focusing particularly on denumerable Markov processes in continuous time and renewal processes. The principal objective is to convey a deep understanding of the main results and their proofs, sufficient to allow students to make theoretical contributions to engineering research.

SYS 716 - (3) (Y)
Artificial Intelligence
Prerequisite: SYS 616 or CS 616.
In-depth study of major areas considered to be part of artificial intelligence. In particular, detailed coverage is given to the design considerations involved in automatic theorem proving, natural language understanding, and machine learning. Cross-listed as CS 716.

SYS 721 - (3) (IR)
Research Methods in Systems Engineering
Corequisite: SYS 601, 603, 605, or equivalent.
The study of the philosophy, theory, methodology, and applications of systems engineering provides themes for this seminar in the art of reading, studying, reviewing, critiquing, and presenting scientific and engineering research results. Applications are drawn from water resources, environmental, industrial and other engineering areas. Throughout the semester, students make a presentation of a chosen paper, followed by a discussion, critique, evaluation, and conclusions regarding the topic and its exposition.

SYS 730 - (3) (IR)
Time Series Analysis and Forecasting
Prerequisite: SYS 605 or equivalent.
An in-depth study of time series analysis and forecasting models from a statistical and engineering perspective. Emphasizes the process of stochastic model building including model identification, estimation, and model diagnostic checking. Topics include smoothing and filtering, ARIMA models, frequency domain analysis, and vector processes.

SYS 734 - (3) (IR)
Advanced System Simulation
Prerequisite: SYS 605, 634, or equivalent.
Seminar on contemporary topics in discrete-event simulation. Topics are determined by student and faculty interests and may include model and simulation theory, validation, experiment design, output analysis, variance-reduction techniques, simulation optimization, parallel and distributed simulation, intelligent simulation systems, animation and output visualization, and application domains. Term project.

SYS 742 - (3) (IR)
Heuristic Search
Prerequisite: SYS 605 or instructor permission.
Characterization and analysis of problem solving strategies guided by heuristic information. The course links material from optimization, intelligence systems, and complexity analysis. Formal development of the methods and complete discussion of applications, theoretical properties, and evaluation. Methods discussed include best-first strategies for OR and AND/OR graphs, simulated annealing, genetic algorithms and evolutionary programming, tabu search, and tailored heuristics. Applications of these methods to engineering design, scheduling, signal interpretation, and machine intelligence.

SYS 750 - (3) (IR)
Risk Analysis
Prerequisite: APMA 310, SYS 321, or equivalent.
A study of technological systems, where decisions are made under conditions of risk and uncertainty. Part I: Conceptualization: the nature of risk, the perception of risk, the epistemology of risk, and the process of risk assessment and management. Part II: Systems engineering tools for risk analysis: basic concepts in probability and decision analysis, event trees, decision trees, and multiobjective analysis. Part III: Methodologies for risk analysis: hierarchical categorical modeling, uncertainty taxonomy, risk of rare and extreme events, statistics of extremes, partitioned multiobjective risk method, multiobjective decision trees, fault trees, multiobjective impact analysis method, uncertainty sensitivity index methods, and filtering, ranking, and management method. Case studies.

SYS 752 - (3) (IR)
Sequential Decision Processes
Prerequisite: SYS 605, 614, or equivalent.
Topics include stochastic sequential decision models and their applications; stochastic control theory; dynamic programming; finite horizon, infinite horizon models; discounted, undiscounted, and average cost models; Markov decision processes, including stochastic shortest path problems; problems with imperfect state information; stochastic games; computational aspects and suboptimal control, including neuro-dynamic programming; examples: inventory control, maintenance, portfolio selection, optimal stopping, water resource management, and sensor management.

SYS 754 - (3) (IR)
Multiobjective Optimization
Prerequisite: SYS 603, 614, or equivalent.
Analyzes the theories and methodologies for optimization with multiple objectives under certainty and uncertainty; structuring of objectives, selection of criteria, modeling and assessment of preferences (strength of preference, risk attitude, and trade-off judgments); vector optimization theory and methods for generating non-dominated solutions. Methods with prior assessment of preferences, methods with progressive assessment of preferences (iterative-interactive methods), methods allowing imprecision in preference assessments; group decision making; building and validation of decision-aiding systems.

