10 • SCHOOL OF GRADUATE ENGINEERING AND APPLIED SCIENCE

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 10 undergraduate and 32 graduate programs are offered by 8 academic departments.

Address
School of Graduate Engineering and Applied Science
P.O. Box 400242
A108 Thornton Hall
351 McCormick Road
University of Virginia
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 1869 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 Division of Technology, Culture, and Communication. 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.

The 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.

The Center for Applied Biomechanics is one of a limited number of laboratories conducting impact biomechanics research with both dummies and cadavers. The laboratory is a 10,000-square-foot facility equipped with a wide range of biomechanical test equipment, a machine shop, dummy laboratory, and surrogate storage. The laboratory has a multi-disciplinary research program. Impact biomechanics, computational mechanics, and vehicle crashworthiness studies are funded from a variety of industrial and government sources.

The Applied Electrophysics Laboratories (AEpL) serve 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.

The Laboratory for Atomic and Surface Physics 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.

The Cognitive Systems Engineering 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.

The Communications, Control, and Signal Processing Laboratory (CCSP) conducts research and development in a variety of communications 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), and optical communication. Research in CCSP is primarily of an analytical nature, supported by computer simulations.

The Computational Laboratory for Environmental Bioremediation (CLEB) complements U.Va.’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 degradative and migratory abilities of bacteria.

The Laboratory for Computer Architecture focuses on exploring computer “microarchitecture” and the analysis techniques needed to study microarchitectural questions. Three of our research thrusts are branch prediction, exploiting compiler dependence relationships at runtime, and simulation.

The Center for Electrochemical Science and Engineering is a multi-disciplinary research effort that incorporates the departments of Materials Science and Engineering, and Chemical Engineering, as well as interactions with Electrical and Computer Engineering, Computer Science, and Physics. It is one of the nation’s leading research groups of its kind, and its research affects the performance and reliability of most products manufactured in the world today.

The Electron Microscope and Image Processing Facility is a comprehensive service and user facility for biomedical research. Its services include Transmission Microscopy, Scanning Microscopy and Confocal Microscopy. Equipment available includes Transmission and Scanning Electron Microscopes; Laser Scanning Confocal Microscope; High Resolution Vacuum Evaporator; Ultramicrotomes; Critical Point Dryer; Sputter Coater; Freeze-substitution Unit and Gatan Cold Stage, and a Cryotransfer Unit.

The Center for Embedded Computing explores means through which faculty and staff at U.Va. can coordinate research on embedded computing technology to produce the new intelligent devices that our society has come to expect. U.Va. has a unique combination of abilities that offer great potential to advance the state of the art in this field.

The Far Infrared Receiver Laboratory (FIRLab) operates within the Departments of Electrical and Computer Engineering and Physics at the University of Virginia. The FIRLab 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, U.Va.’s Departmental Research Team for Hyperpolarized Gases has been exploring and conducting research in this field.

The 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.

The 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.

The Program of Interdisciplinary Research in Contaminant Hydrogeology 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.

The 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.

The 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 an entrepreneurial environment, 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.

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 microelectronic 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 Virginia Institute for Justice Information Systems 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 fund
ing agencies including the Virginia Department of Criminal Justice Services, and the National Institute of Justice's Crime Mapping Research Center.

The 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.

The Center for Magnetic Bearings conducts applied research in the area of magnetic bearings 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.

The 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.

The Institute for Microelectronics 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.

The Microscale Heat Transfer Laboratory is dedicated to developing new techniques to assist in measuring, understanding, and utilizing microscale thermal phenomena. The laboratory’s research is aimed at developing a fundamental understanding of energy transport on ultra short time and length scales. Current work focuses on heat transfer in thin films and in materials with partial fractal geometry; and on thermophysical property measurements of thin film materials.

The 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.

The 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.

The 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.

The Laboratory for Next Generation Real-Time Computing 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.

The Laboratory for Optics and Quantum Electronics 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-dimethilsiloxane.

The Center for Risk Management of Engineering Systems 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.

The 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.

The Center for Safety Critical Systems 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 transport 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.

The 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.

The Semiconductor Device Laboratory 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.

The 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 U.Va. Both facilities are staffed by University students and researchers.

The Center for Semicustom Integrated Systems 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.
The Smart Travel Laboratory is a state-of-the-art facility 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 by the Virginia Department of Transportation. This connection provides researchers with direct access to real ITS data and systems.

The 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.

The 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 composition depth profiles.

The Center for Survivable Information Systems 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.

The Virginia Institute for Technology and the Environment 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.

The 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.

The 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.

The Center for Wound Prevention and Repair 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 Division of Technology, Culture, and Communication; 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. 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 networks and can be used independently, or to access other computers at the University or world-wide. 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 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 inter-library 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.

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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.
The application requires completion of an essay, complete transcript should have a B average for admission into graduate studies. To remedy deficiencies must be taken without credit. An applicant to the field of engineering or applied science, degrees in other fields and women from other countries whose diverse perspectives are welcomed. The Engineering School welcomes applications from men without regard to race, color, religion, sex, national origin, political affiliation, disability, age, sexual orientation, or veteran status. 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 do not require a thesis and are professionally oriented.

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 fee of $40 must accompany the application; an application will not be considered if this 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 (http://www.virginia.edu/provost/caele/summer.html) prior to admission.

Applications may be completed and submitted on-line (http://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, P.O. Box 400242 Thornton Hall, Room A-108, University of Virginia, 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 February 1 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. This time is necessary for the International Student Office to review and process necessary papers. A prospective international student must have appropriate, current, valid, and legal non-immigrant status before he/she can be offered final admission to the University. Also, all international students (other than permanent residents) must provide bank certification of the amount of U.S. dollars they will have available for their first year in Charlottesville.

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 credit hours of lecture-laboratory courses and/or research during the academic year, must maintain a grade point average of 3.0 and also maintain satisfactory progress toward a degree. Summertime graduate research assistants must register for a minimum of 6 credit hours of research during the summer. 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, are 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 credit hours 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 credit hours 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, astro-physics, 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 of $6,000 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.

