COLLEGE OF ENGINEERING

ADMINISTRATION

John E. Hopcroft, dean

Michael S. Isaacson, associate dean for research and graduate studies

Gerald Rehkugler, associate dean for undergraduate programs

Mark K. Spiro, associate dean for administration

Deborah Cox, assistant dean for student services

Murray Deathe, assistant dean for development and alumni relations

FACILITIES AND SPECIAL PROGRAMS

Most of the academic units of the College of Engineering are on the Joseph N. Pew, Jr. Engineering Quadrangle. Facilities for applied and engineering physics are located in Clark Hall on the College of Arts and Sciences campus, and facilities for agricultural and biological engineering are centered in Riley-Robb Hall on the campus of the New York State College of Agriculture and Life Sciences.

Special university and college facilities augment the laboratories operated by the various engineering schools and departments, and special centers and programs contribute to opportunities for study and research.

Computing equipment, for example, is widely available through centers administered by the university and by the College of Engineering, as well as in laboratories run by schools, departments, or programs. The university facilities include personal computers for student use, terminals connected to the mainframe, computer-graphics equipment, and a supercomputer. The College of Engineering operates, in addition to several computing centers for student use, a workstation facility, which provides advanced computer-graphics equipment used in course work throughout the college.

Cornell programs and centers of special interest in engineering include the following:

Center for Applied Mathematics. A cross-disciplinary center that administers a graduate program.

Center for the Environment. A sponsor of interdisciplinary programs that are currently in the areas of environmental law and policy, ecosystem research, remote sensing, water resources, the global environment, biological resources, waste management, and solid-waste combustion.

Center for Radiophysics and Space Research. An interdisciplinary unit that facilitates research in astronomy and the space sciences.

Center for Theory and Simulation in Science and Engineering. A national supercomputer facility used for advanced research in engineering and the physical and biological sciences.

Cornell Electronic Packaging Alliance. A cooperative venture involving Cornell and several corporations in the areas of computing and microelectronics, organized to undertake precompetitive, interdisciplinary research in electronic packaging.

Cornell High Energy Synchrotron Source (CHESS). A high-energy synchrotron radiation laboratory operated in conjunction with the university's high-energy storage ring. Current research programs at CHESS are in areas of structural biology, chemistry, materials science, and physics.

Center for Manufacturing Enterprise. A joint venture of Cornell, industrial organizations, and the federal government to encourage the development and implementation of modern manufacturing systems.

Cornell Program in Power Systems Engineering. A research and instructional program centered in a laboratory that has a complete real-time model of an electric power system.

Cornell Waste Management Institute. A research, teaching, and extension program within the Center for Environmental Research that addresses the environmental, technical, and economic issues associated with solid waste; one facility sponsored by the institute is the Combustion Simulation Laboratory in the Sibley School of Mechanical and Aerospace Engineering.

Institute for the Study of the Continents. An interdisciplinary organization that promotes research on the structure, composition, and evolution of the continents.

Laboratory of Plasma Studies. A center for interdisciplinary research in plasma physics and lasers.

Materials Science Center. An interdisciplinary facility with substantial support from the National Science Foundation, providing sophisticated equipment.

Mathematical Sciences Institute. An interdisciplinary program in applications of mathematics funded by the U.S. Army.

National Astronomy and Ionosphere Center. The world's largest radio-radar telescope facility, operated by Cornell in Puerto Rico.

National Earthquake Engineering Research Center. A facility recently established by the National Science Foundation at a group of universities in New York State to study response and design of structures in earthquake environments.

National Institutes of Health/National Science Foundation Developmental Resource in Biophysical Imaging and Optoelectronics. A resource that develops novel measurement and optical instrumentation for solving biophysical problems.

National Nanofabrication Facility (part of the National Nanofabrications Users Network). A center that provides equipment and services for research in the science, engineering, and technology of structures (for electronic, chemical, physical, and biological applications) with dimensions as small as nanometers.

Program of Computer Graphics. An interdisciplinary research center that operates one of the most advanced computer-graphics laboratories in the United States.

Program on Science, Technology, and Society. A cross-disciplinary unit that sponsors courses and promotes research on the interaction of science, technology, and society.

SRC Center for the Program on Microscience and Technology. A center sponsored by the Semiconductor Research Corporation to promote research essential to the development of VLSI devices and circuits.

Statistics Center. Coordinates a university-wide program in statistics and probability.

Ward Laboratory of Nuclear Engineering. Irradiation, isotope production, and activation analysis facilities for interdisciplinary research.

Programs sponsored by College of Engineering units include several for industrial affiliates. These are in the areas of injection molding, computer science, materials science, geologic study of the continents, and nanometer scale structures.

DEGREE PROGRAMS

Cornell programs in engineering and applied science lead to the degrees of Bachelor of Science, Master of Engineering (with field designation), Master of Science, and Doctor of Philosophy.

General academic information concerning the Bachelor of Science degree is given here under the heading "Undergraduate Study." Curricula for major studies are described under the various academic areas.

Programs leading to the Master of Science and Doctor of Philosophy degrees are administered by the Graduate School. They are described in the *Announcement of the Graduate School* and the special announcement *Graduate Study in Engineering and Applied Science.* The professional Master of Engineering programs and cooperative programs with the Johnson Graduate School of Management are described below.

UNDERGRADUATE STUDY

Bachelor of Science (B.S.) degrees are offered in the following areas:*

Agricultural and biological engineering†

Chemical engineering

Civil engineering

College program

Computer science

Electrical engineering

Engineering physics

Geological sciences

Materials science and engineering

Mechanical engineering

Operations research and engineering

Students in the College of Engineering begin their undergraduate studies in the Common Curriculum, which is administered by the faculty members of the College Curriculum Governing Board (CCGB) through the associate dean for undergraduate programs and the Engineering Advising office. Subsequently most students enter *field* programs, which are described separately for each academic area. Criteria for entrance into the field programs are described in the section titled "Affiliation with a Field Program." Alternatively students may enter the *College Program* (described below), which permits them to pursue a course of study adapted to individual interests.

Students interested in bioengineering may arrange a suitable curriculum with a bioengineering option within one of the field programs or through the College Program. Information about the bioengineering option is available in the Engineering Advising office, 167 Olin Hall. Students interested in environmental engineering may pursue the environmental option offered by the School of Civil and Environmental Engineering.

*Agricultural and biological engineering, chemical engineering, civil engineering, electrical engineering, engineering physics, materials science and engineering, mechanical engineering, and operations research and engineering are accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology.

†To major in agricultural and biological engineering students normally enroll in the College of Agriculture and Life Sciences for the first and second years, and jointly in that college and the College of Engineering for the third and fourth years. However, students enrolled in the College of Engineering for the first two years may affiliate with the field of agricultural and biological engineering and become jointly enrolled in the Colleges of Agriculture and Life Sciences and Engineering for the third and fourth years.

Requirements for Graduation

To receive the Bachelor of Science degree, students must meet the requirements of the Common Curriculum, as set forth by the College of Engineering, including the requirements of the field program, as established by the school or department with which they become affiliated. Students entering the college in the Class of 1998 or later must meet the Common Curriculum as explained below. (Further explanation of the revised Common Curriculum and field flow charts are provided in the 1995–96 edition of the *Engineering Undergraduate Handbook*.)

Course Category	*Credits*
1) Mathematics	16
2) Physics	8–12
3) Chemistry	4–8
4) Freshman writing seminar*	6
5) Computer programming†	4
6) Engineering distribution (3 courses)	
a. One Introduction to Engineering (ENGRI)	3
b. Two other distribution courses (ENGRD)	6
7) Liberal studies distribution (6 courses)	18
8) Approved electives	6
9) Field program	
a. Field required courses	30 cr. min.
b. Field approved electives	9
c. Courses outside the field	9

*One writing-intensive technical course or a course in technical or scientific writing must also be taken; this course may simultaneously satisfy some other requirement.

†One approved course in computing applications must also be taken; this course may simultaneously satisfy some other requirement, such as an engineering distribution course, an approved elective, or a field program course.

From 123 to 129 credit hours are required for graduation; the specific number of required credit hours will vary depending on which field program is chosen. (See field curricula for specific field requirements.) Two terms of physical education must be taken in the freshman year and students must meet the swimming requirement to satisfy a university requirement.

Mathematics

The normal program in mathematics includes Mathematics 191, 192, 293, and 294. Every student must attain a grade of at least C– in Mathematics 191, 192, 293, and 294, or other courses that may be approved as substitutes for these courses. If this requirement is not met the first time a course is taken, the course must be repeated immediately and a satisfactory grade attained before the next course in the sequence may be taken. Courses that are taken a second time in order to meet this requirement do not yield additional credit toward a degree.

Physics

The normal program in physics includes Physics 112, 213, and 214 or the corresponding honors courses (Physics 116, 217, and 218). Engineering students are required to have attained a minimum grade of C- in Mathematics 191 or equivalent before taking Physics 112. The same minimum grade is required in each subsequent mathematics course before taking the physics course for which it is a prerequisite (e.g., C- in Mathematics 192 before taking Physics 213, or C- in Mathematics 293 before taking Physics 214). Students in the field programs of ABEN, ChE, CEE (environmental track), or OR&IE may substitute Chemistry 208 for Physics 214.

Chemistry

Chemistry 211 or 207 is required for all students.

Chemistry 211 is a course designed for students who do not intend any further study in chemistry and may be taken either in the fall or spring of the freshman year.

In general, students intending to affiliate with the following departments and schools should take Chemistry 211: electrical engineering, operations research and industrial engineering, computer science, mechanical and aerospace engineering, applied and engineering physics (applied and engineering physics students should discuss this option with the field consultant), and civil engineering (not students in the environmental engineering option). Students in chemical engineering must take Chemistry 207 in the fall of their freshman year, to be followed by Chemistry 208 in the spring term. All students considering environmental engineering, materials science and engineering, geological sciences, or a health-related career such as medicine should take Chemistry 207.

Freshman Writing Seminars

Each semester of their freshman year, students choose a freshman writing seminar from among more than seventy courses offered by over twenty different departments in the humanities, social sciences, and expressive arts. These courses offer the student practice in writing English prose. They also assure beginning students the benefits of a small class.

Technical Writing

In addition to the two Freshman Writing Seminars required, engineering students must take a course that includes a significant amount of technical and scientific writing. This course may be used to satisfy another graduation requirement. A student can fulfill the technical writing requirement by enrolling in an engineering course specifically designed to include a writing-intensive component or by taking a course in technical or scientific writing. Courses that currently satisfy this requirement are A&EP 264, CHEM E 432, COMM 352*, COMM 360*, COMM 363*, COMM 365*, ENGRC 350, ENGRC 435, M&AE 427, MS&E 435, and MS&E 443–444 if both courses are taken. Students participating in the Engineering Cooperative Program may also arrange for a writing-intensive co-op experience to satisfy this requirement. Additional courses are being reviewed. Updated information on these approved courses may be obtained from Engineering Advising, 167 Olin Hall.

*Note that there is limited enrollment in all Communications Department writing courses.

Computing

In either the first or second term of their freshman year, students normally take COM S 100, Introduction to Computer Programming. Before graduation they must take an additional course with a significant amount of computing applications; this course may also be used to meet another graduation requirement. Courses that satisfy this requirement are ABEN 475, COM S 212, ENGRD 211 or 212, ENGRD 222, ENGRD 241, ENGRD 264, ELE E 423, M&AE 389, M&AE 489, M&AE 575, M&AE 578, and M&AE 670. The recommended choice for students intending to enter the Field Program in Engineering Physics is ENGRD 264; in Chemical Engineering, ENGRD 222 or 241; in Computer Science, ENGRD 211 or COM S 212; in Electrical Engineering, ENGRD 211; in Civil Engineering, ENGRD 241; in Mechanical Engineering, M&AE 389, M&AE 489, M&AE 575, or M&AE 670; and in Operations Research and Engineering, ENGRD 211.

Engineering Distribution

Three engineering distribution courses (9 credits) are required. One course must be an Introduction to Engineering Course (designated by ENGRI). The Introduction of Engineering course will introduce students to the engineering process and provide a substantive experience in an open-ended problem solving context. See the Introduction to Engineering Course listing for currently offered courses.

The other two distribution courses must be selected from two different categories listed below. A student may use any one of the possible substitutions described.

1) *Scientific computing*

   ENGRD 211, Computers and Programming
   ENGRD 212, Modes of Algorithmic Expression
   ENGRD 222, Introduction to Scientific Computing
   ENGRD 241, Engineering Computation

2) *Materials science*

   ENGRD 261, Introduction to Mechanical Properties of Materials
   ENGRD 262, Introduction to Electrical Properties of Materials

3) *Mechanics*

   ENGRD 202, Mechanics of Solids
   ENGRD 203, Dynamics

Students in the Field Program in Engineering Physics may substitute A&EP 333 for ENGRD 203.

4) *Probability and statistics*

   ENGRD 270, Basic Engineering Probability and Statistics

Students in the Field Program in Electrical Engineering may substitute ELE E 310 for ENGRD 270. Students in the Field Program in Engineering Physics may substitute ELE E 310 or Mathematics 471 for ENGRD 270. Students in the Field Programs in Civil Engineering and Agricultural and Biological Engineering may substitute CEE 304 for ENGRD 270.

5) *Electrical sciences*

   ENGRD 210, Introduction to Electrical Systems
   ENGRD 230, Introduction to Digital Systems
   ENGRD 264, Computerized-Instrumentation Design

6) *Thermodynamics and energy balances*

   ENGRD 219, Mass and Energy Balances
   ENGRD 221, Thermodynamics

7) *Earth and life sciences*

   ENGRD 201, Introduction to the Physics and Chemistry of the Earth

8) *Biology and chemistry*

   BIO S 101 and 103, Biological Sciences, Lecture and Laboratory

   BIO S 105, Introductory Biology

   BIO S 107, General Biology (summer only)

   CHEM 389, Physical Chemistry I

Some fields require a specific engineering distribution course as a prerequisite for the upperclass course sequence. These requirements are:

Chemical Engineering: ENGRD 219

Civil Engineering: ENGRD 202, and ENGRD 219 (for environmental option)

Computer Science: ENGRD 211 or ENGRD 212

Electrical Engineering: ENGRD 230

Materials Science and Engineering: ENGRD 261 or 262

Mechanical Engineering: ENGRD 202

Operations Research and Engineering: ENGRD 270

Liberal Studies Distribution

The six required liberal studies courses (totaling at least 18 credits) may be chosen from approved courses in four categories: (a) humanities or history, (b) social sciences, (c) foreign languages, and (d) expressive arts.

At least two courses must be chosen from category (a). No more than 3 credits toward this requirement may be taken in category (d). At least two courses in categories (a) or (b) must be from the same field of study. One of these courses must be at or above the 200-level or be an explicit prerequisite of the other.

No freshman seminar may be used to meet the liberal studies requirement.