SYS 763 - (3) (IR)
Response Surface Methods
Prerequisite: SYS 601, 605, and 674, or instructor permission.
Response surface methods provide process and design improvement through the collection and analysis of data from controlled experimentation. This course investigates the construction of response models for systems with discrete and continuous valued responses. The course will cover design of experiments for optimization and methods for building and using response surfaces from simulation, known as simulation-optimization.

SYS 770 - (3) (IR)
Sequencing and Scheduling
Prerequisite: SYS 603, 605, or equivalent.

SYS 775 - (3) (IR)
Forecast-Decision Systems
Prerequisite: SYS 605, 614, or equivalent.
Presents the Bayesian theory of forecasting and decision making; judgmental and statistical forecasting, deterministic and probabilistic forecasting, post-processors of forecasts; sufficient comparisons of forecasters, verification of forecasts, combining forecasts; optimal and suboptimal decision procedures using forecasts including static decision models, sequential decision models, stopping-control models; economic value of forecasts; communication of forecasts; and the design and evaluation of a total forecast-decision system.

SYS 781 - 782 - (3) (IR)
Advanced Topics in Systems Engineering
Detailed study of an advanced or exploratory topic determined by faculty and student interest. Offered as required.

SYS 793 - (Credit as arranged) (S)
Independent Study
Detailed study of graduate course material on an independent basis under the guidance of a faculty member.

SYS 796 - (1) (S)
Systems Engineering Colloquium
Regular meeting of graduate students and faculty for presentation and discussion of contemporary systems problems and research. Offered for credit each semester. Registration may be repeated as necessary.

SYS 895 - (Credit as arranged) (S)
Supervised Project Research
Formal record of student commitment to project research for Master of Engineering degree under the guidance of a faculty advisor. Regis-
tration may be repeated as necessary.

SYS 897 - (Credit as arranged) (S)
Graduate Teaching Instruction
For doctoral students.

SYS 999 - (Credit as arranged) (S)
Dissertation
For doctoral students.

Faculty

Office of the Dean of the School of Engineering and Applied Science
James H. Aylor, Ph.D., Interim Dean
Mary P. Beck, M.S., Applied Math Instruction, Lecturer
Nancy J. Cable, Ph.D., Vice President for Development of Virginia Engineering Foundation, Associate Dean
James F. Groves, B.S., M.S., Ph.D., Assistant Professor, Director of Distance Learning Program
Frances Hersey, Associate Director of Center for Engineering Career Development, Lecturer
Clarence J. Livesay, B.S., Director of Center for Engineering Career Development, Lecturer
P. Paxton Marshall, B.S., M.A., M.E., Ph.D., Associate Dean for Undergraduate Programs, Professor
John D. Maybee, B.S., M.S., Ph.D., Associate Professor of Applied Mathematics
Mitchel C. Rosen, B.E., M.S., Ph.D., Chief Technology Officer, Associate Professor
Mary D. Smith, B.S., M.S., Assistant Dean for Finance and Budget, Lecturer
Kathryn C. Thornton, B.S., M.S., Ph.D., Associate Dean for Graduate Programs
William J. Thurneck, Jr., B.S., M.S.E., Ph.D., Associate Dean for Administrative and Academic Affairs, Professor
Carolyn A. Vallas, B.A., M.S., Director of Center for Diversity in Engineering, Lecturer
Haydn N. G. Wadley, B.Sc., Ph.D., University Professor, Edgar A. Starke, Jr., Professor of Materials Science, Senior Associate Dean for Research