**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 hours 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 the 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, graduate studies committee, and the Office of the Dean.

**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 Committee on Graduate Studies 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**
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. These graduate courses must have been completed at another school of recognized standing. 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. These graduate courses must have been completed at another school of recognized standing. 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 from other schools of recognized standing 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 hours, 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 60 credits for the Master of Business Administration degree in the Darden Graduate School of Business Administration. Of the 24 hours in SEAS, 21 hours will be normal course work and 3 hours will be a project course taken in an appropriately numbered course. A minimum of 12 hours of course work must be taken in the major department, with a maximum of 6 hours at the 500 level. None of the 24 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 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. 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; 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, Applied Mathematics, 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 credit hours of 500-level courses; no more than six of those credits may be taken within the department conferring the 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 an 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. Computer engineering, electrical engineering, mechanical and aerospace engineering, and systems engineering.

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 (SYS601), Systems Integration (SYS 602), Enterprise Analysis and Modeling (SYS603) and Probabilistic Modeling (SYS605). 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, Engineering Physics, Mechanical and Aerospace Engineering, and Systems Engineering; 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, 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.

All 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 curriculum study area. 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) of graduate study 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 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, VA. 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.

Program Descriptions

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 minor 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. We also plan to introduce a new Major in biomedical engineering, starting in Fall 2002.
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 practicai 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 pro-
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 biotechnology, molecular and cell engineering, imaging, bioelectricity, biotransport, or biomechanics. 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 bachelor’s, 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; surgical 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 has moved into 30,000 square feet of a brand new, state-of-the-art Biomedical Engineering and Medical Sciences Building in January 2002. The building is in the heart of the School of Medicine in close proximity to the hospital and basic medical science departments. This 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, ultrasonic, 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 a renovated wing of Thornton Hall and in Phase I of the Chemical Engineering Building. 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).

After completing the basic courses, passing the preliminary examination, beginning research and passing the research examination usually within 12 months of entrance, qualified doctoral students are admitted to doctoral study. Doctoral candidates in chemical engineering serve as teaching assistants for at least two semesters. 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 and administers the interdepartmental graduate degree program in applied mechanics. 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.

Applied mechanics provides the fundamental underpinning for a number of engineering disciplines, bringing together the classical disciplines of solid and fluid mechanics and dynamics, and using the
basic principles of physics and applied mathematics as building blocks. Within this framework, applied mechanics attempts to describe the gross response of materials and systems to mechanical and environmental loads.

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 provides 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, the Master of Applied Mechanics, the Master of Science in Applied Mechanics, 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 or the Master of Science degrees. These courses are broadcast via satellite 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, Master of Applied Mechanics and Master of Science in Applied Mechanics 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, structures and mechanics, transportation engineering, and applied mechanics.

Environmental Engineering emphasizes environmental hydraulics, surface and ground water hydrology, water quality control, and water quality modeling. Research areas include storm water 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.

Structures and Mechanics The educational program in structural engineering is based on the fundamental principles of structural mechanics, analysis and design of structural systems, properties and uses of basic civil engineering materials, and soil mechanics and foundation engineering. Research activities include dynamic response of structures, field testing of highway bridges, mechanics of composite materials, soil-structure interaction, hysteretic random vibration, and structural reliability.

Transportation Engineering and Planning Transportation interests in the department are concerned with the management and planning of urban, rural, and intercity facilities, and the need to improve the mobility and safety of existing systems and develop new projects. Research areas include decision support systems for intelligent vehicle highway systems, highway safety, geographic information systems, applications of artificial intelligence, public transportation operations, and transportation demand management.

Applied Mechanics In addition to study within the Department of Civil Engineering, students may also pursue a Ph.D. degree in Mechanical and Aerospace Engineering or Applied Mathematics with a concentration in applied mechanics. Students interested in applied mechanics should contact the Office of the Director of Applied Mechanics Program or the Office of the Dean.

The faculty of the Applied Mechanics Program possess an outstanding record of scholarly achievements. As a group, they have been very active in the publication of books and journal papers, and quite successful in attracting research support. Among the faculty are chaired professors, editors, associate editors and board members of leading mechanics journals, and active participants in national and international affairs of the mechanics community. Many are recognized for their outstanding teaching ability.

Students from a wide variety of backgrounds in engineering, mathematics, or physical sciences are considered for admission in the applied mechanics program. It is desirable for students to have had some undergraduate exposure to mechanics courses and applied mathematics beyond standard calculus. Only those students with superior academic records can anticipate admission to graduate studies in applied mechanics.

Areas of study include mechanics of composite materials; shell theory; nonlinear elasticity; fracture mechanics; structural mechanics; random vibrations; continuum mechanics; high temperature test methods; thermal structures; fluid mechanics; nonlinear dynamical systems and chaos; biomechanics; optimization; finite elements; anisotropic elasticity; vibrations; galactic dynamics; planetary systems; fatigue; and micromechanics.

Department of Computer Engineering

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.

The graduate degree programs in Computer Engineering are new, with the first set of students graduating in the Summer of 2003. Detailed requirements for these degrees are posted on the web site.
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 areas typical 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 (UltraSparc-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 world-wide virtual computer linking major super-computer centers across the country; POP, or package-oriented programming for large-scale software reuse and integration; BEEHIVE, a global, virtual, real-time database; ZEPHYR, a major component of the National Compiler Infrastructure that is primarily located at UVa; 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), Building Complex Software (CS 650), and Theory of Computation (CS 660). In addition, they must demonstrate competence in at least one of the following: Programming Languages (CS 655), Operating Systems (CS 656), Analysis of Algorithms (CS 661), Computer Networks (CS 757), or Compilers (CS 771).

Graduate students are also expected to master one area of computer science in depth. To this end, each new student must choose a research advisor within the first semester, take at least one advanced seminar each semester, 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.