Following each category is a list of approved courses. Every effort has been made to keep the lists up to date, but errors sometimes occur. Students who wish to use a course that seems to fit the category description but is not listed should contact the Engineering Advising office.

a) Humanities or History

Architecture 181, 182

Art 317, 318

Africana Studies 202, 204, 205, 211, 219, 280, 285, 344, 350, 360, 361, 370, 381, 405, 422, 425, 431, 432, 455, 460, 471, 475, 482, 483, 490

Anthropology 290, 355, 356, 420

Archeology (courses in Old World Archeology and 493)

Asian Studies (courses in Asian art, literature, religion or cultural history)

Classics (all courses except 285, 356, 360, 361 and language courses)

Collective Bargaining, Labor Law and Labor History 100, 101, 303, 304, 305, 381, 384, 385, 386, 406, 482

Comparative Literature (all courses)

Economics 315, 323, 324, 325, 326

Engineering 250, 292

English (all courses except ENGL 285 and writing courses, whose numbers end in the 80s; e.g., 288, 289, 382, etc.

French Literature (all courses)

German Literature (all courses)

History (all courses)

History of Art (all courses)

International and Comparative Labor Relations 430

Italian Literature (all courses)

Jewish Studies 274, 351, 352

Labor Economics 448

Music (only introductory, music theory, and music history courses)

Natural Resources 407

Near Eastern Studies (courses listed under history, civilization, or literature)

Philosophy (all courses except courses in logic)

Religious Studies 101

Russian Literature (all courses)

Spanish Literature (all courses)

Theater Arts (only courses in Theater Studies, film analysis and history)

Women's Studies 227, 238, 273, 307, 336, 357, 426

b) Social Sciences

Africana Studies 171, 172, 190, 191, 231, 280, 290, 301, 302, 344, 345, 346, 352, 382, 400, 410, 420, 451, 460, 481, 484, 485, 495

Agricultural Economics 100, 252, 332, 430, 431, 450, 464, 492

Anthropology (all courses except 101 and courses in Biological and Ecological Anthropology)

Archeology (all courses except those in Methodology and Technology)

Architecture 342

City and Regional Planning 100, 101, 218, 261, 314, 382, 404

Collective Bargaining, Labor Law and Labor History 384

Communication 116, 120, 314, 416

Consumer Economics and Housing (110, 111, 247, and any course having one or more of these as a prerequisite)

Design and Environmental Analysis 150, 250

Economics (all courses except 105, 315, 317, 318, 319, 320, 326. Engineering students should generally take Economics 203–204 and *not* 101–102, unless they have had no calculus.)

Education 210, 211, 212, 271, 310, 311, 317, 321, 322, 360, 378, 477

Engineering 360

Government (all courses)

Human Development and Family Studies (all courses)

Human Service Studies (all courses)

International and Comparative Labor Relations (all courses)

Labor Economics (all courses)

Linquistics (all courses)

Natural Resources 201

Organizational Behavior (all courses)

Psychology (all courses *except* 123, 307, 322, 324, 326, 332, 350, 361, 396, 422, 425, 426, 429, 465, 470, 471, 472, 473, 475, 476, 478, 479, 492)

Rural Sociology (all courses)

Sociology (all courses)

Textiles and Apparel 245

Women's Studies 210, 218, 220, 238, 244, 277, 281, 297, 305, 321, 353, 362, 365, 366, 372, 406, 408, 425, 428, 438, 450, 454, 463, 468, 479, 480, 493

c) Foreign Language

This category includes all foreign language courses; if two or more foreign language courses are used to fulfill part of the liberal studies requirement, then they must be a sequence of courses in the same language. The rules for placement and advanced placement credit in languages are those of the College of Arts and Sciences. Speakers of languages other than English may obtain up to 6 advanced placement credits according to these rules.

d) Expressive Arts

Africana Studies 303, 425, 430

Art (studio courses)

Biological Sciences 208, 209

Communications (all courses)

Design and Environmental Analysis 101, 102, 114

Engineering (all Engineering Communications courses, which are designated ENGRC)

English (expository and creative writing courses, whose numbers end in the 80's, e.g., 288, 289, 382, etc.)

Floriculture (courses in Freehand Drawing and Scientific Illustration)

Industrial and Labor Relations 452

Music (courses in musical performance and musical organizations and ensembles)

Theater Arts (all courses except those listed in category (a) above)

Electives

Six credits of approved electives are required. Approved electives can help develop the skills of a broadly educated engineer, so students should give serious thought to their educational objectives and not propose approved-elective courses haphazardly. Advisers generally accept as approved electives: one introduction to engineering course, engineering distribution courses, courses stressing oral or written communication, upper-level engineering courses, advanced courses in mathematics, and rigorous courses in the biological and physical sciences. Courses in business, economics, and language are often approved by advisers when they serve a student's educational and academic objectives. In other cases, the student's interests are better served by approved electives that expand the field program or other parts of the curriculum, including the humanities and social sciences requirement.*

In addition, nine credits of electives are determined by field approval. These electives are designated by the field program faculty and the field program faculty advisers. These electives are a part of a coordinated field curriculum, and students should refer to the Field Program curricula for descriptions of the field approved electives.

To ensure breadth of engineering studies, field programs also will include nine hours of courses outside the major.

Students are encouraged to take as many courses offered at the university in addition to the minimum engineering curriculum requirement as they wish.

*No ROTC courses may be used as approved electives unless they are co-listed by an academic department.

Social Issues of Technology

It is important for engineers to realize the social and ethical implications of their work. Consequently, in selecting their humanities, social sciences, approved electives, and free electives, students are urged to consider courses listed within the "Science, Technology, and Society" undergraduate area of concentration (see Interdisciplinary Centers and Programs section). These courses may provide students with an important perspective on their studies and their future careers.

Engineering Advising Office

From the time that students enter the college as freshmen until they apply for a affiliation with a major field or the College Program during the fall term of the sophomore year, they are under the administration of the Engineering Advising office, which implements the academic policies of the College Curriculum Governing Board. The office also offers general advising and counseling services, publishes a college newsletter, and serves as the primary resource center for undergraduate students in the college. The Engineering Minority Programs office and the Women's Programs in Engineering office provide additional specialized services.

Freshman Year

At the end of the freshman year, students are expected to have completed or received credit for at least eight courses, including Math 191, Math 192, Chemistry 211 or 207, Physics 112, COM S 100, two terms of Freshman Writing Seminars, and an Introduction to Engineering course. In addition, students need to complete two terms of physical education during their first year. *Many variations in the freshman schedule are possible*, depending on the individual student's background, advanced placement credit, and career goals. Those receiving advanced placement for first term calculus may take Physics 112 in term one. Students with an interest in bioengineering may take biology in terms one and two as approved electives. Students preparing to study medicine should take one year of biology and Chemistry 207 and 208 in the first year.

Affiliation with a Field Program

Students must apply for affiliation with a field program during the first term of their sophomore year. This is done by going to the undergraduate field consultant's office in the field of their choice and completing the "Application for Field Affiliation" form. To affiliate with a field program, students must (1) have a 2.0 cumulative grade point average and (2) have satisfied the field's course and grade requirements as specified below:

Field Program	*Courses and Minimum Grade Requirements*
Agricultural and Biological Engineering	No more than one grade below C in mathematics and science courses and ABEN 151 or equivalent
Applied and Engineering Physics	2.7 GPA in all mathematics and physics courses
Chemical Engineering	No more than one grade below C- in chemistry, mathematics, physics, or chemical engineering courses and a 2.2 GPA in mathematics, science, and chemical engineering courses
Civil & Environmental Engineering	A grade of C- in ENGRD 202 and a 2.0 GPA in all engineering and science courses
Computer Science	A grade of B- in COM S 280, ENGRD 211 or 212 and all mathematics courses
Electrical Engineering	A grade of C or better in all 200-level mathematics and physics courses
Geological Sciences	Passing grades in required field courses
Material Sciences & Engineering	A grade of C in ENGRD 261 or 262
Mechanical & Aerospace Engineering	A grade of C- in mathematics and science courses and ENGRD 202
Operations Research and Engineering	A grade of C- in Math 191 and 192

Students must be affiliated or conditionally affiliated by the end of their fourth semester or they will be withdrawn from the College of Engineering, unless allowed to participate in a terminal semester.

Special Programs

College Program

Individually arranged courses of study under the College Program are possible for those well-qualified students whose educational objectives cannot be met by one of the regular field programs. Often the desired curriculum is in an interdisciplinary area. Each program is developed by the student in consultation with faculty advisers and must be approved by the College Program Committee, which is responsible for supervising the student's work.

Students apply to enter the College Program by the end of the first term of the sophomore year. A student should seek assistance in developing a coherent program from professors in the proposed major and minor subject areas. If approved, the program is the curricular contract to which the student must adhere. Normally, students applying to the College Program should have a 3.0 cumulative grade point average.

Every curriculum in the College Program, with the exception of certain faculty-sponsored programs, must comprise an engineering major and an educationally related minor. The major may be in any subject area offered by schools or departments of the college; the minor may be in a second engineering subject area or in a logically connected nonengineering area. The combinations must clearly form an engineering education in scope and in substance and should include engineering design and synthesis as well as engineering sciences. In addition to 48 credits in the major and minor subjects, including at least 32 credits in engineering courses, each program includes the normally required courses in humanities and social sciences and approved electives.

Further information about the College Program may be obtained from the associate dean for undergraduate programs, 221 Carpenter Hall.

College Program in the Science of Earth Systems

A new curriculum in the Science of Earth Systems highlights study of the Earth as one of the outstanding intellectual challenges in modern science and as the necessary foundation for the future management of our home planet. The curriculum coalesces Cornell's strengths across a broad range of earth and environmental sciences to provide students with a rigorous scientific foundation for the study of our complex, highly interactive earth. Students in the College of Engineering can take this curriculum under the College Program. The curriculum includes a freshman/sophomore emphasis on strong preparation in mathematics, physics, chemistry, and biology. In the junior and senior years, students take a set of four core common courses and an additional set of advanced disciplinary or interdisciplinary courses that build on the basic sequences. The curriculum in Science of Earth Systems is outlined in more detail in the section, Interdisciplinary Centers, Programs, and Studies, in the front part of the catalog. Students interested in the new field should select ENGRI 122 and ENGRD 201 and contact Profs. B. Isacks, W. Brutsaert, Y. Parlange, or M. Kelley.

Bioengineering Option

Students who elect this option will graduate with a B.S. degree in one of the traditional fields and with an administrative note on their transcript formally recognizing their efforts in bioengineering.

The requirements for completion of the option are four courses (12 credit hours minimum) and one credit hour of Bioengineering Seminar (ENGRG 501). These courses can simultaneously satisfy other degree requirements and are not necessarily four additional courses. These four courses must be selected from two categories: science-based courses and bioengineering courses. At least one course must be from the science-based course list and at least two from the bioengineering course list. Each student interested in the bioengineering option can request through the Engineering Advising office a bioengineering adviser who would assist the student in course selection for this option. The bioengineering adviser is in addition to the student's regular academic adviser.

A list of approved courses is available in the Engineering Advising office, 167 Olin Hall.

International Programs

An international perspective, sensitivity to other cultures, and the ability to read and speak a second language are increasingly important to today's engineers. In keeping with the university goals of internationalizing the curriculum, the College of Engineering encourages students to study or work abroad during their undergraduate years. The college sponsors a specially designed Semester in Europe program, supports students who wish to study abroad in regular exchange programs, and offers a special International Scholars College program for students to minor in international studies and study abroad during their junior year. For further information on these and other opportunities to add an international dimension to your undergraduate education, see Professor Richard Lance, 322 Thurston Hall; telephone: 255-5064; e-mail: rhl1@cornell.edu. Information on co-op programs abroad is available from the Engineering Professional Programs office in 148 Olin Hall.

Dual Degree Option

A special academic option, intended for superior students, is the dual degree program, in which both a Bachelor of Science and a Bachelor of Arts degree can be earned in about five years. Students registered in the College of Engineering or the College of Arts and Sciences may apply and, after acceptance of their application, begin the dual program in their second or third year. Those interested should contact the coordinator of dual degree programs, 172 Goldwin Smith Hall; the associate dean for undergraduate programs in 221 Carpenter Hall; or an adviser in Engineering Advising, 167 Olin Hall.

Double Major in Engineering

The Double Major option, which makes it possible to develop expertise in two allied fields of engineering, generally requires at least one semester beyond the usual four years. Students affiliate with one field in the normal way and then petition to enter a second field before the end of their junior year. All the requirements of both fields must be satisfied. Further information is available from Engineering Advising, 167 Olin Hall, and the individual field consultant offices.

Engineering Communications Program

The ability to communicate effectively is an essential aspect of successful professional practice. The Engineering Communications Program offers instruction in written, oral, and visual presentation. Engineering Communications (ENGRC 350) and Communications for Engineering Managers (ENGRC 435) are three-credit seminar courses designed for students who desire intensive work in these areas. Examples from real-life engineering contexts are analyzed, and many specific assignments are presented as professional case studies. Students learn to address audiences having different levels of technical expertise and to investigate the social and ethical implications of written and oral communication. These courses fulfill the college's technical writing requirement (see Requirements for Graduation). The program also offers courses on topics of special interest and independent studies or projects in technical/professional communications. In addition to offering free-standing communications courses, the program works with engineering fields to integrate communications into technical courses. The program's faculty also advises student publications, facilitates writing and oral presentation competitions, and arranges discussions of professional communications with students and alumni. For further information, contact the director, 205 Carpenter Hall.

Engineering Cooperative Program

A special program for undergraduates in most fields of engineering is the Engineering Cooperative Program, which provides an opportunity for students to gain practical experience in industry and other engineering-related enterprises before they graduate. By supplementing course work with carefully monitored, paid jobs, co-op students are able to explore their own interests and acquire a better understanding of engineering as a profession.

Sophomores in the upper half of their class are eligible to apply for the co-op program. (Students in computer science and agricultural and biological engineering are eligible, even though they may not be registered in the College of Engineering.) Applicants are interviewed by representatives of cooperating companies and select their work assignments from any offers they receive. Those students who are offered assignments and elect to join the program usually take their fifth-term courses at Cornell during the summer following their sophomore year and begin their first co-op work assignment that fall. They return to Cornell to complete term six with their classmates and then undertake a second work assignment with the same company the following summer. Co-op students return to campus for their senior year and graduate with their class.

Further information may be obtained from the Engineering Professional Programs office, 148 Olin Hall.

MASTER OF ENGINEERING DEGREE PROGRAMS

One-year Master of Engineering (M.Eng.) programs are offered in thirteen fields. These programs are discussed in this announcement in connection with the corresponding upperclass engineering field programs because the curricula are integrated. Cornell baccalaureate engineering graduates frequently continue their studies in the M.Eng. program, although the program is also open to qualified graduates of other schools. The M.Eng. degrees and the academic fields under which they are described are listed below.

M.Eng. (Aerospace): Mechanical and aerospace engineering

M.Eng. (Agricultural and Biological): Agricultural and biological engineering

M.Eng. (Chemical): Chemical engineering

M.Eng. (Civil & Environmental): Civil and environmental engineering

M.Eng. (Computer Science): Computer science

M.Eng. (Electrical): Electrical engineering

M.Eng. (Engineering Physics): Applied and engineering physics

M.Eng. (Geology): Geological sciences

M.Eng. (Materials): Materials science and engineering

M.Eng. (Mechanical): Mechanical and aerospace engineering

M.Eng. (Engineering Mechanics): Theoretical and Applied Mechanics

M.Eng. (Nuclear): Nuclear science and engineering

M.Eng. (OR&IE): Operations research and industrial engineering

Candidates for a professional master's degree who wish to specialize in areas related to manufacturing may avail themselves of two special programs. The manufacturing systems engineering option may be centered in any one of the fields listed above. This option is attested to by a Dean's Certificate in addition to a diploma at the time of graduation. An industrial internship program provides opportunities to combine on-campus education with off-campus industrial experience.