Department of Chemical Engineering

Professors
Giorgio Carta, Laurea, M.Ch.E., Ph.D.
Robert J. Davis, B.S., M.S., Ph.D., Chair
Erik J. Fernandez, B.S., M.S., Ph.D.
Roseanne Marie Ford, B.S., M.S., Ph.D. (joint appt.)
John L. Hudson, B.S., M.S.E., Ph.D., P.E., Wills Johnson Professor of Chemical Engineering
Donald J. Kirwan, B.S., M.S., Ph.D.
Cato T. Laurencin, B.S., Ph.D., M.D.
Matthew Neurock, B.S., M.S., Ph.D., Alice M. and Guy A. Wilson Professor of Chemical Engineering
John P. O’Connell, B.A., B.S., M.S., Ph.D., Harry Douglas Forsyth Professor of Chemical Engineering

Assistant Professors
David L. Green, B.S., M.S., Ph.D.
Steven McIntosh, B.Eng., M.S., Ph.D.
James Oberhauser, B.S., M.S., Ph.D.

Research
Ramon Espino, B.S., M.S., Sc.D., Professor

Department of Civil Engineering

Professors
Michael J. Demetsky, B.S.C.E., M.S.C.E., Ph.D., P.E., Chair
Roseanne Marie Ford, B.S., M.S., Ph.D. (joint appt.)
Nicholas J. Garber, B.Sc., M.S., Ph.D., M.I.C.E., P.E., Henry L. Kinnier Professor of Civil Engineering
Lester A. Hoel, B.C.E., M.C.E., D.Eng., P.E., L. A. Lacey Distinguished Professor of Civil Engineering
Cornelius O. Horgan, B.Sc., M.Sc., Ph.D., D.Sc., Wills Johnson Professor of Applied Mathematics and Mechanics
Wu-Seng Lung, B.S., M.S., Ph.D., P.E.
Richard W. Miksad, B.S., M.S., Sc.D., P.E., Thomas M. Linville Professor (joint appt.)
Marek-Jerzy Pindera, B.S., M.S., Ph.D.

Associate Professors
Thomas T. Baber, B.S., M.S., Ph.D., P.E.
Matthew R. Begley, B.S.C.E., M.S.C.E., Ph.D., M.E., Assistant Chair for Civil Engineering Graduate Studies
Edward J. Berger, B.S.C.E., M.S.C.E., Ph.D., M.E.
Teresa B. Culver, B.S., M.S., Ph.D., Assistant Chair for Undergraduate Studies
William T. Scherer, B.S., M.E., Ph.D. (joint appt.)
Brian L. Smith, B.S., M.S., Ph.D.
James A. Smith, B.S., M.S., Ph.D.

Assistant Professors
Byungkyu (Brian) Park, B.S., M.S., Ph.D.
Garrick E. Louis, B.Sc., M.Sc., Ph.D.

Visiting Professor
Jose P. Gomez, B.S.C.E., M.E.C.E., Ph.D., P.E.

Visiting Associate Professor
Susan E. Burns, B.C.E., M.S., Ph.D., P.E.

Visiting Assistant Professor
Roseanna M. Neupauer, B.S., S.M., Ph.D., P.E.

Lecturers
Michael C. Brown, B.S.C.E., M.S.C.E., Ph.D., P.E.
Rodney T. Davis, B.S.C.E., M.S.C.E., Ph.D., P.E.
Jose P. Gomez, B.S.C.E., M.E.C.E., Ph.D., P.E.
M. Shabbir Hossain, B.S.C.E., M.S.C.E., Ph.D.
Joseph G. Howe, Jr., B.S.C.E., M.E.C.E.
William A. McIntosh, B.S.C.E., P.E.
H. Celik Ozvildirim, B.S.C.E., M.S.C.E., Ph.D., P.E.
David M. Salzer, B.S., M.E.C.E., Ph.D.
Department of Computer Science