Department of Electrical and Computer Engineering

The Department of Electrical and Computer Engineering offers the Master of Engineering, Master of Science, and Doctor of Philosophy degrees in electrical engineering. Programs of study and research opportunities are available in the areas of automatic controls, digital systems, design automation, solid state devices, 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 http://www.ece.virginia.edu. Financial aid is available to qualified graduate students in the form of graduate research or teaching assistantships 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. It is designed so that over a three-year period, a minimum of two-thirds (and possibly all) of the master’s degree requirements can be completed through course work taken in the late afternoon. 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 electrophysics (solid state 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, Giras, 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 evaluation.
tors 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, Mag Lev, 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.

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, Hesler, 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 one of the first Ph.D. granting programs 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 Masters 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 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 come from 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, 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 Nano-technology 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 newly established NSF-sponsored MRSEC for Nanoscopic Materials Design spearheads department efforts in the emerging field of nanotechnology.

The department offers the degrees of Master of Materials Science and Engineering (MMSE), Master of Science (MS) and Doctor of Philosophy (PhD). The MS and PhD degrees involve extensive-advised research, leading to a thesis or dissertation, respectively. The MMSE 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.

MS Degree The MS 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-MS graduate students are enrolled in a 4-course, 12-credit core that includes:

1. Thermodynamics of Materials
2. Materials Structures and Defects
3. 1 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 MS 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 MS degree requires at least 6 credits of research, under the supervision of a faculty advisor, culminating in a written dissertation that is presented and defended in a public forum.

MMSE Degree The MMSE degree in MSE emphasizes classroom and perhaps laboratory learning, and requires that the student achieve satisfactorily 30 course credits beyond the BS level. The MMSE program follows the MS 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.

PhD Degree The PhD 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 PhD 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 advisor and PhD-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 MS program in another department, school or university, as approved by the MSE Curriculum Committee, to achieve any part of the core requirement. The PhD candidate's advisory committee will tailor the program of courses to reflect the importance of both breadth and breadth in MSE. Breadth may be crossdisciplinary.

The PhD 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 MS degree. The PhD 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 PhD dissertation. The PhD 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 MS degree and to follow this PhD program of study. This petition may only be submitted after the core courses for the PhD 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 (HRTM) equipped with a Gatan imaging filter (GIF) and energy-dispersive X-ray spectrometer (EDXS); a 400 kV dedicated HRTM 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, a wavelength-dispersive spectrometer (WDS) and electron backscattered pattern (EBSP) apparatus; 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
Research in dynamical systems and control covers a wide range of problems of practical interest including control of machining chatter more generally systems with time delay, neurodynamic control mechanisms of animal locomotion as applied to autonomous mobile robots and biological information processing, intelligent control, and 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 control of industrial machinery, especially rotating machines with magnetic bearings. Finally, the department hosts a strong activity in rotordynamic research which includes interest in hydrodynamic bearings and seals, turbomachinery, model identification techniques, and experimental stability margin assessment. Other work in rotating machinery is directed at flywheels and artificial heart pumps.

Research in the thermomechanics includes topics from micro- and non-Fourier heat transfer, combustion (including supersonic), reduced-order chemical kinetics, thermoacoustics, aerosols, 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 characterization 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, 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 knowledge through 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, semiconductor 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.

**Televised 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 absence 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 introductory graduate courses recommended for advanced 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; linearization; concept of stress; conservation laws of mechanics and equations of motion and equilibrium; constitutive theory; constitutive laws for nonlinear elasticity; generalized Hooke’s law for a linearly elastic solid; constitutive laws for Newtonian and non-Newtonian fluids; basic problems of continuum mechanics as boundary-value problems for partial differential equations. Cross-listed as AM 613.

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 624 - (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. Analyses of regular perturbations; roots of polynomials; singular perturbations in ODE’s; periodic solutions of simple nonlinear differential equations; multiple-Scales method; WKB1 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.


Various physical applications. Study of complex variable theory. Functions of a complex variable, and complex integral calculus, Taylor series, Laurent series, and the residue theorem, and various applications. Serious work and efforts in the further development of analytical skills and expertise. Cross-listed as MAE 642.

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 tran-
sient 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-stream function algorithms for incompressible, multidimensional flows. Extensive use of personal computers/workstations including graphics. Cross-listed as MAE 672.

APMA 603 - (Credit as arranged) (SI) Independent Study
Detailed study of graduate-level material on an independent basis under the guidance of a faculty member.

APMA 605 - (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 702 - (3) (SI) Applied Partial Differential Equations I
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.

APMA 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 AM 708.

APMA 714 - (3) (SI) Nonlinear Elasticity Theory
Prerequisite: AM/APMA 602.
Describes the theory of finite (nonlinear) elasticity governing large deformations of highly deformable elastic solids. Emphasizes new features not present in the linear theory, including instabilities (both material and geometric), normal stress effects, non-uniqueness, bifurcations, and stress singularities. A variety of illustrative boundary value problems that exhibit some of the foregoing features are discussed. 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 757 - (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) Selected Topics in Applied Mathematics
Prerequisite: AM 601 or 602.
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.
Includes the classical analysis of plates and shells; plates of various shapes (rectangular, circular, skew) and shells of various shape (cylindrical, conical, spherical, hyperbolic, paraboloidal); 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: APMA 641 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 Cartesians 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 constitute 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, Castiglano’s Theorems, theorem of least work, and unit force and displacement theorems. Introduces generalised, 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, inertia tensor; momental ellipsoid; rigid body equations of motion, Euler’s equation, force-free motion; polohde and herpolhode; theory of tops and gyroscopics; variational principles; Hamiltonian equations of motion, Poincare representation. Cross-listed as MAE 621.

AM 622 - (3) (O)
Waves
Prerequisite: MAE/AM 620 Continuum Mechanics and Applications, or equivalent.
The topics covered are: plane waves; d’Alembert solution; method of characteristics; dispersive systems; wave packets; 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 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 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 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, micro-mechanics, 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 thermodynamic 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 parametered 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)
Special Topics in Biomedical Engineering

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 604 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. Bioinstrumentation 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 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, hemodilution, 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) 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) (SI) 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 genochip 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 physiologic 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 trade-offs, 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, classification 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 MAE 602, or instructor permission.