An M.Eng. option of potential interest to engineers from all fields is the program in engineering management, offered by the School of Civil and Environmental Engineering. This option is described in the section related to the M.Eng. (Civil & Environmental) degree. A new management option in the M.Eng. (Chemical) degree program is also available.

Cornell engineering graduates in the upper half of their class will generally be admitted to M.Eng. programs; however, requirements for admission vary by field. Superior Cornell applicants who will be, at the time of matriculation, eight or fewer credits short of a baccalaureate degree may petition for early admission. Other applicants must have a baccalaureate degree or its equivalent from a college or university of recognized standing, in an area of engineering or science that is judged appropriate for the proposed field of study. They must also present evidence of undergraduate preparation equivalent to that provided by a Cornell undergraduate engineering education, a transcript, two letters of recommendation, and a statement of academic purpose. A candidate who is admitted with an undergraduate background that is judged inadequate must make up any deficiencies in addition to fulfilling the regular course requirements for the degree. Applicants from foreign universities must submit the results of the Graduate Record Examination aptitude tests and must have an adequate command of the English language. Financial aid providing partial support is available for very highly qualified candidates, primarily those who are residents of the U.S. Industry-sponsored internships, which extend the program to two years, are also available to residents of the United States. Application forms and further information are available from the graduate field offices.

Cooperative Programs with the Johnson Graduate School of Management

Two programs culminate in both Master of Engineering and Master of Business Administration degrees. One, which Cornell students enter during their undergraduate career, makes it possible to earn the B.S., M.Eng., and M.B.A. in six years—one year less than such a program would normally require. The second program, which is available to students who already hold baccalaureate degrees from Cornell or other institutions, requires five semesters and leads to both the M.Eng. and M.B.A.

Undergraduate students at Cornell interested in the six-year program should seek advice and information from the department with whose field they intend to affiliate during their upperclass years. Information about admission to either program and about special scholarship aid may be obtained from the Engineering Professional Programs office, 148 Olin Hall.

ACADEMIC PROCEDURES AND POLICIES

Advanced Placement Credit

The College of Engineering awards a significant amount of advanced placement (AP) credit to entering freshmen who demonstrate proficiency in the subject areas of introductory courses. Students may qualify for AP credit in one of two ways:

1) by receiving sufficiently high scores on advanced placement examinations given and scored by the College Entrance Examination Board (CEEB); or

2) by receiving sufficiently high scores on Cornell's departmental placement examinations, which are given during orientation week before fall-term classes begin. Advanced placement is granted only to first-term freshmen, and the placement examinations are scored before the students begin classes.

Advanced placement credit is intended to permit students to develop more challenging and stimulating programs of study. Students who receive AP credit for an introductory course may use it in three different ways.

1) They may enroll in a more advanced course in the same subject right away.

2) They may substitute an elective course from a different area.

3) They may enroll in fewer courses, using the AP credit to fulfill basic requirements.

Acceptable Subjects and Scores

The most common subjects for which AP credit is awarded in the College of Engineering, and the scores needed on qualifying tests, are listed below. In mathematics, physics, chemistry, and computer science, AP credit is awarded only for courses required in the engineering curriculum.

Mathematics: Math 191, 192, 293, and 294 are required.

First-term math (Math 191). AP credit may be earned by:

- a score of 3 or 4 on the CEEB BC exam, or
- a score of 4 or 5 on the CEEB AB exam, or
- a passing score on the Cornell departmental exam for first-term math.

First-year math (through Math 192). AP credit may be earned by:

- a score of 5 on the CEEB BC exam, or
- a passing score on the Cornell departmental exam for first-year math.

Physics: Physics 112 or 116 and 213 or 217 are required.

Physics 112. AP credit many be earned by:

- a score of 4 or 5 on the mechanics portion of the CEEB exam, or
- a score of 5 on the CEEB B exam *only* if the student has at least one semester of AP or transfer credit in first-term mathematics at the time of matriculation, or
- a passing score on the Cornell departmental exam for Physics 112.

Note: Students who have received credit for Physics 112 **may not** enroll in Physics 213 unless concurrently enrolled in Math 293.

Physics 213. Students, receiving a 5 on the Electricity and Magnetism portion of the C exam may choose to accept AP credit for Physics 213 or placement in Physics 217 with no AP credit for Physics 213. For advice or more information contact Professor Rich Galik, the departmental representative. His telephone number is 607/255-3633.

Chemistry: Chem 207 or Chem 211 is required.

Chem 207 or Chem 211. AP credits may be earned by:

- a score of 5 on the CEEB AP exam, or
- a passing score on the Cornell departmental exam for Chemistry.

Note: Students who are successful in obtaining AP credit for Chem 207 and who are considering majors in chemical engineering or materials science and engineering should consider enrolling in Chem 215. Those who are offered AP credit for Chem 207 and then elect to take Chem 215 will also receive academic credit for Chem 207. You may want to discuss this option with your faculty adviser.

Computing: Computer Science 100 is required. AP credit may be earned by:

- a score of 4 or 5 on the CEEB A or AB exam, or
- a passing score on the Cornell departmental exam for Computer Science 100.

Biology: Biology is not required of engineering students, although it is a popular option as an elective, especially for students who intend to pursue health-related careers. AP credit may be earned as follows:

- eight credits will be offered to students who receive a 5 on the CEEB AP exam;
- students receiving a 4 on the CEEB AP exam will be offered six credits.

Those who want to study more biology should contact the Office for Academic Affairs, Division of Biological Sciences, 200 Stimson Hall, to discuss proper placement.

Freshman Writing Seminar: Two Freshman Writing Seminars (for a total of six credits) are required.

- AP credit for one Freshman Writing Seminar may be earned by a score of 5 on the CEEB AP English exam.

A score of 4 on the AP English exam will earn a student three credits in English. These three credits cannot be applied toward the Freshman Writing Seminar requirement, but can be applied toward the expressive arts category in the Liberal Studies Distribution requirement. AP credit earned in the humanities and social sciences cannot be used to fulfill the "upper level" liberal studies requirement.

Liberal Studies Distribution: Six courses beyond two Freshman Writing Seminars are required. Students may earn AP credit toward the liberal studies distribution by taking College Entrance Examination Board (CEEB) AP tests. AP credit earned in the humanities or social sciences cannot be used to fulfill the "upper level" liberal studies requirements.

Modern Languages: Students may earn AP credit for competence in a foreign language by taking the College Entrance Examination Board (CEEB) AP test or by taking the Cornell Advanced Standing Examination (CASE). Those who score 4 or 5 on the CEEB AP test are entitled to three credits. In order to qualify for the CASE exam, the student must score at least 650 on a College Placement Test (taken either in high school or at Cornell during Orientation Week). A score of 2 on the CASE entitles the student to three credits, and a score of 3 entitles the students to six credits. Modern language AP credits may be used to satisfy the foreign language category of the liberal studies distribution, or may meet an approved elective requirement, contingent on discussions with the faculty adviser.

General Policies for AP Credit

The general policies in the College of Engineering governing awards of AP credit are as follows:

1. AP credit will not be offered in any subject area without a documented examination (CEEB or departmental).
2. All AP examinations (both CEEB and departmental) are normally taken and scored before fall-term classes begin. Students who take CEEB AP tests in high school should have an official report of their scores sent directly to Cornell as soon as possible. Those who wish to take departmental examinations must do so during Orientation Week; permission to take these tests after the start of fall-term classes must be requested in a written petition to the College's Committee on Academic Standards, Petitions, and Credit (ASPAC), and must be filed within the first three weeks of the fall semester.
3. Except when permission for late testing has been granted, students offered AP credit must accept or decline within the first three weeks of the first term at Cornell in the Engineering Registrar's office, 170 Olin Hall. Final AP awards are recorded on the last day of the third week.

A more detailed description of the college's policies concerning advanced placement credit and its use in developing undergraduate programs may be found in the pamphlet *Advanced Placement and Transfer Credit for First-Year Engineering Students*, which may be obtained from Engineering Advising, 167 Olin Hall.

Transfer Credit

Entering freshmen and transfer students who have completed courses at recognized and accredited colleges may, under certain conditions, have credits for such courses transferred to Cornell. Such courses must represent academic work in excess of that required for the secondary school diploma. Courses deemed acceptable for transfer credit must be equivalent in scope and rigor to courses at Cornell.

Transfer credit must be applied for by petition, and the application must be accompanied by a course description. Transfer Credit forms are available from the Engineering Advising office or Registrar. An official transcript (bearing the institutional seal and registrar's signature) must be sent to the Engineering Registrar's office before official transfer credit will be awarded.

To apply for transfer credit to satisfy requirements in mathematics, science, and engineering courses, and the Freshman Writing Seminar, a student must receive approval from the department offering an equivalent course at Cornell. The department certifying the course may require course materials, textbooks used, etc., in addition to the course description before approving the course.

To apply for transfer credit to satisfy liberal studies distribution or elective requirements, departmental approval is not required. The course will be reviewed for approval by a representative of the Committee on Academic Standards, Petitions, and Credit (ASPAC) in the Engineering Advising office.

Cornell does not award credit for courses in which a student earned a grade less than C; schools and departments may stipulate a higher minimum grade.

College courses completed under the auspices of cooperative college and high school programs will be considered for advanced placement credit only if students demonstrate academic proficiency by taking the appropriate CEEB or Cornell departmental placement examination, as described in the Advanced Credit section.

After matriculation no more than 18 credits of transfer or Cornell extramural credit may be used to satisfy bachelor's degree requirements. Summer session courses taken at Cornell are not considered transfer credits.

Transfer students may transfer up to 36 credits for each year spent in full-time study at another institution, provided that the courses are acceptable for meeting graduation requirements. No more than 72 transfer credits may be used to meet graduation requirements.

A more detailed description of the college's regulations governing transfer credit may be found in the pamphlet, *Advanced Placement and Transfer Credit for First-Year Engineering Students*, available from Engineering Advising, 167 Olin Hall.

Academic Standing

Full-time students are expected to remain in good academic standing. The criteria for good standing change somewhat as a student progresses through the four years of the engineering curriculum. At all times, the student must be making adequate progress toward a degree, but what this actually means varies from field to field.

Requirements for freshman engineering students to be in good standing at the end of the first semester are as follows. Failure to meet these standards will result in a review by the Committee on Academic Standards, Petitions, and Credit (ASPAC), and the actions of warning, stern warning, required leave of absence, or withdrawal from the College of Engineering may be taken.

1. at least 12 credits passed, including at least two courses from mathematics, science, and/or engineering;
2. a C- or better in the mathematics course;
3. a semester average of 2.0 or higher.

Requirements for second-semester freshman and first-semester sophomores to be in good standing are as follows. Failure to meet these standards will result in a review by the Committee on Academic Standards, Petitions, and Credit (ASPAC), and the actions of warning, stern warning, required leave of absence, or withdrawal from the College of Engineering may be taken.

1. at least 14 credits passed in courses that meet engineering degree requirements;
2. a C- or better in the mathematics course, if one was taken;
3. a semester average of 2.0 or higher.

Academic Progress

The total number of credits required for graduation range from 123 to 129, depending upon the field program. Therefore, an average semester credit load ranges from approximately 15 to 16 credits.

Because mathematics is pivotal to the study and practice of engineering, students must earn a grade of C- or better in Math 191, 192, 293, and 294. Those who fail to meet this standard are allowed to repeat a course once, in the following semester. Failure to achieve at least a C- the second time will generally result in dismissal from the engineering program. Physics and advanced mathematics courses often have mathematics prerequisites, and having to repeat the prerequisite course may delay your progress in the physics and mathematics curricula.

Dean's List

Dean's List citations are presented each semester to engineering students with exemplary academic records. The criteria for this honor, which are determined by the dean of the college, are a term average of 3.25 or higher with no failing, unsatisfactory, or *incomplete* grades (even in physical education) and 12 credits or more of **letter grades**. Students may earn Dean's List status retroactively if they meet these criteria after making up incompletes according to college rules.

S-U Grades

The option of receiving a grade of "satisfactory" or "unsatisfactory" (S-U) in a particular course, rather than a grade on a graduated scale, may be selected only in the following circumstances: Students who want to take a course on an S-U basis must have completed at least one full semester of study at Cornell, and they may take only one course per semester on an S-U basis. Only courses in the liberal studies and approved electives categories may be taken as S-U courses. Students may preregister for the S-U option. To change a grading option, a properly completed and approved add/drop form must be filed with the registrar of the College of Engineering by the end of the first three weeks of the semester. After this deadline, the grading option *may not be changed under any circumstances,* even by petition, and no courses may be added with the S-U option selected.

The S-U policy does not apply to courses in physical education and other courses that are not taken to fulfill degree requirements. When a particular course is offered **only** on an S-U basis, a student may petition to take a second S-U course in the same term.

Residence Requirements

Candidates for an undergraduate degree in engineering must spend at least four semesters or an equivalent period of instruction as full-time students at Cornell. They must also spend at least three semesters of this time affiliated with an engineering field program or with the College Program.

Students who are voluntarily not enrolled at Cornell as full-time students may take individual courses extramurally through the School of Continuing Education and Summer Sessions. Students who have been required to take time off are permitted to register for courses extramurally only with the approval of their field (or the college, for unaffiliated students). No more than 18 credits earned through extramural study or acquired as transfer credit (or a combination thereof) may be used to satisfy the requirements for the bachelor's degree in engineering.

Degree candidates may spend periods of time studying away from the Cornell campus with appropriate authorization. Information on programs sponsored by other universities and on procedures for direct enrollment in foreign universities is available at the Cornell Abroad office, 474 Uris Hall. Programs should be planned in consultation with Professor Richard Lance, 322 Thurston Hall, or with the staff of Engineering Advising, who can provide information on credit-evaluation policies and assist in the petitioning process.

Transferring within Cornell

It is not uncommon for students to change their academic or career goals after matriculation in one college and decide that their needs would be better met in another college at Cornell. While transfer between colleges is not guaranteed, efforts are made to assist students in this situation.

The office responsible for assisting students with the transfer process is the Internal Transfer Division office. Students who wish to transfer out of the College of Engineering to another college at Cornell should consult initially with the Engineering Advising office.

Students who wish to transfer into the College of Engineering can make application to the Office of Engineering Admissions—application forms are available in the Carpenter Hall Annex. Students who would enter the college as second-semester sophomores or upperclassmen must be accepted by a field program as part of the admission process. Others may be accepted into the college without the requirement of field affiliation.

Students who hope to transfer into engineering should take courses in mathematics, chemistry, computer science, and physics that conform to the requirements of the Common Curriculum. Interested students should discuss their eligibility with an adviser in Engineering Advising, 167 Olin Hall.

Leave of Absence

A leave of absence may be voluntary, medical, or required. Following is a description of each:

Voluntary Leave: Students sometimes find it necessary to suspend their studies. To do this, students must petition for a leave of absence for a specified period of time and receive written approval.

Affiliated students request leave through their fields. Unaffiliated students request leave through Engineering Advising; the first step is an interview to establish conditions for the leave and subsequent return. Those who take a leave before affiliating with a field and while not in good standing may be given a "conditional leave." This requires them to meet specific conditions, established at the time the leave is granted, before they will be reinstated.