Professors
Jack W. Davidson, B.A.S., M.S., Ph.D.
Andrew S. Grimshaw, B.A., M.S., Ph.D.
Anita K. Jones, A.B., M.A., Ph.D.,
University Professor, Lawrence R.
Quarles Professor of Engineering and
Applied Science
John C. Knight, B.Sc., Ph.D.
Jörg Liebeherr, B.S., M.S., Ph.D.
Paul F. Reynolds, Jr., B.A., M.A., Ph.D.
Gabriel Robins, B.S., M.S.E., Ph.D.
Mary Lou Soffa, B.S., M.S., Ph.D., Owen
R. Chentham Professor of Sciences, Chair
Sang H. Son, B.S., M.S.E.E., M.S.C.S.,
Ph.D.
America Professor of Computer Science
Alfred C. Weaver, B.S., M.S., Ph.D.,
Lucien Carr III Professor of
Engineering and Applied Science
William A. Wulf, B.S., M.S., Ph.D.,
American Telephone and Telegraph
Company Professor of Engineering and
Applied Science and University
Professor

Associate Professors
Tarek F. Abdelzaher, B.S., M.S., Ph.D.
James P. Cohoon, B.S., M.S., Ph.D.
Thomas B. Horton, B.A., Ph.D.
Worthy N. Martin, B.A., M.A., Ph.D.
Kevin Skadron, B.A., B.S., M.A., Ph.D.
Kevin J. Sullivan, B.A., M.S., Ph.D.
Malathi Veeraraghavan, B.Tech., M.S.,
Ph.D.

Assistant Professors
Aaron Bloomfield, B.S., B.S., M.S., Ph.D.
David C. Brogan, B.A., Ph.D.
David E. Evans, S.B., S.M., Ph.D.
Marty A. Humphrey, B.S., M.S., Ph.D.
Grigori R. Humphreys, B.S.E., Ph.D.
David P. Luebke, B.A., Ph.D.
Christopher W. Milner, A.B., M.S., Ph.D.

Research
James C. French, B.A., M.S., Ph.D.,
Associate Professor

Lecturer
Ruth Anderson, B.S., M.S.

Charles L. Brown Department of
Electrical and Computer
Engineering

Professors
Scott Acton, B.S., M.S., Ph.D.
J. Milton Adams, B.S., Ph.D., Vice Provost
of Academic Programs
James H. Aylor, B.S., M.S., Ph.D.
Mary Lou Soffa, B.S., M.S., Ph.D., Owen
R. Chentham Professor of Sciences, Chair
John C. Bean, B.S., M.S., Ph.D., John
Marshall Money Professor
Joanne Bechta Dugan, B.A., M.S., Ph.D.
Joe C. Campbell, B.S., M.S., Ph.D.,
Shannon Center Fellow
Mool Gupta, B.S., M.S., Ph.D., Langley
Professor
Lloyd R. Harriott, B.S., M.A., Ph.D.,
Virginia Microelectronics Consortium
Professor, Chair
Robert Hull, B.A., Ph.D. Charles A.
Henderson Professor of Engineering
Barry W. Johnson, B.S., M.E., Ph.D.
Zongli Lin, B.S., M.E., Ph.D.
P. Paxton Marshall, B.S., M.A., E.,
Ph.D., Associate Dean
Michael L. Reed, B.S., M.Eng., Ph.D.
Stephen G. Wilson, B.S., M.S., Ph.D.,
Associate Chair

Associate Professors
Travis N. Bla洛克, B.S., M.S., Ph.D.
Maite Brandt-Pearce, B.S., M.S., M.E.,
Ph.D.
Mircea R. Stan, Diploma, M.S., Ph.D.
Gang Tao, B.S., M.S., Ph.D.
Malathi Veeraraghavan, B.Tech., M.S.,
Ph.D., Director, Computer Engineering
Program
William F. Walker, B.S.E., Ph.D.
Robert M. Weikle, B.S., B.A., M.S., Ph.D.
Ronald D. Williams, B.S., M.S., Ph.D.,
P.E.

Assistant Professors
N. Scott Barker, B.S., M.S., Ph.D.
Tommy Guess, B.S., M.S., Ph.D.
John Lach, B.S., M.S., Ph.D.
Yibin Zheng, B.S., M.A., Ph.D., Ph.D.