The course is to provide a comprehensive coverage of the mechanical properties of living tissues and fluids. The formulation of their mechanical and rheological properties for quantitative analysis of biophysical deformation and fluid flow in vivo and the implications of the active and passive mechanical properties to biological problems are emphasized.

**BIOM 823 - (3) (SI) Cell Mechanics, Adhesion, and Locomotion**

*Prerequisite:* BIOM 822 or instructor permission.

Biomechanics and structural biology of cell structure and function, focusing on

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 side lobes, 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)
Biomolecular 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 doctoral 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 characteristics 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, adhesion, 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 antibiotics. Topics may include fermentation and cell culture processes, biological mass transfer, enzyme engineering, purification techniques, and implications of recent advances in molecular biology, genomics, and proteomics.

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 antibiotics. Topics may include fermentation and cell culture processes, biological mass transfer, enzyme engineering, purification techniques, 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 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 891 - (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) (S)
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 613 - (3) (Y)
**Infrastructure Management**
Prerequisite: CE 444 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 pavement management systems. Topics include methods for obtaining distress measurements and pavement condition ratings for flexible and rigid pavements; prioritizing procedures for establishing priority listings for rehabilitation and maintenance activities.

CE 615 - (3) (Y)
**Critical Path Methods**
Prerequisite: CE 441.
Analyzes the contractual, legal, and financial considerations in construction management of transportation projects; the planning and scheduling of projects with the aid of the Critical Path Methods networks including the arrow-on-line and precedence of diagramming, the Program Evaluation and Review Technique (PERT) and Graphical Evaluation and Review Technique (GERT); simulation methods to determine probable project duration time and cost distributions; cash flow analyses of early start schedules and resource leveling techniques; a method of resource leveling is given. A number of transportation case studies and a review of recent research papers.

CE 633 - (3) (Y)
**Transportation Systems Planning and Analysis I**
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.
Introduces geographic information systems (GIS) through reading, lecture, discussion, research, and hands-on experience gained through laboratory work using the ArcView GIS package. The primary objective of this course is to investigate the GIS application process.

CE 635 - (3) (Y)
**Intermodal Transportation**
Prerequisite: CE 633.
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)
**Traffic Systems Management**
Prerequisite: CE 344 and 444 or instructor permission.
A study of different transportation systems management strategies, including their long-range impact on efficient use of the systems and on safety. Focuses on traffic signals, isolated intersections, arterials and networks, geometrics, HOV lanes, and safety. A case study will also be conducted of a system in operation.

CE 638 - (3) (Y)
**Public Transportation**
Prerequisite: Graduate standing.
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 640 - (3) (Y)
**Wastewater Treatment**
Prerequisite: CE 430 or instructor permission.
Presents a concise summary of wastewater treatment processes, with emphasis on applications to municipal and industrial wastewaters. Physical, chemical, and biological treatment processes are discussed. Also covers practices of removing conventional and toxic pollutants in wastewaters.

CE 641 - (3) (Y)
**Water Quality Modeling**
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 wastewater 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 flow. 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,
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 (AM 665). Focuses on 3-D anisotropic constitutive theory, edge effects and interlaminar stresses, failure criteria, fracture, anisotropic elasticity, micromechanics, laminated plates, hygro-thermal 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 derivation 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, stress 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 every spring semester.

CE 724 - (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 parametered 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 Systems Planning and Analysis II
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 733 - (3) (IR)
Transportation Systems Planning and Analysis III
Prerequisite: CE 633 and 732.
Advanced transportation systems analysis concepts; integrated model systems and applications; real time computer-aided tools; IVHS software; expert systems applications; neural networks; applications: incident management; real time network analysis.

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 an application including cases where arrival rates exceed service rates; acceleration noise and traffic simulation.

CE 736 - (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 737 - (3) (E)
Intelligent Transportation Systems
Prerequisite: CE 633, 635, and 636 or 638.
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. Provides an introduction to the concepts of intelligent transportation systems (ITS) through a systems engineering case study approach. Students work in teams on ITS case studies through the course of the semester. The cases are actual problems for state and federal departments of transportation. Provides students with experience applying systems engineering, exposure to ITS concepts, and opportunities to examine advanced ITS technology.

CE 738 - (3) (O)
Integrated Transportation Systems Models
Prerequisite: CE 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 groundwater 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 design considerations 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 767 - (3) (SI)
Micromechanics of Heterogeneous Media
Prerequisite: CE 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, AM 767.

CE 773 - (3) (Y)
Advanced Finite Element Applications in Structural Engineering
Prerequisite: CE 671 or equivalent.
Development and application of two- and three-dimensional finite elements; plate bending; isoparametric formulation; solid elements; nonlinear element formulation with application to material and geometric nonlinearities; stability problems; formulation and solution of problems in structural dynamics; use of commercial computer codes.

CE 776 - (3) (SI)
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. Foci in 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.

CE 782 - (3) (E-O)  
Design of Slab and Shell Structures  
Prerequisite: CE 683 or 684.  
Using both exact and simplified methods of thin shell theory, such structures as domes, cylindrical roofs, tanks, hyperbolic paraboloids, folder plate roofs, and suspension forms are analyzed and designed. Effects of 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  
Prerequisites: 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 multiprocesssing 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  
Prerequisites: 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 system security, and policies of privacy and confidentiality.

CS 588 - (3) (Y)  
Cryptography: Principles and Applications  
Prerequisites: CS 302 or instructor permission. Introduces the basic principles and mathematics 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  
Prerequisites: 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++. Introduces the use of parallel computing systems. Develops applications of cryptography such as anonymous email, digital cash and code signing.

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 as 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 documentation 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 OSs; microkernels and OS architectures; processes and threads; IPC; files servers; distributed shared memory; object-oriented OSs; reflection in OSs; 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 662 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 663 - (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 toolkits, word processors, publishing systems, HTML, JAVA, browsers, Web tools, and personal time management.

CS 715 - (3) (Y)
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 evaluations; performance 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 deadlocks. 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, 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 webbased 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 image processing and machine vision. The contents vary with each semester and each instructor. An in-depth study of recent research in narrowly defined areas of 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
Prerequisite: Instructor permission.