Leaves of absence are not generally granted for more than two years. A leave of absence or withdrawal granted during a semester goes into effect on the day it is requested and lasts for a *minimum of six months*. Leaves requested after the twelfth week of a semester generally take effect at the end of the semester, and all courses in which the student was registered at the time of the request are treated as having been dropped. Students who owe money to the university are ineligible for leaves of absence. If courses taken during a leave are to satisfy Cornell degree requirements, they must be approved *in advance* through a formal transfer petition. No more than 18 credits earned while on leave can be used to meet degree requirements.

Students who intend to take a leave of absence should check with the Office of Financial Aid and Student Employment to find out about financial implications; this is especially true for those who have take out educational loans. Medical insurance eligibility may also be affected.

To return after a leave of absence, the conditions established when the leave was granted must be satisfied, and the college must be notified.

Students wishing to rejoin the college who have not yet affiliated with a field should request permission to rejoin in a letter to Engineering Advising; affiliated students should contact their field office. This must be done at least six weeks before the beginning of the semester in which the student wishes to return. The letter should describe the student's activities while away from Cornell, detail any academic work completed during this time, and specify the courses the student intends to take upon return.

Medical Leave: Medical leaves are granted by the college only upon recommendation by a physician from Gannett Health Center. Such leaves are granted for at least six months and up to five years with the understanding that the student may return at the beginning of any term after the medical condition in question has been corrected. In some cases students must satisfy the Gannett Health Center that the condition has been corrected before they may return. The student's academic standing will also be subject to review at the time of the leave and on return.

Required Leave: A required leave of absence is imposed in cases where the academic progress of a student is so poor that simply continuing into the next semester does not appear prudent. An example where a leave of absence would be required might be failure in several courses in a semester. Unless the student is ahead in the curriculum, returning later to repeat the semester makes better academic sense than continuing without the necessary background. In many cases, the leave is dictated by courses that are only offered in the fall or the spring semester. Leaves are given when the probability of success is increased substantially by deferring the student's return by one semester (or, in unusual circumstances, one year).

Withdrawal from the College

A withdrawal from the College of Engineering may be voluntary or required. Following is a description of each:

Voluntary Withdrawal: Students who voluntarily withdraw from the engineering degree program sever all connection with the college. Unaffiliated students who wish to withdraw should do so through Engineering Advising. Affiliated students should contact their field office. If a withdrawal is requested during the semester, courses in which the student is enrolled must be dropped in accordance with applicable regulations.

Any student who fails to register in the first three weeks of the semester, without benefit of a leave of absence or permission for study in absentia, will be deemed to have withdrawn.

Students who withdraw from the College of Engineering are eligible to apply for admission to one of the other six colleges at Cornell. The intra-university transfer process should be followed.

If students who have withdrawn subsequently wish to return, they must make a formal application for readmission. This is rarely granted. It is subject to a review of the student's academic background and depends on available space in the college and in the student's major field.

Required Withdrawal: Students are withdrawn from the college only when their overall record indicates that they are either incapable of completing the program or not sufficiently motivated to do so. This action only withdraws them from the College of Engineering and does not, in and of itself, adversely affect their ability to transfer and complete a degree in one of the other colleges in the university.

ENGINEERING CAREER SERVICES

Individual advising and group seminars are available for students who desire assistance in career and job-search matters. Interviews are arranged between students and more than 250 national companies that visit the campus to recruit technical graduates. A state-of-the-art résumé referral service is offered for a small fee. Both undergraduate and graduate students can use these services to pursue permanent or summer employment opportunities. Further information on all services is available from the Engineering Career Services office, 201 Carpenter Hall (255-5103).

AGRICULTURAL AND BIOLOGICAL ENGINEERING

M. F. Walter, chair; L. D. Albright, D. J. Aneshansley, J. A. Bartsch, S. G. Capps, J. R. Cooke, A. K. Datta, R. C. Derksen, R. B. Furry, K. G. Gebremedhin, D. A. Haith, J. B. Hunter, L. H. Irwin, W. J. Jewell, D. C. Ludington, J.-Y. Parlange, R. E. Pitt, G. E. Rehkugler, N. R. Scott, T. S. Steenhuis, M. B. Timmons, L. P. Walker

Bachelor of Science Curriculum

The Field Program in Agricultural and Biological Engineering prepares students for engineering practice in biological and physical systems represented in agriculture and its supporting industries and agencies, environmental or resource protection agencies, the biotechnological industries, the health industries, international engineering, and the food industries. Engineering is applied to production, handling, storage, processing, distribution, and use of plant and animal products and biomass. Issues of environmental quality and safety and preservation of soil, water, and energy resources are important. Emerging areas of study include engineering aspects of biotechnology and animal and human health. Biological sciences are integrated into the field program along with engineering design and studies in the physical sciences. Areas of concentration include agricultural engineering, biological engineering, and environmental systems engineering.

The program is jointly administered by the College of Engineering and the College of Agriculture and Life Sciences. Students are enrolled only in the College of Agriculture and Life Sciences during their first four semesters and jointly in the College of Engineering in the remaining semesters. Engineering college tuition is required for one year and is typically paid during the fifth and sixth semesters of study. Additional information about the program may be found in the section on the College of Agriculture and Life Sciences in this publication.

Graduates find employment in agricultural and food processing industries, environmentally related firms and government agencies, and the biotechnology and health industries. Many graduates pursue a professional (Master of Engineering) or research (Master of Science or doctoral) degree. Agricultural and biological engineers are employed in private industry, consulting firms, government agencies, utility companies, and educational institutions. The unique blend of engineering and the biological sciences and the breadth of education of the agricultural and biological engineer has been attractive to employers.

For further details see the department's undergraduate programs publication, available at 207 Riley-Robb Hall, or contact the field's coordinator of instruction Professor Kifle Gebremedhin at 255–2499.

The field program requirements are outlined below.

Basic Subjects	*Credits*
Math 191, 192, 293, 294, Calculus for Engineers and Engineering Mathematics	16
Chem 211, General Chemistry, or equivalent	4
Phys 112, 213, 214, Physics I, II, and III (organic chemistry or biochemistry may be substituted for Physics 214)	12
Introductory biological sciences	6 or 8
ABEN 151, Introduction to Computer Programming	4
ABEN 200, Undergraduate Seminar	1
Engineering distribution (two courses, including Mechanics of Solids)	6
Liberal studies (two freshman seminars and at least two courses in humanities or history)	24
Advanced and Applied Subjects	
Engineering sciences in any field (must include fluid mechanics and thermodynamics), plus ABEN 250, 350, 396 and 496 (Engineering Applications in Biological Systems, Transport Principles, Fundamental of Design, and Capstone Design Project, respectively) and a minimum of three agricultural and biological engineering courses (at least 9 credits) chosen from courses numbered 450 to 495	35
Biological or agricultural sciences (at least 3 credits of biological sciences beyond the introductory level)	9
Approved electives (at least 3 credits in the College of Agriculture and Life Sciences)	6
Total (minimum)	123

Master of Engineering (Agricultural and Biological) Degree Program

The program for the M.Eng.(Agricultural and Biological) degree is intended primarily for those students who plan to enter engineering practice. The curriculum is planned as an extension of an undergraduate program in agricultural and biological engineering but can accommodate graduates of other engineering disciplines. The curriculum consists of 30 credits of courses intended to strengthen the students' fundamental knowledge of engineering and develop their design skills. At least three of the required 30 credits are earned for an engineering design project that culminates in a written and oral report.

A candidate for the M.Eng.(Agricultural and Biological) degree may choose to concentrate in one of the subareas of agricultural and biological engineering or take a broad program without specialization. The subareas include aquaculture, agricultural engineering, biological engineering, energy, environmental engineering, food engineering, structures and their environments, waste management, and highway engineering. Elective courses are chosen from among engineering subject areas relevant to the student's interests and design project. Courses in technical communication, mathematics, biology, and the physical sciences may also be taken as part of a coherent program. Master of Engineering students in agricultural and biological engineering can qualify for the Dean's Certificate in energy, manufacturing, or bioengineering by choosing their design project and some electives from the designated topic areas. More information is available from the ABEN Student Services office, 207 Riley Robb Hall (255-2173), or the Master of Engineering (ABEN) faculty representative, Professor Jean B. Hunter, at 255-2297.

APPLIED AND ENGINEERING PHYSICS

R. A. Buhrman, director; M. S. Isaacson, associate director; B. W. Batterman, J. D. Brock, T. A. Cool, H. G. Craighead, H. H. Fleischmann, A. L. Gaeta, B. R. Kusse, R. V. E. Lovelace, T. N. Rhodin (emeritus), J. Silcox, W. W. Webb, F. W. Wise; dual appointments: K. B. Cady, D. D. Clark, V. O. Kostroun, R. L. Liboff, R. N. Sudan, G. J. Wolga; adjunct faculty: D. H. Bilderback; senior research associate: E. J. Kirkland

Bachelor of Science Curriculum

The undergraduate engineering physics curriculum is designed for students who want to pursue careers of research or development in applied science or advanced technology and engineering. Its distinguishing feature is a focus on the physics and mathematics fundamentals, both experimental and theoretical, that are at the base of modern engineering and research and have a broad applicability in these areas. By choosing areas of concentration, the students may combine this physics base with a good background in a conventional area of engineering or applied science.

The industrial demand for graduates with baccalaureates is high, and many students go directly to industrial positions where they work in a variety of areas that either combine, or are in the realm of, various more conventional areas of engineering. Recent examples include bioengineering, computer technology, electronic-circuit and instrumentation design, energy conversion, environmental engineering, geological analysis, laser and optical technology, microwave technology, nuclear technology, software engineering, solid-state-device development, technical management, and financial consulting. A number of our graduates go on for advanced study in all areas of basic and applied physics, as well as in a diverse range of areas in advanced science and engineering. Examples include applied physics, astrophysics, atmospheric sciences, biophysics, cell biology, computer science and engineering, electrical engineering, environmental science, fluid mechanics, geotechnology, laser optics, materials science and engineering, mechanical engineering, medical physics, mathematics, medicine, nuclear engineering, oceanography, and physics. The undergraduate program can also serve as an excellent preparation for medical school, business school, or specialization in patent law.

The engineering physics program fosters this breadth of opportunity because it both stresses the fundamentals of science and engineering and gives the student direct exposure to the application of these fundamentals. Laboratory experimentation is emphasized, and ample opportunity for innovative design is provided. Examples are A&EP 110, The Laser and Its Applications in Science, Technology, and Medicine (a freshman Introduction to Engineering course); A&EP 264, Computer-Instrumentation Design (a recommended sophomore engineering distribution course); A&EP 330, Modern Experimental Optics (a junior/senior course); A&EP 363, Electronic Circuits (a sophomore/junior course); Physics 410, Advanced Experimental Physics; and A&EP 438, Computational Engineering Physics (a senior computer laboratory).

Undergraduates who plan to enter the Field Program in Engineering Physics are advised to arrange their Common Curriculum with their developing career goals in mind. Students are also encouraged to take Physics 112 or Physics 116 during their first semester (if their advanced placement credits permit) and are recommended to satisfy the computing applications or technical writing requirement with the engineering distribution course A&EP 264. Engineering physics students need to take only two engineering distribution courses, since A&EP 333, which they take in their junior year, counts as a third member of this category. Engineering Physics students are advised to take A&EP 363 in the spring semester of the sophomore year. Students with a year of advanced placement in math may wish to enroll in A&EP 321 and 322 in their sophomore year.

In addition to the requirements of the Engineering Common Curriculum,* the upperclass course requirements of the field program are as follows:

Course	*Credits*
A&EP 333, Mechanics of Particles and Solid Bodies	4
A&EP 355, Intermediate Electromagnetism	4
A&EP 356, Intermediate Electrodynamics	4
A&EP 361, Introductory Quantum Mechanics	4
A&EP 363, Electronic Circuits	4
A&EP 423, Statistical Thermodynamics	4
A&EP 434, Continuum Physics	4
Physics 410, Advanced Experimental Physics	4
A&EP 321, Mathematical Physics I; Mathematics 421; or T&AM 610 (applied mathematics)	4
A&EP 322, Mathematical Physics II; Mathematics 422; or T&AM 611 (applied mathematics)	4
Applications of quantum mechanics†	3 or 4
Four technical electives‡	12–16
A third approved elective (in addition to the two required by the Common Curriculum)	3

Total field credits=58 credit hours minimum.

*The Engineering Common Curriculum allows students to take only 4 courses each semester of their freshman year if they so desire. This course load is fully consistent with the requirements of the EP major, but entering students with strong preparation are encouraged to consider taking an additional course during one or both semesters of the freshman year so that they may have additional flexibility in developing a strong, individualized educational program in their latter years, and for best maintaining such options as a semester or year abroad, or early graduation.

†Some courses (though the list is not all-inclusive) that will satisfy this requirement are Physics 444, Nuclear and High-Energy Particle Physics; Physics 454, Introductory Solid-State Physics; A&EP 438, Computational Engineering Physics; A&EP 440, Quantum and Nonlinear Optics; A&EP 609, Low-Energy Nuclear Physics; ELE E 430, Lasers and Optical Electronics; and ELE E 531, Quantum Electronics I.

‡If a scientific computing course was not selected as an engineering distribution course, one of these technical electives may be needed to satisfy the computing applications requirement. For students going on to graduate school a third course in mathematics is recommended.

Areas of concentration. A distinctive aspect of the Engineering Physics curriculum is the strong opportunity it provides students to develop individualized programs of study to meet their particular educational and career goals. These can include the pursuit of dual majors or the development of a broad expertise in one or more of a number of advanced technical and scientific areas. With at least seven technical and approved electives in the sophomore, junior, and senior years, Engineering Physics majors are encouraged to work closely with their adviser to develop a coherent academic program that is in accordance with those goals. For those students who look toward an industrial position after graduation, these electives should be chosen to widen their background in a specific area of practical engineering. A different set of electives can be selected as preparation for medical, law, or business school. For students who plan on graduate studies, the electives provide an excellent opportunity to explore upper-level and graduate courses, and to prepare themselves particularly well for graduate study in any one of a number of fields. Various programs are described in a special brochure available from the School of Applied and Engineering Physics, Clark Hall. Students interested in these options are advised to consult with their EP adviser, a professor active in their area of interest, or with the associate director of the school, Professor Michael S. Isaacson.

Electives need not be all formal course work: Qualified students are encouraged to undertake informal study under the direction of a member of the faculty (A&EP 490). This may include research or design projects in areas in which faculty members are active.

The variety of course offerings and many electives provide a sizable flexibility in scheduling. If scheduling conflicts arise, the school may allow substitution of courses nearly equivalent to the listed required courses.

The Engineering Physics program requires that a minimum GPA of 2.7 (B-) be attained in all physics and mathematics courses taken by a student before entering the Engineering Physics field unless approval is obtained from the A&EP associate director. To remain in good standing in the field, the engineering physics student is expected to pass every course for which he or she is registered, to earn a grade of C- or better in specifically required courses, and to attain each semester a grade point for that semester of at least 2.3. In addition, students with a cumulative GPA of 3.5 or greater who elect to do an independent study project (A&EP 490) are eligible for a degree with honors."