Research
Thomas Crowe, B.S., M.S., Ph.D.,
Professor
Boris Gelmont, M.S., Ph.D., D.Sc.,
Associate Professor
Tatiana Globus, M.S., Ph.D., Associate
Professor
Arthur W. Lichtenberger, B.S., M.S.,
Ph.D., Associate Professor
Seth Silverstein, B.S., M.S., Ph.D.,
Professor

Department of Materials Science
and Engineering

Professors
Raul A. Baragiola, M.S., Ph.D., Alice M.
and Guy A. Wilson Professor of
Engineering
George L. Cahen, Jr., B.E.S., M.S., Ph.D.
John J. Dorning, B.S., M.S., Ph.D.,
Whitney Stone Professor of Nuclear
Engineering, Professor of Engineering
Physics
Richard P. Gangloff, B.S., M.S., Ph.D.,
Ferman W. Perry Professor, Chair
James M. Howe, B.S., M.S., Ph.D.
Robert Hull, B.A., Ph.D., Charles A.
Henderson Professor of Engineering
William A. Jesser, B.A., M.S., Ph.D.,
Thomas Goodwin Digges Professor of
Materials Science and Engineering
Robert E. Johnson, B.A., M.A., Ph.D.,
John Lloyd Newcomb Professor of
Engineering Physics
William C. Johnson, B.S., M.S., Ph.D.
Robert G. Kelly, B.E.S., M.S.E., Ph.D.
John R. Scully, B.E.S., M.S.E., Ph.D.
Gary J. Shiflet, B.S., M.S., Ph.D., William
G. Reynolds Professor
William A. Soffa, B.S., M.S., Ph.D.
Edgar A. Starke, Jr., B.S., M.S., Ph.D.,
Earnest Oglesby Professor of
Engineering and Applied Science and
University Professor
Haydn N. G. Wadley, B.S., Ph.D., Edgar A.
Starke, Jr., Research Professor of
Materials Science
Stuart A. Wolf, A.B., Ph.D.

Associate Professors
Pete Reinke, Diploma, Ph.D.
Giovanni Zangari, M.S., Ph.D., Wilsdorf
Distinguished Professor

Assistant Professors
Sean R. Agnew, B.S., M.S., Ph.D.
James M. Fitz-Gerald, B.S., M.S., Ph.D.
James F. Groves, B.S., M.S., Ph.D.
Leonid V. Zhigilei, M.S., Ph.D.

Research
Dana M. Elzey, B.S., D.Sc.,
Associate Professor

Department of Mechanical
and Aerospace Engineering

Professors
Paul E. Allaire, B.E., M.E., Ph.D., Mac
Wade Professor of Mechanical and
Aerospace Engineering
Lloyd E. Barrett, B.S., M.S., Ph.D.
John J. Dorning, B.S., M.S., Ph.D.,
Whitney Stone Professor of Nuclear
Engineering, Professor of Engineering
Physics
Hossein Haj-Hariri, S.B., S.M., Ph.D.
Joseph A.C. Humphrey, Dipl., M.S.,
D.I.C., Ph.D., D.Sc., Nancy and Neal
Wade Professor of Engineering and
Applied Science, Chair
Tetsuya Iwasaki, B.S., M.S., Ph.D.
Eric H. Maslen, B.S., Ph.D.
James C. McDaniel, Jr., B.S., M.S.A.A.,
M.S.E.E., Ph.D.
Richard W. Miksdad, B.S., M.S., Sc.D.,
P.E., Thomas M. Linville Professor
(joint appt.)
Pamela M. Norris, B.S., M.S., Ph.D.
Walter D. Pilkey, B.A., M.A., Ph.D.,
Frederick Tracy Morse Professor of
Mechanical and Aerospace Engineering
William W. Roberts, Jr., B.S., Ph.D.,
Commonwealth Professor of Engineer-
ing and Applied Science
John G. Thacker, B.M.E., M.S.M.E.,
Ph.D., P.E., Associate Chair
Kathryn C. Thornton, B.S., M.S., Ph.D.
Haydn G. Wadley, B.Sc., Ph.D.,
Associate Dean
Huston G. Wood III, B.A., M.S., Ph.D.