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

CS 898 - (Credit as arranged) (SI)
Thesis
Prerequisite: Instructor permission.

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

CS 999 - (Credit as arranged) (SI)
Dissertation
Prerequisite: Instructor permission.

Electrical and Computer Engineering

ECE 525 - (3) (SI)
Introduction to Robotics
Prerequisite: ECE 402, or 621, or equivalent.
Prerequisite: ECE 402, or 621, or equivalent.
Analyses 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 303, 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.
The fundamentals of discrete-time signal processing are presented. Topics include discrete-time linear systems, Z-transforms, the DFT and FFT algorithms, and digital filter design. Problem-solving using the computer will be stressed.
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 immittance 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 immittance-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 (samples 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.
Provides 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: APMA 615, ECE 621, or instructor permission.
Studies linear dynamical systems emphasizing canonical representation and decomposition, state representation, controllability, observability, normal systems, state feedback and the decoupling problem. Representative physical examples. Cross-listed as MAE 652.

ECE 631 - (3) (Y)
Logic Synthesis
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.

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
Prerequisite: 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 507 or equivalent. Design and analysis of analog integrated circuits. Topics include feedback amplifier analysis and design including stability, compensation, and offset-correction; layout and floorplanning 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-dimensional 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, PSK, 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 775 - (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 Ricatti 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 multi-variable control theory; matrix fraction descriptions, state-space realizations, multi-variable 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; H₂-optimal control and loop transfer recovery; H₂-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. 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.
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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)
Advanced Digital Signal Processing
Prerequisite: ECE 611, 576, or equivalent; corequisite: ECE 614.
Topics include a review of matrix analysis tools, the elements of estimation theory, and the Cramer-Rao bound; spectral estimation, especially nonparametric (incl. filterbank) methods; parametric methods for rational spectra; parametric methods for linear spectra; spatial spectral analysis; and adaptive filtering, especially least mean squares (LMS) and recursive least squares (RLS) algorithms.

ECE 776 - (3) (O)
Multi-Dimensional and Array 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 2-D Fourier analysis, 2-D stability, 2-D spectral estimation, and inverse problems such as beamforming and reconstruction from projections. The theory developed serves as the foundation of digital image processing, and is applied to array signal processing (e.g., radar, sonar, seismic, medical, and astronomical data processing).

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 images; 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 792 - (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 parametrized control 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) (SI)
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 Tunneling 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 556, 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 895 - (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. Registration 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 studies 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 Research
Formal record of student commitment to project research under the guidance of a faculty advisor. Registration may be repeated.

EP 700 - (S) (S)
Graduate Seminar
For students who have established resident credit. Weekly meeting of graduate students and faculty for presentation and discussion of contemporary research. This seminar is offered every 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 796 - (1) (S)
Graduate Seminar
Weekly meetings of graduate students and faculty for presentation and discussion of contemporary research. This seminar is offered each semester and is required for every student establishing resident credit.

EP 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. Registration may be repeated as necessary.

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

EP 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.

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

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

Materials Science and Engineering

MSE 500 - (1-3) (SI)
Special Topics in Materials Science and 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 materials science and engineering field. Offering is based on student and faculty interests.

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
Prerequisite: At least two 300-400 level MSE courses or instructor permission.
Introduces computer modeling in several primary areas of Materials Science and Engineering: atomistics, kinetics and diffusion, elasticity, and processing. Applications are made to the energy and configuration of defects in materials, solute segregation, phase transformations, stresses in multicomponent systems, and microstructural development during processing, for example.

MSE 532 - (3) (Y)
Deformation and Fracture of Materials
Prerequisites: MSE 306 or instructor permission.
Exploration 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-dependence, experimental design, and damage-tolerant life prediction.

MSE 567 - (3) (Y)
Electronic, Optical and Magnetic 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 materials.
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.
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 of Solid Materials
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 Materials
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. Open systems, chemical reactions, capillarity effects and external fields are also discussed.

MSE 624 - (3) (Y)
Kinetics of Solid-state Reactions
Prerequisite: MSE 623.
Serves as 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 will 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 will develop analytical and numerical techniques for solving these equations and will apply them to understanding microstructural evolution during growth and coarsening in one, two and three dimensions.

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 alloys of transition elements. Emphasizes microstructural evolution by composition and thermomechanical process control. Topics include phase diagrams, transformation kinetics, martensitic transformation, precipitation, diffusion, recrystallization, and solidification. Considers both experimental and model-simulation approaches.

MSE 667 - (3) (Y)
Semiconductor Materials and Devices
Prerequisite: Some background in solid state materials and elementary quantum principles.
Provides an understanding of the fundamental, 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 693 - (Credit as arranged) (S)
Independent Study
Detailed study of graduate course material on an independent basis under the guidance of a faculty member.

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.
Analyzes 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; high-voltage electron microscopy.

MSE 706 - (3) (E)
Advanced Electron Microscopy
Prerequisite: MSE 703 or instructor permission.
Emphasizes the applications of advanced techniques of transmission and scanning electron microscopy to modern research problems in materials science and engineering.
MSE 721 - (3) (Y)
**Diffusional Processes in Materials**
*Prerequisite: MSE 623.*
Phenomenological theory of diffusion in crystalline solids is developed for binary and multicomponent alloys and then applied to problems in solid-state phase transformations, segregation and homogenization, and thin films. Solution techniques for time-independent and time-dependent problems in one and two dimensions are constructed for single- and multi-phase systems. Interfacial kinetic barriers and elastic stress on diffusion are presented.

MSE 714 - (3) (SI)
**Quantization in Solids**
*Prerequisite: Instructor permission.*
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.*
Analyzes 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)
**Fatigue and Fracture 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 734 - (3) (Y)
**Phase Transformations**
*Prerequisite: MSE 623 or comparable thermodynamics.*
Includes the fundamental theory of diffusional phase transformations in solid metals and alloys; applications of thermodynamics to calculation of phase boundaries and driving forces for transformations; theory of solid-solid nucleation, theory of diffusional growth, comparison of both theories with experiment; applications of thermodynamics and of nucleation and growth theory to the principal experimental systematics of precipitation from solid solution, the massive transformations, the cellular and the pearlite reactions, martensitic transformations, and the questions of the role of shear in diffusional phase transformations.