Master of Engineering (Engineering Physics) Degree Program

The M.Eng.(Engineering Physics) degree may lead directly to employment in engineering design and development or may be a basis for further graduate work. Students have the opportunity to broaden and deepen their preparation in the general field of applied physics, or they may choose the more specific option of preparing for professional engineering work in a particular area such as laser and optical technology, microstructure science and technology, device physics, materials characterization, or software engineering. A wide latitude is allowed in the choice of the required design project.

One example of a specific area of study is solid-state physics and chemistry as applied to microstructure science and technology. Core courses in this specialty include the microcharacterization of materials (A&EP 661) and the microprocessing and microfabrication of materials (A&EP 662). The design project may focus on such areas as semiconductor materials, device physics, microstructure technology, or optoelectronics. Another area of study may be applied optics where core courses can be chosen from applied physics, electrical engineering, and physics.

Each individual program is planned by the student in consultation with the program chair. The objective is to provide a combination of a good general background in physics and introductory study in a specific field of applied physics. Candidates may enter with an undergraduate preparation in physics, engineering physics, or engineering. Those who have majored in physics usually seek advanced work with an emphasis on engineering; those who have majored in an engineering discipline generally seek to strengthen their physics base. Candidates coming from industry usually want instruction in both areas. All students granted the degree will have demonstrated competence in an appropriate core of basic physics; if this has not been accomplished at the undergraduate level, subjects such as electricity and magnetism, or classical, quantum, and statistical mechanics should be included in the program.

The general requirement for the degree is a total of 30 credits for graduate-level courses or their equivalent, earned with a grade of C or better and distributed as follows:

1) a design project in applied science or engineering (not less than 6 nor more than 12 credits)
2) an integrated program of graduate-level courses, as discussed below (14 to 20 credits)
3) a required special-topics seminar course (4 credits)

The design project, which is proposed by the student and approved by the program chair, is carried out on an individual basis under the guidance of a member of the university faculty. It may be experimental or theoretical in nature; if it is not experimental, a laboratory physics course is required.

The individual program of study consists of a compatible sequence of courses focused on a specific area of applied physics or engineering. It is planned to provide an appropriate combination of physics and physics-related courses (applied mathematics, statistical mechanics, applied quantum mechanics) and engineering electives (such as courses in biophysics, chemical engineering, electrical engineering, materials science, computer science, mechanical engineering, or nuclear engineering). Additional science and engineering electives may be included. Some courses at the senior level are acceptable for credit toward the degree; other undergraduate courses may be required as prerequisites but are not credited toward the degree.

Students interested in the M.Eng.(Engineering Physics) degree program should contact Professor R. V. E. Lovelace.

APPLIED MATHEMATICS

The Center for Applied Mathematics administers a broadly based interdepartmental graduate program that provides opportunities for study and research in a wide range of the mathematical sciences. For detailed information on opportunities for graduate study in applied mathematics, contact the director of the Center for Applied Mathematics, 657 Engineering and Theory Center Building.

There is no special undergraduate degree program in applied mathematics. Undergraduate students interested in application-oriented mathematics may select an appropriate program in the Department of Mathematics or one of the departments in the College of Engineering.

A list of selected graduate courses in applied mathematics may be found in the description of the Center for Applied Mathematics, in the section "Interdisciplinary Centers and Programs."

CHEMICAL ENGINEERING

W. L. Olbricht, director; A. B. Anton, P. Clancy, C. Cohen, T. M. Duncan, J. R. Engstrom, K. E. Gubbins, D. A. Hammer, P. Harriott, D. L. Koch, R. P. Merrill, A. Panagiotopoulos, F. Rodriguez, M. L. Shuler, P. H. Steen, W. B. Streett

Bachelor of Science Curriculum

The undergraduate Field Program in Chemical Engineering comprises a coordinated sequence of courses beginning in the sophomore year and extending through the fourth year. Special programs in biochemical engineering and polymeric materials are available. Students who plan to enter the field program take Chemistry 208 as an approved elective during the freshman year. The program for the last three years, for students who have taken two engineering distribution courses during the first year and entered Cornell before Fall 1994 is as follows:

Term 3	*Credits*
Math 293, Engineering Mathematics	4
Phys 213, Electricity and Magnetism	4
Chem 389, Physical Chemistry (approved elective)	4
CHEME 219 (engineering distribution course)	3
Humanities or social sciences course	3
Term 4	
Math 294, Engineering Mathematics	4
Phys 214, Optics, Waves, and Particles	4
Chem 290–390, Physical Chemistry	6
Engineering distribution course	3
Humanities or social sciences course	3
Term 5	
Chem 253, Organic Chemistry**	4
Chem 251, Organic Chemistry Laboratory	2
CHEME 313, Chemical Engineering Thermodynamics	4
CHEME 323, Fluid Mechanics	3
Humanities or social sciences course	3
Term 6	
Applied Science elective†	3
CHEME 101, Nonresident Lectures	1
CHEME 324, Heat and Mass Transfer	3
CHEME 332, Analysis of Separation Processes	4
CHEME 390, Reaction Kinetics and Reactor Design	3
Humanities or social sciences course	3
Term 7	
CHEME 432, Chemical Engineering Laboratory	4
CHEME 472, Process Control	3
Electives*	6
Term 8	
CHEME 462, Chemical Process Design	4
Humanities or social sciences course	3
Electives*	3
Humanities or social sciences course	3

*The electives in terms seven and eight comprise 6 credits of technical electives, and 3 credits of CHEME process or systems elective. CHEME process or systems electives include CHEME 564, Design of Chemical Reactors; CHEME 566, Systematic Methods for Process Design; CHEME 640, Polymeric Materials; CHEME 643, Introduction to Bioprocess Engineering; CHEME 656, Separations Using Membranes or Porous Solids; CHEME 661, Air Pollution Control.

**Chemistry 357 may be substituted for CHEM 253. The applied science elective must then be CHEM 358.

†Applied science electives include Biological Sciences 290, General Microbiology Lectures; Biological Sciences 330 and 331, Principles of Biochemistry; CEE 654, Aquatic Chemistry; CHEME 640, Polymeric Materials; CHEME 673, Adsorption and Reactions on Chemically Reactive Solids; Food Science 409, Food Chemistry; MS&E 331, Structure of Materials; MS&E 332, Electrical and Magnetic Properties of Materials; MS&E 441, Microprocessing of Materials; MS&E 449, Introduction to Ceramics; MS&E 452, Properties of Solid Polymers; any A&EP course numbered 333 or above; any Chemistry course numbered 301 or above; any Physics course numbered 300 or above.

Students entering in Fall 1994 or later should contact the field office for a copy of the curriculum.

Master of Engineering (Chemical) Degree Program

The professional master's degree, M.Eng.(Chemical), is awarded at the end of one year of graduate study with successful completion of 30 credits of required and elective courses in technical fields including engineering, mathematics, chemistry, physics, and business administration. Courses emphasize design and optimization based on the economic factors that affect design alternatives for processes, equipment, and plants. General admission and degree requirements are described in the college's introductory section.

Specific requirements include

1) two courses in advanced chemical engineering fundamentals chosen from CHEME 711, 713, 731, 732, and 751
2) two courses in applied chemical engineering science chosen from CHEME 564, 566, 640, 643, 656, and 661
3) a minimum of 3 credits of a design project, CHEME 565

Dean's certificate programs in Bioengineering, Engineering Management, Energy Engineering, and Manufacturing are available. A program offered jointly with the Food Science Department is also available, leading to both the Master of Engineering and the Master of Professional Studies degrees.

CIVIL AND ENVIRONMENTAL ENGINEERING

A. H. Meyburg, director; J. F. Abel, associate director; J. J. Bisogni, Jr., W. H. Brutsaert, G. G. Deierlein, R. I. Dick, P. Gergely, J. M. Gossett, M. D. Grigoriu, D. A. Haith, K. C. Hover, A. R. Ingraffea, G. H. Jirka, F. H. Kulhawy, J. A. Liggett, L. W. Lion, P. L-F. Liu, D. P. Loucks, W. R. Lynn, L. K. Nozick, T. D. O'Rourke, T. Pekoz, W. D. Philpot, M. J. Sansalone, R. E. Schuler, C. A. Shoemaker, J. R. Stedinger, H. E. Stewart, M. A. Turnquist, R. N. White

Bachelor of Science Curriculum

The School of Civil and Environmental Engineering offers an accredited undergraduate program in civil engineering and permits students to pursue one of two options leading to the B.S. degree: civil engineering or environmental engineering. Within civil engineering, students may emphasize structural engineering, geotechnical engineering, hydraulics and hydrology, or transportation. The environmental engineering curriculum emphasizes study of environmental engineering, environmental and water resource systems, and hydraulics and hydrology. Sample curricula are available in the school office, 220 Hollister Hall.

Requirements for Admission to the Field:

Students planning to enter the Field Program in Civil and Environmental Engineering are required to complete ENGRD 202, Mechanics of Solids, either before or during the sophomore year with a grade of C- or better. Additional requirements for affiliation in the field are grade-point averages of at least 2.0: (1) in all engineering and science courses, (2) in the term immediately prior to affiliation, and (3) cumulatively for all courses.

Recommended Engineering Distribution Courses:

The recommended engineering distribution course for students planning to enter the environmental engineering option is ENGRD 219, Mass and Energy Balances. Students entering the environmental option who have not taken ENGRD 219 will be required to do so as part of the Field Program.

Recommended engineering distribution courses for students planning to enter the civil engineering option are:

ENGRD 261, Introduction to Mechanical Properties of Materials, for students interested in structural engineering or civil engineering materials;

ENGRD 201, Introduction to the Physics and Chemistry of the Earth, for students interested in geotechnical engineering;

ENGRD 221, Thermodynamics, for students interested in fluid mechanics and hydralics/ hydrology;

ENGRD 211, Computers and Programming, for students interested in transportation.

Field Program:

These field program requirements will apply to all students in the Class of 1998, and students in the Class of 1997 are strongly encouraged to follow these new curriculum options as well.

Environmental Engineering

For the Field Program in Environmental Engineering, students must take CHEM 208 in place of PHYS 214. The following nine courses are required in addition to those required for the Common Curriculum:

Courses	*Credits*
ENGRD 241, Engineering Computation*	3
CHEM 253, Elementary Organic Chemistry	4
BIOMI 290, General Microbiology, Lectures	3
CEE 304, Uncertainty Analysis in Engineering†	4
CEE 323, Engineering Economics	3
CEE 331, Fluid Mechanics	4
CEE 341, Introduction to Geotechnical Engineering	4
CEE 351, Environmental Quality Engineering	3
ABEN 475, Environmental System Analysis	3

Additional requirements include a set of two field-approved electives and three design electives from an approved list of courses which is available in the school office. In addition, students must complete one technical communications course from among the courses designated ENGRC or approved Communications courses. If the technical communications course is taken as an expressive art, then students must take an additional approved elective.

Civil Engineering

For the Field Program in Civil Engineering, students may elect to substitute CHEM 208 for PHYS 214. The following nine courses are required in addition to those required for the Common Curriculum.

Courses	*Credits*
ENGRD 203, Dynamics	3
ENGRD 241, Engineering Computation*	3
CEE 304, Uncertainty Analysis in Engineering†	4
CEE 323, Engineering Economics	3
CEE 331, Fluid Mechanics	4
CEE 341, Introduction to Geotechnical Engineering	4
CEE 351, Environmental Quality Engineering	3
CEE 361, Transportation Engineering	3
CEE 371, Structural Behavior	4

Additional requirements include a set of two field-approved electives (one from outside the field) and three design electives from an approved list of courses which is available in the school office. In addition, students must complete one technical communications course from among the courses designated ENGRC or approved Communications courses. If the technical communications course is taken as an expressive art, then students must take an additional approved elective from a department or school other than Civil and Environmental Engineering.

*ENGRD 241 can be used to satisfy both the computer application requirement and a field program requirement.

†ENGRD 270 may be accepted (on petition) as a substitute for CEE 304 in the field program, but only if ENGRD 270 is taken before entry into the field, or in some special cases where co-op or study abroad programs necessitate such a substitution.

Master of Engineering (Civil) Degree Program

The M.Eng. (Civil) degree program is a 30-credit (usually ten-course) curriculum designed to prepare students for professional practice. There are two options in this program: one in civil and environmental engineering design and one in engineering management. Both options require a broad-based background in an engineering field. Applicants holding an ABET-accredited (or equivalent) undergraduate degree in engineering automatically satisfy this requirement. Those without such preparation will require course work beyond the graduate program's 30-credit minimum to fulfill the engineering preparation requirement. Both options also require one course in professional practice and a two-course project sequence. The project entails synthesis, analysis, decision making, and application of engineering judgment. Normally it is undertaken in cooperation with an outside practitioner, and it includes an intensive, full-time, three-week session between semesters. The general degree requirements and admissions information are described above in the section entitled "Master of Engineering Degree Programs." Each student's program of study is designed individually in consultation with an academic adviser and then submitted to the school's Professional Degree Committee for approval.

For the M.Eng. (Civil) program in civil and environmental engineering design options, the requirements are:

1) Three courses, one in professional engineering practice (CEE 503) and a two-course design project (CEE 501 and 502)
2) Specialization in a major—three to five courses in either environmental engineering, environmental and public systems engineering, geotechnical engineering, hydraulic engineering, remote sensing, structural engineering, or transportation engineering
3) Two courses in a single related or minor area
4) Technical electives (up to two courses)

Courses in the minor and electives may consist of graduate or advanced courses in fields related to the major, either inside or outside of the school.

For the M.Eng. (Civil) program in the engineering management option, the requirements are:

1) Five courses: Management Practice (CEE 590), Engineering Management Methods (CEE 593 and 594), and the Management Project (CEE 591 and 592).
2) One course in finance, accounting, or engineering economics, as appropriate given a student's background.
3) One course in individual and/or organizational behavior from a recommended list.
4) Three courses from a disciplinary or functional specialization, subject to adviser's approval.

The School of Civil and Environmental Engineering cooperates with the the Johnson Graduate School of Management in two joint programs leading to both Master of Engineering and Master of Business Administration degrees. See the introductory section under College of Engineering.

Applications for the six-year B.S./M.Eng./ M.B.A. program must be submitted at the beginning of the sixth term of study.

COMPUTER SCIENCE

R. L. Constable, chair; K. Birman, B. Bloom, C. Cardie, T. Coleman, B. Donald, D. Gries, J. Hartmanis, T. Henzinger, J. E. Hopcroft, D. Huttenlocher, D. Kozen, P. Pedersen, K. Pingali, M. Rauch, R. A. Rubinfeld, G. Salton, F. B. Schneider, B. Smith, D. Subramanian, R. Teitelbaum, S. Toueg, N. Trefethen, C. Van Loan, S. Vavasis, T. vonEicken, R. Zabih

Bachelor of Science Curriculum

The Field Program in Computer Science is intended for students who are interested in the computing process and in the fundamental structure of algorithms, data, and languages that underlie that process.