Associate Professors
James T. Beard, B.M.E., M.S., Ph.D., P.E.
Harsha K. Chelliah, B.S., M.S., Ph.D.
Jeffrey Crandall, B.S., M.S., Ph.D.
Carl R. Knope, B.S., Ph.D.
Gabriel Laufer, B.Sc., M.Sc., M.A., Ph.D.
Eric H. Maslen, B.S., Ph.D.
Larry G. Richards, B.S., M.A., Ph.D.
Timothy C. Scott, B.S., M.S., Ph.D.
Pradip N. Sheth, B.E., M.S., Ph.D.

Assistant Professor
Hilary Bart-Smith, B.Eng., S.M., Ph.D.

Research
George Gillies, B.S., M.S., Ph.D., Professor
Christopher Goyne, B.E., Ph.D., Assistant Professor
Richard Kent, B.S., M.S., Ph.D., Assistant Professor
Robert Lindberg, B.S., M.S., Eng.Sc.D., Professor

Department of Science, Technology, and Society

Professors
W. Bernard Carlson, A.B., M.A., Ph.D.
Michael E. Gorman, B.A., M.A., Ph.D.
Deborah G. Johnson, B.Ph., M.A., M.Phil., Ph.D., Anne Shirley Carter Olson Professor of Applied Ethics, Chair
Ingrid H. Townsend, B.A., M.A., Ph.D.

Associate Professors
John K. Brown, B.A., M.A., Ph.D.
Patricia C. Click, B.A., M.A., Ph.D.
Kathryn C. Thornton, B.S., M.S., Ph.D.

Assistant Professor
Rosalywn W. Berne, B.A., M.A., Ph.D.

Visiting Assistant Professor
Dean Nieusma, B.S., M.S., Ph.D.

Lecturer
Catherine D. Baritud, B.A., M.A., M.Ed., Ph.D.

Research
Joanne McGrath Cohoon, B.A., M.A., Ph.D., Assistant Professor

Postdoctoral Research Fellow
Alex Checkovich, B.A., M.A., Ph.D.

Department of Systems and Information Engineering

Professors
Donald Edward Brown, B.S., M.S., M.Engr., Ph.D., William Stansfield Calcott Professor of Engineering and Applied Science, Chair
Joanne Bechta Dugan, B.A., M.S., Ph.D.
Michael E. Gorman, B.A., M.A., Ph.D.
Yacov Y. Haimes, B.S., M.S., Ph.D., P.E., Lawrence R. Quares Professor of Engineering and Applied Science
Barry M. Horowitz, B.E.E., M.S., Ph.D.
Roman Krzysztofowicz, M.S., M.Sc., Ph.D.
K. Preston White Jr., B.S.E., M.S., Ph.D.

Associate Professors
Peter A. Beling, B.A., M.S., Ph.D.
William T. Scherer, B.S., M.E., Ph.D. (joint appt.)
Michael C. Smith, B.S., M.S., Ph.D.

Assistant Professors
Ellen J. Bass, B.S., M.S., Ph.D.
Michael D. DeVore, B.S. M.S., D.Sc.
Jennifer M. Farver, B.S., M.S., Ph.D.
Alfredo Garcia, M.Sc., Ph.D.
Stephanie A. E. Guerlain, B.S., M.S., Ph.D.
Garrick E. Louis, B.S.C., M.Sc., Ph.D.