MSE 741 - (3) (Y)
**Crystal Defect Theory**
*Prerequisite: MSE 662 or instructor permission.*
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, tackiness, glass transitions, crystallization, dielectric and mechanical relaxation, and permselectivity). 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, NRM, 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 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 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)
**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: AM 641, AM 601 or AM 602.
Topics include the classical analysis of plates and shells; plates of various shapes (rectangular, skew) and shells 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: AM602 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 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 Transfer
Prerequisite: Undergraduate fluid mechanics or instructor permission.

MAE 612 - (3) (E)
Microscale Heat Transfer
Prerequisite: MAE 610, ThermoMechanics.
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)
Nonequilibrium Gas Dynamics
Prerequisite: MAE 610 or instructor permission.
Boltzmann equation: Dynamics of molecular collisions; Chapman-Enskog solution of non-equilibrium flows; transport properties; application to shock structure; and shear and mixing layers with chemical reactions.

MAE 616 - (3) (IR)
Advanced Thermodynamics
Prerequisite: Instructor permission.
Analyzes 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 617 - (3) (IR)
Microscopic Thermodynamics
Prerequisite: Instructor permission.
Topics include the thermodynamics of gases developed from a microscopic point of view; kinetic theory derivation of equilibrium thermodynamic and transport properties of gases; introduction to advanced non-equilibrium kinetic theory; quantum mechanical treatment of atomic and molecular energy level structure; statistical mechanics derivation of the thermodynamic properties of equilibrium gases; chemical thermodynamics and chemical equilibrium of reacting gas mixtures; applications of the theory of high temperature gas behavior, gas-phase combustion and equilibrium and non-equilibrium gas dynamics.

MAE 620 - (3) (IR)
Energy Principles in Mechanics
Prerequisite: Instructor permission.
Analyzes 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, Castigliano'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; 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.
The topics covered are: Newtonian mechanics; Newton's laws, energy, work, conservation principles; Reference frames: transformations, Euler angles, kinematics; Rotational motion: rigid bodies, inertia tensors; constraints and generalized coordinates; Other equations of motion: Kane's equations, Lagrange's equations, Gibbs-Appell equations; Variational principles. 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 waves and Rayleigh waves; layered media and Love waves; slowly-varying media and WKBJ method; Time-depend-
ent 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 perturbation theory, and applies them to the study of stability in the contexts of nonlinear dynamical systems and nonlinear waves, including free and forces 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 motions, 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; streamlines, 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 fluid; 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 organelles in cells to 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 biomechanical understanding of these systems through the construction of simplified mathematical models amenable to analytical, numerical or statistical formulation and solution including the identification and quantification of model uncertainties.

MAE 636 - (3) (O)

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. Further and deeper understanding of partial differential equations that govern physical phenomena in science and engineering. Solution of linear partial differential equations by eigenfunction expansion techniques. Green’s functions for time-independent and time-dependant boundary value problems. Fourier transform methods, and Laplace transform methods. Solution of variety of initial-value, boundary-value problems. Various physical applications. Study of complex variable theory. Functions of complex variable, the complex integral calculus, Taylor series, Laurent series, and the residue theorem, and various applications. Serious work and efforts in the further development of analytical skills and response. Cross-listed as APMA 642.

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-posed-ness 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.
Analyses 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 course 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
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
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 presented. Up to three credit hours 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) (O)
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 multi-component 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 not required, but would help.
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, 2-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 Studies
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
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: Advanced Level
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 - (see below regarding credit) (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-hour 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 - (see below regarding credit) (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 semester-hours equal to the difference between his or her regular course load (not counting the one-hour 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.
Prepares the foundation of mathematical modeling and optimization, with emphasis on problem formulation and solution techniques. Coverage includes linear programs, nonlinear programs, combinatorial models, optimality conditions, search strategies, and numerical algorithms. Topics are illustrated through classic problems such as service planning, operations management, manufacturing, transportation, and network flow.
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 queuing systems.

SYS 609 - (3) (IR)
**The Art and Science of Systems Modeling**
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: Dimension I: The building blocks of mathematical models and the centrality of the state variables in systems modeling, including: state variables, decision variables, random variables, exogenous variables, inputs and outputs, objective functions, and constraints. Dimension II: Effective tools in systems modeling, including: multiobjective models, influence diagrams, event trees, systems identification and parameter estimation, hierarchical holographic modeling and dynamic programming.

SYS 612 - (3) (IR)
**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 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**
Introduces the fundamental concepts necessary for successful research in, and real world application of, knowledge-based decision support systems. Emphasizes knowledge acquisition, system design principles, and testing systems with human subjects. Students are required to work through several design and testing exercises and develop a final project that applies principles learned in class. Cross-listed as CS 616.

SYS 618 - (3) (Y)
**Data Mining**
*Prerequisite: SYS 605 or STAT 512.*
Data mining describes an approach to turning data into information. Rather than the more typical deductive strategy of building models using known principles, data mining uses an inductive approach to discover the appropriate model. 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: SYS 605 or equivalent.*
A first graduate 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. 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 holographic 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 method, and filtering, ranking, and management method. Case studies.

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 670 - (3) (Y)
**Environmental Systems Analysis**
*Prerequisites: CHEM 152, PHYS 421.*
Examines the constitution of environmental systems and the science underlying observed perturbations to these systems. Presents the main tools used to analyze the effect of perturbations to environmental systems and to frame policy interventions for mitigating the impacts of such disturbances. Begins with a treatment of technology design and the environment with a focus on automobiles, electric power, drinking water supply, wastewater and sewage treatment, and solid waste management. Proceeds to a study of modeling of environmental processes, with a focus on photochemical smog, PCBs in the aquatic environment, CFCs and the ozone hole, and global warming and the greenhouse effect. Progresses to a study of the tools in environmental systems analysis: lifecycle assessment, environmental economics and natural resource accounting, benefit-cost analysis, risk analysis and environmental forecasting. Includes an analysis of environmental justice
and the role of stakeholders in environmental systems and closes with a synthesis of the course material in the context of sustainable development.