A student entering the Field Program in Computer Science must take COM S 211 or 212 and COM S 280 before beginning the upperclass sequence. Students who do not earn a grade of B– or better in both COM S 211 or 212 and COM S 280 are strongly advised against attempting the computer science field program. Students who have not maintained an average of at least 3.0 in the mathematics courses required by the Common Curriculum are also discouraged from entering the program. Apart from these requisites and those of the college, the courses required for the Field Program in Computer Science are:

Course Work	*Credits*
Systems sequence COM S 314, Systems and Organization COM S 410, Data Structures COM S 414, Systems Programming and Operating Systems	11
Theory sequence COM S 381 or 481, Theory of Computing COM S 482, Analysis of Algorithms	8
Numerical Analysis COM S 222, Scientific Computation, or COM S 421, Numerical Solutions of Algebraic Equations	3–4
Computer science electives	8–9
Two nonrequired computer science courses numbered 400 or above,* plus a laboratory project course (for example, COM S 413, 415, 418, 433, 463, or 473).	
Related electives	14–16
One mathematically oriented course plus three courses forming an upper-level concentration in mathematics, operations research, electrical engineering, or another technical area.	

*Must be three or more credits.

For more information, refer to the *Computer Science Undergraduate Handbook*, available from 303 Upson Hall.

The performance of students in the Field of Computer Science is reviewed each term. To remain in good standing with the department, they must have an overall term average of at least 2.3 with no courses failed and a term average for field program courses of at least 2.7 with no course grade less than C–, and they must be making satisfactory progress in the field.

Cooperative Program with the Johnson Graduate School of Management

Undergraduates majoring in computer science may be interested in a program that can lead, in the course of six years, to B.S., M.Eng.(Computer Science), and M.B.A. degrees. This program, which is sponsored jointly by the College of Engineering and the Johnson Graduate School of Management, enables students to study several subjects required for the M.B.A. degree as part of their undergraduate curriculum. Planning must begin early, however, if all requirements are to be completed on schedule.

For further details and assistance in planning a curriculum, students should contact the assistant director of undergraduate programs in Upson Hall.

Master of Engineering (Computer Science) Degree Program

The one-year program leading to the degree of M.Eng.(Computer Science) admits forty to seventy students a year. A strong undergraduate background in computer science or a related field is required. Early admission is available for Cornell seniors who apply in the fall semester.

The emphasis of the curriculum can be on programming languages and systems or theory of algorithms and theory of computation or numerical analysis, artificial intelligence, or information processing, which includes databases and information organization and retrieval. The required design project could be, for example, the design of a compiler for a large subset of a general-purpose programming language, or the solution of a significant engineering problem using computer science techniques.

ELECTRICAL ENGINEERING

J. S. Thorp, director; J. M. Ballantyne, T. Berger, A. W. Bojanczyk, G. M. Brown, H.-D. Chiang, R. C. Compton, D. F. Delchamps, L. F. Eastman, D. T. Farley, T. L. Fine, Z. Haas, D. A. Hammer, C. Heegard, S. S. Hemami, C. R. Johnson, Jr., M. C. Kelley, P. M. Kintner, R. Kline, J. P. Krusius, M. E. Leeser, R. L. Liboff, Y.-H. Lo, N. C. MacDonald, P. R. McIsaac, J. A. Nation, T. W. Parks, A. Phillips Jr., C. R. Pollock, C. Pottle, A. P. Reeves, C. E. Seyler, Jr., J. R. Shealy, R. N. Sudan, C. L. Tang, R. J. Thomas, H. C. Torng, G. J. Wolga

Bachelor of Science Curriculum

The undergraduate Field Program in Electrical Engineering provides a foundation that reflects the broad scope of this engineering discipline.

Concentrations include computer engineering; control systems; electronic circuit design; information, communication, and decision theory; microwave electronics; plasma physics; power and energy systems; quantum and optical electronics; radio and atmospheric physics; and semiconductor devices and applications.

New Curriculum (starting with Class of 1998)

Students planning to enter the Field Program in Electrical Engineering must take ELE E 230, Introduction to Digital Systems, as an engineering distribution course. The fall of the sophomore year is the preferred term for EE 230 for students without advanced standing in mathematics. Electrical engineering students with an interest in computer engineering are encouraged to take COM S 211 as an engineering distribution course prior to entry into the field program. In addition, the field program begins normally in the spring of the sophomore year, as shown below. All of these courses (except ELEE 210) are taught only once a year, either spring or fall, as indicated in the course descriptions.

Course	Credits
Field Required Courses	
ELE E 210, Introduction to Electrical Systems	3
ELE E 215, Electrical Systems Laboratory	3
ELE E 301, Electrical Signals and Systems I	4
ELE E 303, Electromagnetic Waves and Fields I	4
ELE E 315, Electrical Laboratory	4
A choice of three courses from among:	12
ELE E 302, Electrical Signals and Systems II	
ELE E 304, Electromagnetic Waves and Fields II	
ELE E 306, Fundamentals of Quantum and Solid State Electronics	
ELE E 308, Fundamentals of Computer Engineering	
ELE E 310, Probability and Random Signals*	
Field Elective Courses	
Electrical Engineering Approved Electives†	12
Electives Outside Field‡ (3 courses)	9
Total minimum field credits	51

*ELE E 310 can be taken in place of ENGRD 260 or 270 or TAM 310 to satisfy the college application of probability and statistics requirement.

†Must include two electrical engineering laboratory courses and at least one course at the 400-level or above.

‡See *Electrical Engineering Handbook* for detailed definitions, but must include one course at the 300-level or above. At least one of the required electrical engineering laboratory courses must be selected from a list including ELE E 320, 425, 430, 453, 457, 475, 476, 488, 497 and 530. The other may be selected from the above list or from among ELE E 423, 426, 433, 451, 452, 471, 472, 481, 526, 536, 539, 554, and 558.

All students graduating with a B.S. degree must fulfill the engineering design requirement. To meet this requirement, students must demonstrate that they have completed courses that contain at least 16 credits of engineering design. A table listing the engineering design content of all relevant electrical engineering and computer science courses is available in the electrical engineering undergraduate program office.

Undergraduate specialization is achieved through the various electrical engineering elective courses, as well as other courses in related technical fields within engineering, mathematics, the physical sciences, and the analytical biological sciences. The School of Electrical Engineering offers more than thirty courses that are commonly taken as electives by undergraduates.

Maximum technical course scheduling flexibility in the field program is preserved only for those students who *do not* complete their 6 credits of college approved electives prior to entry into the field program. Accordingly, intended electrical engineering students are advised to consider course selection carefully during their first three terms in engineering.

An electrical engineering honors program also exists for those students who so desire and meet the program entrance requirements. The honors program requires additional courses, a required undergraduate research or design project, or an honors thesis. Details are available in the *1995–96 Electrical Engineering Handbook*.

Students with advanced standing frequently take one or more graduate-level courses prior to graduation and may actually begin the Master of Electrical Engineering program in their last semester of undergraduate course work so long as 8 or fewer credits remain toward B.S. degree requirements and a 3.0 GPA has been maintained. Admission must be approved in advance of this last semester of undergraduate work.

All students majoring in electrical engineering are expected to meet the following academic standards:

1. Students must achieve a grade-point average of at least 2.3 every semester.
2. No course with a grade of less than C– may be used to satisfy degree requirements in the field program or serve as a prerequisite for a subsequent electrical engineering course.
3. Students must complete satisfactorily ELE E 210, ELE E 215, MATH 294, and PHYS 214 by the end of the first semester in the Field Program of Electrical Engineering, and make adequate progress toward the degree in subsequent semesters.
4. Honors program students must meet the GPA and progress requirements specified in the *Electrical Engineering Handbook* to remain active participants.

Master of Engineering (Electrical) Degree Program

The M.Eng.(Electrical) degree program prepares students either for professional work in electrical engineering and closely related areas or for further graduate study in a doctoral program. The M.Eng. degree differs from the Master of Science degree mainly in its emphasis on engineering design and analysis skills rather than basic research.

The program requires 30 credits of advanced technical course work, including a minimum of four courses in electrical engineering. An electrical engineering design project is also required and may account for 3 to 8 credits of the M.Eng. program. Occasionally, students take part in very extensive projects and may apply for a waiver of the 8-credit maximum and increase the project component to 10 credits. Students with special career goals, such as engineering management, may apply to use up to 8 credits of approved courses that have significant technical content, but are taught in disciplines other than engineering, mathematics, or the physical sciences.

Although admission to the M.Eng.(Electrical) program is highly competitive, all well-qualified students are urged to apply. Further information is available from the Master of Electrical Engineering Program Office in 222 Phillips Hall.

GEOLOGICAL SCIENCES

B. L. Isacks, chair; R. W. Allmendinger, K. Attoh, M. Barazangi, W. A. Bassett, J. M. Bird, A. L. Bloom, L. D. Brown, L. M. Cathles, J. L. Cisne, T. E. Jordan, D. E. Karig, R. W. Kay, S. Mahlburg Kay, F. H. T. Rhodes, W. B. Travers, D. L. Turcotte, W. M. White

Bachelor of Science Curriculum

Study in geological sciences is offered for engineering students who are preparing for careers in earth sciences and for those who want a broad background in the geological sciences as preparation for careers in other engineering fields. The Department of Geological Sciences is organized as an intercollege department in the College of Arts and Sciences and the College of Engineering. College of Arts and Sciences students should consult that college's section on geological sciences as well as the course listing here.

The Department of Geological Sciences is also taking part in a new intercollege program in the Science of Earth Systems, which will be available to students in the Colleges of Arts and Sciences, Engineering, and Agricultural and Life Sciences beginning fall 1995. This program, which is being developed as a new intercollege major, will emphasize a strong preparation in basic mathematics and sciences and an integrated approach to the study of the earth system including the lithosphere, biosphere, hydrosphere, and atmosphere. The aim is to prepare students for graduate study and careers across the broad spectrum of earth sciences required for successful understanding and management of our planet. For a description of the program and proposed requirements for the major, see the section, Interdisciplinary Centers, Programs, and Studies, in the front part of the catalog.

All geology majors take substantially the same set of upper-level geology courses regardless of their college affiliation. The difference between the curricula for students in engineering (B.S.-degree candidates) and those in arts and sciences (B.A.-degree candidates) is in their respective college requirements such as distribution courses, languages, social sciences, and humanities requirements. Both B.S.- and B.A.-degree programs stress a balanced overview of geology, without specialization. Within the B.S.-degree program, substantial specialization can be achieved by careful selection of field approved electives.

Students in the College of Engineering who may wish to affiliate with the Field Program of Geological Sciences may take ENGRI 122 and ENGRD 201 as distribution courses. As a prerequisite for the major, they should take GEOL 201 (ENGRD 201) or GEOL 101 or 103 as a field approved elective, preferably during their freshman or sophomore year. For those interested in geobiology, BIO G 101–103 and 102–104 are recommended. Chemistry 208 may be substituted for PHYS 214 with approval of the adviser.

Geological Sciences requires the following courses for the engineering major: GEOL 210, 214, 326, 355, 356, 375, and 388. GEOL 210 plus 214 count as one course for purposes of graduation requirements. At least two field approved electives should be GEOL 400 or 600-level courses.

In addition, a requirement for field experience may be met by completing one of the following: (a) GS 491–492 (Undergraduate Research) based on field work (2-credit minimum); (b) GS 437 (Geophysical Field Methods) as an additional field approved elective (3 credits); (c) An approved field course taught by another college or university (3 credit minimum); (d) GS 212 (Special January Field Trip) (2 credits). Field observations made during GS 212 could be the basis for GS 491–492.

Core courses may be taken in any reasonable sequence, except that GEOL 355, which is offered in the fall, should be taken before GEOL 356, which is offered in the spring. GEOL 326, 355, 356, and 375 should be taken relatively early in the major program.

It is recommended that students intending to specialize in *geophysics* select most of their field approved electives from the appropriate advanced geology courses and the following courses or their equivalents; these guidelines also apply to the students' choice of other electives outside the major field.

A&EP 333, Mechanics of Particles and Solid Bodies

A&EP 355, Intermediate Electromagnetism

A&EP 356, Intermediate Electrodynamics

A&EP 434, Continuum Physics

Phys 410, Advanced Experimental Physics

T&AM 310–311, Advanced Engineering Analysis I and II

It is recommended that students intending to specialize in *geochemistry* (including petrology and mineralogy) select most of their field approved electives from the appropriate advanced geology courses and the following courses or their equivalents; these guidelines also apply to the students' choice of other electives outside the major field.

CEE 654, Aquatic Chemistry

Chem 207, 208, General Chemistry

Chem 287–288, Introductory Physical Chemistry

Chem 300, Quantitative Chemistry

Chem 301, Experimental Chemistry I

Chem 302, Experimental Chemistry II

Chem 303, Experimental Chemistry III

Chem 357–358, Introductory Organic Chemistry

Chem 389–390, Physical Chemistry I and II

MS&E 331, Structural Characterization and Properties of Materials

MS&E 335, Thermodynamics of Condensed Systems

It is recommended that students intending to specialize in *geobiology* select most of their field approved electives from the appropriate advanced geology courses and the following courses or their equivalents; these guidelines also apply to the students' choice of other electives outside the major field.

BIOPL 241, Introductory Botany

BIOES 261, Ecology and the Environment

BIOES 274, Functional and Comparative Morphology of Vertebrates

BIOES 278, Evolutionary Biology

BIOES 371, Human Biology and Evolution

BIOES 373, Biology of the Marine Invertebrates

BIOPL 448, Plant Evolution and the Fossil Record

Chem 253, Elementary Organic Chemistry

It is recommended that students who want to pursue further training or immediate employment in *applied geology* (environmental and engineering geology, geohydrology, petroleum geology, or geological engineering) select most of their field approved electives from the appropriate advanced geology courses and the following courses or their equivalents, with two of the four from the same field; these guidelines also apply to the students' choice of other electives outside the major field.

GEOL 204 (also SCAS 371 and ABEN 371), Hydrology and the Environment

ABEN 475, Environmental Systems Analysis

ABEN 671, Analysis of the Flow of Water and Chemicals in Soils

SCAS 361, Genesis, Classification, and Geography of Soils

SCAS 366, Soil Chemistry

SCAS 667, Soil Physics

CEE 331, Fluid Mechanics

CEE 332, Hydraulic Engineering

CEE 341, Introductory Soil Mechanics

CEE 351, Environmental Quality Engineering

CEE 611, Remote Sensing Applications

CEE 612, Physical Environment Evaluation

CEE 615, Digital Image Processing

CEE 633, Flow in Porous Media and Groundwater

CEE 640, Foundation Engineering

MS&E 331, Structural Characterization and Properties of Materials

MS&E 445, Mechanical Properties of Materials

OR&IE 260, Introductory Engineering Probability

OR&IE 370, Introduction to Statistical Theory with Engineering Applications

Students intending to specialize in *economic geology* or pursue careers in the mining industries or mineral exploration should consider including economics courses among their liberal studies distribution courses and should select most of their field approved electives from the groups of courses listed above for geochemistry and applied geology plus the following additional courses; these guidelines also apply to the students' choice of other electives outside the major field.

CEE 654, Aquatic Chemistry

CEE 741, Rock Engineering

Students who want a more general background or who want to remain uncommitted with regard to specialty must choose at least two of their field approved electives from the same field, at a level comparable to the courses listed above. The electives outside the field may be chosen from offerings in other science or engineering fields or the liberal arts, but should be at the 300 level or above. Students may request substitution of GEOL 491 and 492, Undergraduate Research, for a fourth-year field approved elective.

Students intending to pursue graduate study in geology are reminded that some graduate schools require proficiency in reading the scientific literature in one or two of the three languages, French, German, and Russian. Undergraduate preparation in foreign languages is advantageous for many careers, as well.