Research
James H. Lambert, B.S.E., M.S., Ph.D., P.E., Associate Professor

Retired Faculty
Antharvedi Anné, B.S., D.Mit., M.S., Ph.D., Professor Emeritus of Biomedical Engineering
Ernst Otto Attinger, B.A., M.D., M.S., Ph.D., Professor Emeritus of Biomedical Engineering
R. Edward Barker, Jr., B.S., M.S., Ph.D., Professor Emeritus of Materials Science and Engineering
Furman W. Barton, B.C.E., M.S., Ph.D., P.E., Professor Emeritus of Civil Engineering
Alan P. Batson, B.Sc., Ph.D., Professor Emeritus of Computer Science
George F. Bland, Sc.B., M.S.E.E., E.E., Associate Professor Emeritus of Electrical Engineering
John Wayne Boring, B.S.M.E., M.S., Ph.D., Professor Emeritus of Engineering Physics
Avery Catlin, B.E.E., M.A., Ph.D., University Professor Emeritus of Engineering and Applied Science
Bruce A. Chartres, B.Sc., M.Sc., Ph.D., Professor Emeritus of Mathematics and Computer Science
Melvin Cherno, B.A., M.A., Ph.D., Professor Emeritus of Technology, Culture, and Communication
William Larken Duren, Jr., A.B., M.S., Ph.D., University Professor Emeritus of Mathematics
Richard T. Eppink, B.S., M.S., Ph.D., Professor Emeritus of Civil Engineering
Samuel S. Fisher, M.E., M.S., Ph.D., Professor Emeritus of Mechanical and Aerospace Engineering
Ronald D. Flack, Jr., B.S., M.S., Ph.D., P.E., Professor Emeritus of Chemical Engineering

Department of Aerospace Engineering

Professors
Mark G. Foster, A.B. (Physics), Ph.D. (Physics), Professor Emeritus of Electrical Engineering
Elmer L. Gaden, Jr., B.S., M.S., Ph.D., Professor Emeritus of Chemical Engineering
John L. Gainer, B.S., M.S., Ph.D., Professor Emeritus of Chemical Engineering
Omer Allan Gianniny, Jr., B.S.E., M.Ed., Ed.D., P.E., Professor Emeritus of Humanities
Luther Y. Gore, B.A., M.A., Ph.D., Professor Emeritus of Humanities
Vera R. Granlund, B.A., M.S., Ph.D., Associate Professor Emeritus of Civil Engineering
Edgar J. Gunter, B.S., M.S., Ph.D., Professor Emeritus of Mechanical Engineering
John Kenneth Haviland, B.Sc., Ph.D., Professor Emeritus of Mechanical and Aerospace Engineering
Carl T. Herakovich, B.S., M.S., Ph.D., P.E., Professor Emeritus of Civil Engineering and Applied Mechanics
Thomas E. Hutchinson, B.S., M.S., Ph.D., Professor Emeritus of Systems Engineering
Fulvio Antonio Iachetta, B.M.E., M.M.E., Ph.D., P.E., Professor Emeritus of Mechanical Engineering
James P. Ignizio, B.S.E., E.E., M.S.E., Ph.D., Professor Emeritus of Systems Engineering
Rafael M. Inigo, Ing.E., M.S., D.Sc., P.E., Professor Emeritus of Electrical Engineering
Richard L. Jennings, B.S., B.S.C.E., M.S., Ph.D., Professor Emeritus of Civil Engineering
Robert A. Johnson, A.B., Ph.D., Professor Emeritus of Materials Science
Walker Reed Johnson, B.A., M.A., Ph.D., Professor Emeritus of Nuclear Engineering
Morris Wiley Jones, B.E., M.E., P.E., Associate Professor Emeritus of Electrical Engineering
James J. Kauzalarich, B.S., M.S., Ph.D., P.E., Professor Emeritus of Mechanical Engineering
James L. Kelly, B.S., M.S., Ph.D., Professor Emeritus of Nuclear Engineering
Henry Lee Kinnier, B.C.E., M.S., P.E., Professor Emeritus of Systems Engineering
Doris Kuhlmann-Wilsdorf, B.Sc., M.Sc., Ph.D., Professor Emeritus of Applied Science
John L. Gainer, B.S., M.S., Ph.D., Professor Emeritus of Chemical Engineering
Hugh Stevenson Landes, B.E.E., Ph.D., P.E., Associate Professor Emeritus of Electrical Engineering
Alwyn C. Lapsley, B.E.E., M.S., Ph.D.,