**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 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. 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 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. Cases are extracted from actual government, industry, and business problems.

**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 of the course is to convey a deep understanding of the main results and their proofs, sufficient to allow the 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. 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. Topics discussed and papers reviewed are selected at the first meeting. Throughout the semester, students make a one-hour presentation of their chosen paper, followed by a one and one-half hour 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 holographic 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 method, 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 and other methods provide engineering design and process improvement through the collection and analysis of data from controlled experimentation. Response surface methods use experimental data to construct and explore the relationship between design variables and measures of product or process performance. This course
investigates the construction of response models for systems with discrete and continuous valued responses. The course will investigate building and using response surfaces from simulation, known as simulation-optimization, as well as, the use of response surfaces in more traditional engineering applications.

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 805 - (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. Registration may be repeated as necessary.

SYS 807 - (Credit as arranged) (S)
**Graduate Teaching Instruction**
For master's students.

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

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

SYS 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.

**Faculty**

**Office of the Dean of the School of Engineering and Applied Science**

Richard W. Miksad, B.S., M.S., Sc.D.,
Thomas M. Linville Professor and Dean
J. Milton Adams, B.S., Ph.D., Associate Dean
Mary P. Beck, M.S., Director of Applied Math Instruction, Lecturer
David Chestnutt, B.S., M.S., M.Phil., Executive Director of Virginia Consortium of Engineering and Science Universities, Lecturer
Thomas N. Connors, B.A., Vice President for Development, Virginia Engineering Foundation, Lecturer
James F. Groves, B.S., M.S., Ph.D, Assistant Professor of Material Science, Director of the Commonwealth Graduate Engineering Program
Frances Hersey, Associate Director of Engineering Career Services, Lecturer
Clarence J. Livesay, B.S., Director of Career Services, Lecturer
P. Paxton Marshall, B.S., M.A., M.E., Ph.D., Assistant Dean for Undergraduate Programs, Associate Professor
Mitchel C. Rosen, B.E., M.S., Ph.D., Director of Information Technology, 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., Assistant Dean for Graduate Programs
William J. Thurneck, Jr., B.S., M.S.E., Ph.D., Assistant Dean for Administrative and Academic Affairs, Professor
Carolyne A. Vallas, B.A., M.S., Director of Minority Programs, Lecturer
Haydn N. G. Wadley, B.S., Ph.D., Edgar A. Starke, Jr. Professor of Materials Science, Associate Dean for Research

**Department of Biomedical Engineering**

**Professors**
J. Milton Adams, B.S., Ph.D.
Paul E. Allaire, B.E., M.E., Ph.D., Mac Wade Professor of Mechanical and Aerospace Engineering
James R. Brookeman, B.S., Ph.D.
Brian R. Duling, A.B., Ph.D.
Samuel J. Dwyer, III, Ph.D.
Richard F. Edlich, M.D., Ph.D.
Sanjiv Kaul, M.D., Francis M. Ball Professor of Cardiology
Yong I. Kim, B.S., M.S., Ph.D.
Cato T. Laurencin, M.D., Ph.D., University Professor, Lillian T. Pratt Distinguished Professor & Chair of Orthopaedic Surgery
Jen-Shih Lee, B.S., M.S., Ph.D.
Klaus F. Ley, M.D.
Thomas C. Skalak, Chair, B.E.S., Ph.D.

**Associate Professors**
Scott T. Acton, B.S., Ph.D.
Frederick H. Epstein, B.S., M.S., Ph.D.
Brent A. French, B.S., Ph.D.
Gregory A. Helm, B.S., M.D.
John A. Hossack, B.Eng., Ph.D.
Associate Professors
Thomas T. Baber, B.S., M.S., Ph.D., P.E.
Teresa B. Culver, B.S., M.S., Ph.D.
James A. Smith, B.S., M.S., Ph.D.

Assistant Professors
Matthew R. Begley, B.S.M.E., M.S.M.E., Ph.D.
Susan E. Burns, B.S., M.S., Ph.D., P.E.
Kirk A. Martini, B.A., M.S., Ph.D., P.E.
Roseanna Neupauer, B.S., M.S., Ph.D.
Brian L. Smith, B.S., M.S., Ph.D.

Research
B. Brian Park, M.S., Ph.D.
Hua-liang (Harry) Teng, B.S., M.S., Ph.D.

Department of Computer Engineering

Professors
Jack W. Davidson, B.A.S., M.S., Ph.D.
Grady R. Grimshaw, B.A.S., M.S., Ph.D.
Anita K. Jones, A.B., M.S., Ph.D., University
Professor, Lawrence R. Quares Professor of
Engineering
John C. Knight, B.S., Ph.D.
Paul F. Reynolds, Jr., B.A., M.A., Ph.D.
Gabriel Robins, B.S., M.S.E., Ph.D.,
Sang H. Son, B.S., M.S.E., Ph.D., M.S.C.S., Ph.D.
John A. Stankovic, Chair, Sc.B., Sc.M., Ph.D.,
BP 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., AT&T
Professor of Computer Science and
University Professor

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

Research
James C. French, B.A., M.S., Ph.D., Associate
Professor
Ruth Anderson, B.S., M.S.
Jane Prey, B.S., M.S., Ph.D.

Department of Electrical and Computer Engineering

Professors
James H. Aylor, Chair, B.S., M.S., Ph.D.
Louis T. Rader Professor
John C. Bean, B.S., M.S., Ph.D. (Applied
Physics), John Marshall Money Professor
Joanne Bechta Dugan, B.A., M.S., Ph.D.
Lloyd R. Harriott, B.S., M.A., Ph.D., Virginia

Microelectronics Consortium Professor
Robert Hull, B.A., Ph.D. (Phys.)
Doris Wilsdorf Distinguished Professor
Barry W. Johnson, B.S., M.E., Ph.D.
Michael L. Reed, B.S., M.Eng., Ph.D.
Stephen G. Wilson, Associate Chair, B.S.,
M.S., Ph.D.