Master of Engineering (Geological Sciences Degree Program)

The Master of Engineering (Geological Sciences) degree is intended to provide future professional geologists with the geological and engineering background they will need to analyze and solve engineering problems that involve geological variables and concepts. Students may choose a program from one of several options, or tailor a program to meet their special interests with the help of a faculty adviser.

The program requires 30 credits of postgraduate instruction, at least 10 of which must involve engineering design. Students must also complete a design project, worth between 3 and 12 credits, that has a significant geological component and results in substantial conclusions or recommendations.

General information on admission and degree requirements for the M.Eng. degree programs can be found in the college's introductory section.

MATERIALS SCIENCE AND ENGINEERING

C. Y. Li, director; D. G. Ast, J. M. Blakely, R. Dieckmann, E. Giannelis, D. T. Grubb, E. J. Kramer, C. Ober, R. Raj, A. L. Ruoff, S. L. Sass, M. O. Thompson

Bachelor of Science Curriculum

Students majoring in materials science and engineering are required to take MS&E 261, Introduction to Mechanical Properties of Materials, **or** MS&E 262, Introduction to Electrical Properties of Materials, before affiliating with the field. They are strongly urged to take it as an engineering distribution course during their sophomore year. Students in materials science and engineering must concentrate in a specialization which may cover an area such as materials science, solid state, metallic materials, ceramic materials, polymeric materials, or electronic materials.

Specialization is achieved through the selection of technical electives in the junior and senior years. Optional research involvement courses provide undergraduates with the opportunity to work with faculty members and their research groups on current projects.

The requirements for a Bachelor of Science degree in Materials Science and Engineering are:

1. Completion of common curriculum including humanities and social sciences.
2. Completion of 11 required field courses below:

   MS&E 331, Structural Characterization of Materials

   MS&E 332, Electrical and Magnetic Properties of Materials

   MS&E 335, Thermodynamics of Condensed Systems

   MS&E 336, Kinetics, Diffusion, and Phase Transformations

   MS&E 441, Microprocessing of Materials

   MS&E 442, Macroprocessing of Materials

   MS&E 433/435, Senior Materials Laboratory I or Senior Thesis I

   MS&E 444/435, Senior Materials Laboratory II or Senior Thesis II

   MS&E 445, Mechanical Properties of Materials

   MS&E 447 & 448, Materials Design Concepts I & II
3. Four courses in a technical specialization.
4. Twelve credits of other electives.
5. One of the elective or specialization courses must include substantial chemical synthesis (e.g., MS&E 414, MS&E 452, CHEM 208 or CHEM 253).

To continue in good standing in the Field of Materials Science and Engineering, students must

1) Maintain an overall 2.0 term average.

2) Maintain an average of 2.3, with no grade below C, in the department's core curriculum.

3) Completion of MS&E 261 or 262 with a minimum grade of C prior to affiliation.

The department's core curriculum consists of all the required MS&E courses including MS&E 261 or 262 and the four courses comprising the student's area of specialization.

An attractive and very challenging program combines the materials science and engineering curriculum with that of either electrical engineering or mechanical engineering, leading to a double major. The combination of materials science and engineering with electrical engineering is particularly well suited to students who will eventually be employed in the electronic materials industry. Mechanical engineers knowledgeable in materials science also will be well equipped for technical careers. Curricula leading to the double-major degree must be approved by both of the departments involved. Students are urged to plan such curricula as early as possible.

Master of Engineering (Materials) Degree Program

Students who have completed a four-year undergraduate program in engineering or the physical sciences can be considered for admission into the M.Eng.(Materials) program. This program consists of 30 credits, including course work and a master's design project. The project, which requires individual effort and initiative, is carried out under the supervision of a faculty member. Twelve credits are devoted to the project, which is normally experimental in nature, although analytical projects are also possible.

Courses for the additional 18 credits are selected from the graduate-level classes in materials science and engineering and from other related engineering fields approved by the faculty. Typically half of the courses are from MS&E. One 3-credit technical elective must include advanced mathematics (modeling, computer application, or computer modeling), beyond the MS&E undergraduate requirements.

MECHANICAL AND AEROSPACE ENGINEERING

D. A. Caughey, director; P. L. Auer, C. T. Avedisian, D. L. Bartel, G. Berkooz, J. F. Booker, I. D. Boyd, P. R. Dawson, P. C. T. deBoer, E. M. Fisher, A. R. George, F. C. Gouldin, S. Kannapan, S. Leibovich, M. Y. Louge, J. L. Lumley, M. P. Miller, F. C. Moon, F. K. Moore, R. M. Phelan, S. B. Pope, M. L. Psiaki, E. L. Resler, Jr., S.-f. Shen, D. L. Taylor, K. E. Torrance, H. B. Voelcker, K. K. Wang, Z. Warhaft, R. Warkentin, C. H. K. Williamson, N. Zabaras

Members of the faculty of the graduate Fields of Aerospace Engineering and Mechanical Engineering are listed in the *Announcement of the Graduate School.*

Bachelor of Science Curriculum in Mechanical Engineering

The upperclass Field Program in Mechanical Engineering is designed to provide a broad background in the fundamentals of this discipline as well as to offer an introduction to the many professional and technical areas with which mechanical engineers are concerned. The program covers both major streams of the field of mechanical engineering.

Mechanical systems, design, and materials processing is concerned with the design, analysis, testing, and manufacture of machinery, vehicles, devices, and systems. Particular areas of concentration are mechanical design and analysis, vehicle engineering, biomechanics, and materials processing and precision engineering. Other topics covered are computer-aided design, vibrations, control systems, and dynamics.

Engineering of fluids, energy, and heat-transfer systems is concerned with the efficient conversion of energy in electric power generation and aerospace and surface transportation, the environmental impact of engineering activity (including pollutants and noise), and the experimental and theoretical aspects of fluid flow, heat transfer, thermodynamics, and combustion. Specific areas of concentration include aerospace engineering; heat, energy, and power engineering; and thermo-fluid sciences.

The undergraduate program is a coordinated sequence of courses beginning in the sophomore year. During the fall term sophomore students who plan to enter the Mechanical Engineering Program take ENGRD 202 (also T&AM 202) as an engineering distribution course. They also are urged to take ENGRD 221 (also M&AE 221), which is a field requirement that may simultaneously satisfy Common Curriculum requirements as an engineering distribution course. Occasionally because of study abroad or requirements for second majors or pre-med, students cannot complete all of the required sophomore courses on schedule. In such cases students should delay ENGRD 221 until the first semester of the junior year. The Sibley School is supportive of students with unusual requirements, but any delays or substitutions must be discussed with and receive approval from the student's adviser.

The requirements for the degree of Bachelor of Science in Mechanical Engineering are as follows:

1. Completion of the Common Curriculum. During the upperclass years this will typically mean earning credit for five humanities or social science courses.
2. Completion of the field requirements, which consist of eleven required courses (beyond ENGRD 202 already mentioned), and five elective courses (24 credits).

The eleven required courses are:

M&AE 212, Mechanical Properties and Processing of Engineering Materials

M&AE 221, Introduction to Thermodynamics

M&AE 225, Mechanical Design and Synthesis

T&AM 203, Dynamics

ELE E 210, Introduction to Electrical Systems

M&AE 323, Introduction to Fluid Mechanics

M&AE 324, Heat Transfer

M&AE 325, Mechanical Design and Analysis

M&AE 326, System Dynamics

M&AE 427, Fluids/Heat Transfer Laboratory

M&AE 428, Engineering Design

Electives

Students should use the flexibility provided by the field approved electives, approved electives, and humanities /social sciences electives to develop a program to meet their specific goals.

Field Approved Electives

The upper-level program includes five field approved electives. Using these five courses, the student must satisfy the following requirements.

At least three of the courses must be upper-level (300+) M&AE courses. Of these three, two must satisfy a concentration chosen by the student.

Typically these are two courses chosen from an appropriate subset of the school's upper-class offering.

However, students can petition for approval of two related courses to form a custom concentration.

The standard concentrations are

Fluids/Aerospace Engineering, M&AE 305, 423, 506, 507

Thermo-Fluids M&AE 423, 449, 506, 543

Materials Processing M&AE 412, 414

Mechanical Systems M&AE 389, 465, 469, 478, 489

Vehicle Engineering M&AE 386, 449, 486, 506, 507

Of the three upper-level M&AE courses, one must be an approved design elective. The design offerings may change from year to year

Typically this list includes M&AE 401, 464, 486, and 489.

Note that the design elective must be taken during the senior year. Note that a single course may satisfy both the design and concentration requirements, in which case the third course could be any upper level M&AE course.

One of the courses must be an approved upper-level mathematics course taken after Math 294. The course must include some material on statistics. Currently, the approved courses are T&AM 310 and OR&IE 270.

One of the field approved electives can be viewed as a technical elective and can be any course at an appropriate level, chosen from engineering, mathematics, or science (physics, chemistry, or biological sciences). Appropriate level is interpreted as being at a level beyond the required courses of the college curriculum. Note that courses in economics, business, and organizations are not accepted. Advisers may approve such courses as approved electives.

Approved Electives

To maximize flexibility (i.e., the option for study abroad, COOP, internships, pre-med, and flexibility during the upper-class years), the Sibley School faculty recommends that students delay use of approved electives until after term three. The faculty encourages students to consider the following as possible approved electives:

- any engineering distribution course
- course stressing oral or written communications
- courses stressing the history of technology
- rigorous courses in the physical sciences (physics, biology, chemistry)
- courses in informational science (mathematics, computer science)
- courses in methodologies (modeling, problem solving, synthesis, design)
- course in technology (equipment, machinery, instruments, devices, processes)
- courses in business enterprise operations (economics, financial, legal, etc.)
- courses in organizational behavior
- courses in cognitive sciences.

Recommendation on Humanities/Social Sciences Electives

Students are encouraged to build a program that includes studies in

- history of technology
- societal impacts of technology
- history
- foreign languages
- ethics
- communications
- political science
- aesthetics
- economics
- architecture

An additional graduation requirement of the field program is proof of elementary competence in technical drawing. The demonstration of competence is expected before completion of M&AE 325, Mechanical Design and Analysis. This proof may be given in a number of ways, including satisfactory completion of

a. a technical drawing course in high school or in a community college,

b. ENGRG 102, Drawing and Engineering Design,

c. another technical drawing course at Cornell, or

d. a departmental examination.

The computer applications requirement of the Common Curriculum may be satisfied by several courses, including M&AE 389 or 489.

The writing requirement of the Common Curriculum is satisfied by M&AE 427.

Introduction to Electrical Systems (ELE E 210) may be replaced or supplemented by Introductory Electronics (PHYS 360).

A limited set of third-year courses is offered each summer under the auspices of the Engineering Cooperative Program.

Applicability: The curriculum requirements described above apply to the Class of '98 and beyond. Graduates of the Classes of 96, and '97 may choose to complete their studies under the previous requirements or those described above. Generally the Sibley School expects the Classes of '96 and '97 to use the requirements described above. More detailed materials describing the Mechanical Engineering Program may be obtained from the Sibley School of Mechanical and Aerospace Engineering, Upson Hall.

Preparation in Aerospace Engineering

Although there is no separate undergraduate program in aerospace engineering, students may prepare for a career in this area by majoring in mechanical engineering and taking courses from the aerospace engineering concentration such as M&AE 305, 506, and 507. Students may prepare for the graduate program in aerospace engineering by majoring in mechanical engineering, in other appropriate engineering specialties such as electrical engineering or engineering physics, or in the physical sciences. Other subjects recommended as preparation for graduate study include thermodynamics, fluid mechanics, applied mathematics, chemistry, and physics.

Master of Engineering (Aerospace) Degree Program

The M.Eng. (Aerospace) degree program provides a one-year course of study for those who wish to develop a high level of competence in engineering science, current technology, and engineering design.

The program is designed to be flexible so that candidates may concentrate on any of a variety of specialty areas. These include aerodynamics, acoustics and noise, turbulent flows, rarefied and non-equilibrium flows, combustion, dynamics and control, CFD, etc.

A coordinated program of courses for the entire year is agreed upon by the student and the faculty adviser. This proposed program, together with a statement of purpose, is submitted for approval to the M&AE Master of Engineering Committee during the first week of class; any subsequent changes must also be approved by the committee. An individual student's curriculum includes a 4- to 8-credit design course, a major concentration consisting of a minimum of 12 credits, and sufficient technical electives to meet the total degree requirement of 30 credits (of which at least 28 credits must have letter grades).

The design projects may arise from individual faculty and student interests or from collaboration with industry. All projects must have an aerospace engineering design focus and have the close supervision of a faculty member.

The courses that constitute the major concentration must be graduate-level courses in aerospace engineering. In general, all courses must be beyond the level of those required in an undergraduate engineering program; credit may be granted for an upper-level undergraduate course if the student has done little or no previous work in that subject area, but such courses must have the special approval of the M&AE Master of Engineering Committee.

The technical electives may be courses of appropriate level in mathematics, physics, chemistry, or engineering; a maximum of 6 credits may be taken in areas other than these if the courses are part of a well-defined program leading to specific professional objectives. It is expected that all students will use technical electives to develop proficiency in mathematics beyond the minimum required of Cornell engineering undergraduates if they have not already done so before entering the program. Courses in advanced engineering mathematics or statistics are particularly recommended.

Students should check with the M&AE graduate field office (104 Upson Hall) for additional degree requirements.

Master of Engineering (Mechanical) Degree Program

The M.Eng. (Mechanical) degree program provides a one-year course of study for those who wish to develop a high level of competence in engineering science, current technology, and engineering design.

The program is designed to be flexible so that candidates may concentrate on any of a variety of specialty areas. These include biomechanical engineering, combustion, energy and power systems, fluid mechanics, heat transfer, materials and manufacturing engineering, mechanical systems and design, CFD, CAE, CAD, CAM, etc.

A coordinated program of courses for the entire year is agreed upon by the student and the faculty adviser. This proposed program, together with a statement of purpose, is submitted for approval to the M&AE Master of Engineering Committee during the first week of class; any subsequent changes must also be approved by the committee. An individual student's curriculum includes a 4- to 8-credit design course, a major concentration consisting of a minimum of 12 credits, and sufficient technical electives to meet the total degree requirement of 30 credits (of which at least 28 credits must have letter grades).

The design projects may arise from individual faculty and student interests or from collaboration with industry. All projects must have a mechanical engineering design focus and have the close supervision of a faculty member.

The courses that constitute the major concentration must be graduate-level courses in mechanical and aerospace engineering or a closely related field such as theoretical and applied mechanics. In general, all courses must be beyond the level of those required in an undergraduate engineering program; credit may be granted for an upper-level undergraduate course if the student has done little or no previous work in that subject area, but such courses must have the special approval of the M&AE Master of Engineering Committee.

The technical electives may be courses of appropriate level in mathematics, physics, chemistry, or engineering; a maximum of 6 credits may be taken in areas other than these if the courses are part of a well-defined program leading to specific professional objectives. It is expected that all students will use technical electives to develop proficiency in mathematics beyond the minimum required of Cornell engineering undergraduates if they have not already done so before entering the program. Courses in advanced engineering mathematics or statistics are particularly recommended.

Students should check with the M&AE graduate field office (104 Upson Hall) for additional degree requirements.