Associate Professors
Scott Acton, B.S., M.S., Ph.D., Walter N.
Munster Associate Professor
Travis N. Blalock, B.S., M.S., Ph.D.
Maite Brandt-Pearce, B.S., M.E., Ph.D.
Stephen G. Carr, Assistant Chair, B.S.
(Physics), Ph.D.
Zongli Lin, B.S., M.E., Ph.D. (Elec. &
Computer Engr.)
P. Paxton Marshall, B.S., M.A., Ph.D.
Mircea R. Stan, Diploma (Electronic Engr.),
M.S., Ph.D. (Elec. & Computer Engr.)
Gang Tao, B.S., M.S., Ph.D.
Malathi Veeraraghavan, Director, Computer
Engineering Program, B.Tech., M.S.,
Ph.D.
Robert M. Weikle, B.S., 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 Lath, B.S., M.S., Ph.D.
William F. Walker, B.S., Ph.D. (Biomed.)
Yibin Zheng, B.S., M.A., (Physics), Ph.D.
(Elec. Engr.), Ph.D. (Physics)

Research
Thomas Crowe, B.S., M.S., Ph.D., Professor
Boris Gelmont, M.S., Ph.D. (Physics), D.Sc.,
Associate Professor
Ted C. Giras, B.S., M.S., Ph.D., Professor
Jeffrey L. Lesler, B.S., M.S., Ph.D., Assistant
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.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.
James M. Howe, B.S., M.S., Ph.D.
Robert Hull, B.A., Ph.D., Charles A.
Henderson Professor of Engineering
William A. Jesser, Chair, B.A., M.S., Ph.D.,
Thomas Goodwin Diggins 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.
Doris Kuhlmann-Wilsdorf, B.Sc., M.Sc.,
Ph.D., University Professor of Applied
Science
John R. Scully, B.S., M.S.E., Ph.D.
Gary J. Shiflet, B.S., M.S., Ph.D., William G.
Reynolds Professor
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 of Electrical Engineering
James J. Kauzlarich, 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 Civil Engineering
Alden Robert Kuhlthau, B.S., M.S., Ph.D., Professor Emeritus of Civil 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., Research Associate Professor of Nuclear Engineering and Engineering Physics
Hiram Gordon Larew, B.S.C.E., M.S.C.E., Ph.D., P.E., Professor Emeritus of Civil Engineering
Kenneth Robert Lawless, B.S., Ph.D., Professor Emeritus of Materials Science
David W. Lewis, B.A., B.S., M.S., Ph.D., P.E., Professor Emeritus of Mechanical and Aerospace Engineering
Lembit U. Lilleleht, B.Ch.E., M.S.E., Ph.D., Professor Emeritus of Chemical Engineering
William B. Looney, B.S., M.D., Ph.D., D.Sc., Professor Emeritus of Biomedical Engineering
Ralph Addison Lowry, B.S., Ph.D., Professor Emeritus of Nuclear Engineering and Engineering Physics
David I. Luik, A.A., B.S., Ph.D., Associate Professor Emeritus of Applied Mathematics
Lois E. Mansfield, B.S., M.S., Ph.D., Professor Emeritus of Applied Mathematics
George B. Matthews, B.S., M.S., M.A., Ph.D., Professor Emeritus of Mechanical and Aerospace Engineering
Fred Campbell McCormick, B.C.E., M.S.E., Ph.D., P.E., Professor Emeritus of Civil Engineering
Eugene S. McVey, B.S.E.E., M.S., Ph.D., P.E., Professor Emeritus of Electrical Engineering
James Lawrence Meem, Jr., B.S., M.S., Ph.D., Professor Emeritus of Nuclear Engineering
Dale Robert Metcalf, B.S., M.S., Ph.D., Associate Professor Emeritus of Nuclear Engineering
Edward Valentine Mochel, B.S., M.S., Associate Professor Emeritus of Mechanical Engineering
James W. Moore, B.S., M.S., Ph.D., P.E., Professor Emeritus of Mechanical and Aerospace Engineering
David Morris, B.C.E., M.S.C.E., D.Sc., P.E., Professor Emeritus of Civil Engineering
Jeffrey B. Morton, B.S., Ph.D., Professor Emeritus of Aerospace Engineering
James M. Ortega, B.S., Ph.D., Professor Emeritus of Computer Science
Robert H. Owens, B.S., M.A., Ph.D., Professor Emeritus of Applied Mathematics
John L. Pfaltz, B.A., M.A., Ph.D. Research Professor and Professor Emeritus
Louis T. Rader, B.Sc., M.S., Ph.D., Professor Emeritus of Electrical Engineering
Donald L. Reid, B.M.E., M.S.E., P.E., Associate Professor of Mechanical Engineering
Albert B. Reynolds, S.B., S.M., Sc.D., Professor Emeritus of Nuclear Engineering
Roger A. Rydin, B.S., S.M., Sc.D., Associate Professor Emeritus of Nuclear Engineering
John E. Scott, Jr., B.S., M.S., M.A., Ph.D., Professor Emeritus of Mechanical and Aerospace Engineering
Clifford Myron Siegel, B.E.E., M.S.E.E., Ph.D., Professor Emeritus of Electrical Engineering
James G. Simmonds, S.B., S.M., Ph.D., Professor Emeritus of Applied Mathematics and Mechanics
Edward Carl Stevenson, B.A., M.A., Ph.D., Professor Emeritus of Electrical Engineering
George C. Theodoridis, B.S., Sc.D., Professor Emeritus of Biomedical Engineering
Earl A. Thornton, B.S., M.S., Ph.D., Professor Emeritus of Aerospace Engineering
Miles A. Townsend, B.Sc., M.Sc., Ph.D., P.E., Professor Emeritus of Mechanical and Aerospace Engineering
Franklin E. Wawner, Jr., B.S., M.S., Ph.D., Professor Emeritus of Materials Science and Engineering
Thomas Garnett Williamson, B.S., M.S., Ph.D., Professor Emeritus of Nuclear Engineering and Engineering Physics