Students enrolled in the M.Eng. (Mechanical) degree program may take courses that also satisfy the requirements of the Manufacturing, Energy, or Electronic Packaging option programs leading to special dean's certificates in those areas.

NUCLEAR SCIENCE AND ENGINEERING

Faculty members in the graduate Field of Nuclear Science and Engineering who are most directly concerned with the Master of Engineering (Nuclear) curriculum include K. B. Cady (faculty representative), D. D. Clark, H. H. Fleischmann, D. A. Hammer, V. O. Kostroun, and S. C. McGuire

Undergraduate Study

Although there is no special undergraduate field program in nuclear science and engineering, students who intend to enter graduate programs in this area are encouraged to begin specialization at the undergraduate level. This may be done by choice of electives within regular field programs (such as those in engineering physics, materials science and engineering, and civil, chemical, electrical, or mechanical engineering) or within the College Program.

Master of Engineering (Nuclear) Degree Program

The two-term curriculum leading to the M.Eng.(Nuclear) degree is intended primarily for individuals who want a terminal professional degree, but it may also serve as preparation for doctoral study in nuclear science and engineering. The course of study covers the basic principles of nuclear reactor systems with a major emphasis on reactor safety and radiation protection and control. The special facilities of the Ward Laboratory of Nuclear Engineering are described in the *Announcement of the Graduate School.*

The interdisciplinary nature of nuclear engineering allows students to enter from a variety of undergraduate specializations. The recommended background is (1) an accredited baccalaureate degree in engineering, physics, or applied science; (2) physics, including atomic and nuclear physics; (3) mathematics, including advanced calculus; and (4) thermodynamics. Students should see that they fulfill these requirements before beginning the program. In some cases, deficiencies in preparatory work may be made up by informal study during the preceding summer. General admission and degree requirements are described in the college's introductory section.

The following courses are included in the 30-credit program:

Fall term

NS&E 509, Nuclear Physics for Applications

A&EP 612, Nuclear Reactor Theory

A&EP 633, Nuclear Engineering

Technical elective

Spring term

A&EP 651, Nuclear Measurements Laboratory

NS&E 545, Energy Seminar

Technical elective

Engineering design project

Mathematics or physics elective

Engineering electives should be in a subject area relevant to nuclear engineering, such as energy conversion, radiation protection and control, feedback control systems, magnetohydrodynamics, controlled thermonuclear fusion, and environmental engineering. The list below gives typical electives.

M&AE 651, Advanced Heat Transfer

ELE E 581, Introduction to Plasma Physics

ELE E 582, Advanced Plasma Physics

ELE E 589, Magnetohydrodynamics

ELE E 471, Feedback Control Systems

ELE E 472, Digital Control Systems

A&EP 638, Intense Pulsed Electron and Ion Beams: Physics and Technology

A&EP 661, Microcharacterization

NS&E 484, Introduction to Controlled Fusion: Principles and Technology

MS&E 459, Physics of Modern Materials Analysis

Program for Applications of Nuclear Analytical Methods (PANAM)

This new program was initiated in 1993–94. It provides for specialization by Ph.D. candidates with either a major or a minor in NS&E. For those with majors in non-nuclear fields who expect to use nuclear analytical methods in their research, the sequence NS&E 509–551–590 forms a suitable minor in NS&E. The laboratory course 551 has been offered since spring 1989. The lecture course 509, offered for the first time in 1993, covers nuclear physics without requiring quantum mechanics as a prerequisite. For NS&E majors, PANAM offers the opportunity to extend and develop new nuclear-analytical methods, for example, uses of cold neutrons and neutron-depth profiling with conversion electrons. They would normally follow the M.Eng. program in the first year, continue with advanced courses in the second year (including a full quantum-mechanical treatment of nuclear physics), and begin, as early as possible, independent projects as precursors to thesis research.

OPERATIONS RESEARCH AND INDUSTRIAL ENGINEERING

J. A. Muckstadt, director; J. Renegar, D. Ruppert, associate directors; L. J. Billera, R. G. Bland, D. C. Heath, P. L. Jackson, W. L. Maxwell, N. Prabhu, S. I. Resnick, R. Roundy, G. Samorodnitsky, L. W. Schruben, D. B. Shmoys, E. Slate, É. Tardos, M. J. Todd, L. E. Trotter, Jr., B. W. Turnbull

Bachelor of Science Curriculum in Operations Research and Engineering

The program is designed to provide a broad and basic education in the techniques and modeling concepts needed to analyze and design complex systems and to provide an introduction to the technical and professional areas with which operations researchers and industrial engineers are concerned. Exceptional students interested in pursuing graduate studies are encouraged to speak with their faculty advisers concerning an accelerated program of study.

A student who intends to enter the Field Program in Operations Research and Engineering should plan to take Basic Engineering Probability and Statistics (ENGRD 270) immediately after completing Math 192. Early consultation with a faculty member of the school or with the associate director for undergraduate studies can be helpful in making appropriate choices. The required courses for the OR&E field program and the typical terms in which they are taken are as follows:

Term 5	*Credits*
OR&IE 310, Industrial Systems Analysis	4
CS 211, Computers & Programming	3
OR&IE 320, Optimization I	4
OR&IE 350, Cost Accounting, Analysis, and Control	4
OR&IE 360, Engineering Probability and Statistics II	4
A course in humanities and social sciences	3
A non-OR engineering course	3
Term 6	
OR&IE 321, Optimization II	4
OR&IE 361, Introductory Engineering Stochastic Processes	4
Behavioral science†	3
Course in humanities and social sciences	3

†The behavioral science requirement can be satisfied by any one of several courses, including the Johnson Graduate School of Management (JGSM) course, NCC 504 (offered only in the fall), which is recommended for those contemplating the pursuit of a graduate business degree, and Industrial and Labor Relations 170, 171, 320, and 461. The adviser must approve the selection in all cases.

The basic senior-year program, from which individualized programs are developed, consists of the following courses:

	Minimum credits
OR&IE 580, Digital Systems Simulation	4
Three upperclass OR&E electives as described below	9
Two non-OR electives	6
Two courses in humanities and social sciences	6
Two approved electives	8

Available OR&E electives are as follows:

Manufacturing and distribution systems: OR&IE 416, 417, 451, 480, 516, 525, and 562 and JGSM NBA 601 and 641*

Optimization methods: OR&IE 431, 432, and 435

Applied probability and statistics: OR&IE 462, 475 (2 credits), 476 (2 credits), 561, 563, 575, and 577

*No more than one course in the Johnson Graduate School of Management may be taken as an OR&E elective.

Scholastic requirements for the field are a passing grade in every course, an overall average of at least 2.0 for each term the student is enrolled in the school, an average of 2.0 or better for OR&E field courses, and satisfactory progress toward the completion of the degree requirements. The student's performance is reviewed at the conclusion of each term.

Master of Engineering (OR&IE) Degree Program

This one-year professional degree program stresses applications of operations research and industrial engineering and requires completion of a project. The course work centers on additional study of analytical techniques, with particular emphasis on engineering applications, especially in the design of new or improved man-machine systems, information systems, and control systems.

General admission and degree requirements are described in the introductory "Degree Programs" section. The M.Eng.(OR&IE) program is integrated with the undergraduate Field Program in Operations Research and Engineering. Also welcome are requests for admission from Cornell undergraduates in engineering programs other than OR&E or from qualified non-Cornellians. To ensure completion of the program in one calendar year, the entering student should have completed courses in statistics and in computer programming (Pascal or C). Students interested in the manufacturing engineering option should obtain further information regarding program requirements from the office of the Center for Manufacturing Enterprise, 103 Engineering and Theory Center Building. Information concerning industrial internships can be obtained from the Master of Engineering Program Office, 148 Olin Hall.

I. *For matriculants with preparation comparable to that provided by the undergraduate Field Program in Operations Research and Engineering:*

Fall term	*Credits*
OR&IE 516, Case Studies	1
OR&IE 893, Applied OR&IE Colloquium	1
OR&IE 599, Project	1
Three technical electives	9
Spring term	
OR&IE 894, Applied OR&IE Colloquium	1
OR&IE 599, Project	minimum of 4
Three technical electives	9

At least 12 credit hours of the electives specified above must be chosen from the list of courses offered by the School of Operations Research and Industrial Engineering. Other restrictions apply. A minimum of 30 credits must be taken to complete the program.

II. *For matriculants from other fields who minimally fulfill the prerequisite requirements (students who have the equivalent of OR&IE 520, 523, and 570 will take technical electives in their place):*

Fall term	*Credits*
OR&IE 560, Engineering and Probability Statistics II	
OR&IE 520, Operations Research I	4
OR&IE 516, Case Studies	1
OR&IE 580, Digital Systems Simulation	4
OR&IE 893, Applied OR&IE Colloquium	1
OR&IE 599, Project	1
Spring term	
OR&IE 523, Introduction to Stochastic Modeling	4
OR&IE 894, Applied OR&IE Colloquium	1
OR&IE 599, Project	minimum of 4
Two technical electives	6

The project requirement can be filled in a variety of ways. Common elements in all project experiences include working as part of a group of three to five students on an engineering design problem, meeting with a faculty member on a regular basis, and oral and written presentation of the results obtained. Most projects address problems that actually exist in manufacturing firms, financial firms, etc.

Cooperative Program with the Johnson Graduate School of Management

Undergraduates majoring in operations research and engineering may be interested in a cooperative program at Cornell that leads to both Master of Engineering and Master of Business Administration (M.B.A.) degrees. With appropriate curriculum planning such a combined B.S./M.Eng./M.B.A. program can be completed in six years.

An advantage for OR&E majors is that they study, as part of their undergraduate curriculum, several subjects that are required for the M.B.A. degree. (This is because modern management is concerned with the operation of production and service systems, and much of the analytical methodology required to deal with operating decisions is the same as that used by systems engineers in designing these systems.) An early start on meeting the business-degree requirements permits students accepted into the cooperative program to earn both the M.Eng.(OR&IE) and M.B.A. degrees in two years rather than the three years such a program would normally take.

The details of planning courses for this program should be discussed with the admissions office of the Johnson Graduate School of Management.

In accordance with this program the candidate would qualify for the B.S. degree at the end of four years, the M.Eng.(OR&IE) degree at the end of five years, and the M.B.A. degree at the end of six years.

Further details and application forms may be obtained at the office of the School of Operations Research and Industrial Engineering, Engineering and Theory Center Building, and at the admissions office of the Johnson Graduate School of Management.

STATISTICS CENTER

The Cornell Statistics Center coordinates university-wide activities in statistics and probability at the graduate and research level. Students interested in graduate study in statistics and probability should apply to the Field of Statistics or to one of the other graduate fields that offer related coursework.

A list of courses in statistics and probability suitable for graduate students in the Field of Statistics is given under the heading "Statistics Center" in the section "Interdisciplinary Centers and Programs" at the front of this book. Further information can be obtained from the director of the Statistics Center, Professor S. R. Searle, or from the graduate field representative for statistics, Professor M. Wells, both at 482 Caldwell Hall.

THEORETICAL AND APPLIED MECHANICS

J. T. Jenkins, chair; J. A. Burns, H. D. Conway, J. M. Guckenheimer, E. W. Hart, T. J. Healey, C. Y. Hui, R. H. Lance, S. Mukherjee, Y. H. Pao, S. L. Phoenix, R. H. Rand, P. Rosakis, A. L. Ruina, W. H. Sachse, S. Strogatz, A. Zehnder

Undergraduate Study

The Department of Theoretical and Applied Mechanics is responsible for courses in engineering mechanics and engineering mathematics, some of which are part of the Common Curriculum.

College Program in Engineering Science

A student may enroll in the College Program in Engineering Science, which is sponsored by the Department of Theoretical and Applied Mechanics. The College Program is described in the section on undergraduate study in the College of Engineering.

Master of Engineering (Engineering Mechanics) Degree Program

Composite materials designed to meet specific requirements of weight, strength, and rigidity are used increasingly in the manufacture of everyday structures and components. The Master of Engineering (Engineering Mechanics) degree program focuses on the mechanical behavior of advanced composite materials and structures and prepares students to play a role in the development of this new technology. Students from diverse engineering backgrounds, such as mechanics, structures, and materials, as well as aerospace and biomedical engineering, can normally complete the requirements for the professional Master of Engineering degree in one year.

Students usually select courses totaling 20 credits, which may be chosen from four different departments. These courses explore the nature of modern composite materials, provide a background in the fundamentals of these materials and their mechanics, and introduce techniques that will be useful in subsequent work. The program offers a series of topical, four-week mini courses on specialized subjects related to composites, taught by experts in the field. The degree program requires satisfactory completion of 30 credits of course work, including 12 credits of courses that involve analysis, computation, design, or laboratory experience. Of these 12 credits, at least 6 must be earned in T&AM 501, 502 *(Topics in Composites I; II)*, 555 *(Introduction to Composite Materials)*, or 655 *(Advanced Composite Materials and Structures)*. Up to 10 credits will be awarded for an individual project involving composites. The balance of the required credits may be earned in elective courses chosen from those in the course listing below or others approved by the student's adviser.

The Department of Theoretical and Applied Mechanics has several laboratories equipped for the fabrication and mechanical testing of composite materials and structures. Extensive computing resources are available for numerical computations, design, or other numerical- or simulation-research activities related to composites. The Materials Science Center, the Center for Theory and Simulation in Science and Engineering, and the Computer-Aided Design Instructional Facility provide additional state-of-the-art laboratories and computer resources. Core courses in the M.Eng.(Engineering Mechanics) program are:

Course	*Credits*
T&AM 555, Introduction to Composite Materials	3
T&AM 655, Advanced Composite Materials and Structures	4
T&AM 663, Solid Mechanics I	4
T&AM 501, Topics in Composites I	1–3
Selected from the following:	
Analysis of Composite Structures	
Mechanical Testing of Composite Constituents	
Fracture Testing of Composites	
Reliability Models for Composites	
Design Principles for Composite Structures	
Biological Composites	
T&AM 502, Topics in Composites II	1–3
Selected from the following:	
Effective Properties of Composites	
Interface Failure and Fracture Processes in Composites	
Boundary-Element Methods for Composites	
Nondestructive Testing of Composites	
Software for Composite Design	
Novel Composite Structures	
T&AM 591, Master of Engineering Design Project I	3–5
T&AM 592, Master of Engineering Design Project II	5–10

Complementary courses from other departments include:

MS&E 450, Physical Metallurgy	3
MS&E 452, Properties of Solid Polymers	3
MS&E 605, Plastic Flow and Fracture of Materials	3

M&AE 465, Biomechanical Systems—Analysis and Design	3
M&AE 569, Mechanical and Aerospace Structures	3
M&AE 670, Mechanical and Aerospace Structures II—Finite-Element Methods	4
CEE 770, Engineering Fracture Methods	3
CEE 772, Finite-Element Analysis	3

ENGINEERING COURSES

Courses offered in the College of Engineering are listed under the various departments and schools.

Courses are identified with a standard abbreviation followed by a three-digit number.

Introduction to Engineering	ENGRI
Engineering Distribution	ENGRD
Engineering General Interest	ENGRG
Engineering Communications	ENGRC
Agricultural and Biological Engineering	ABEN
Applied and Engineering Physics	A&EP
Chemical Engineering	CHEME
Civil and Environmental Engineering	CEE
Computer Science	COM S
Electrical Engineering	ELE E
Geological Sciences	GEOL
Materials Science and Engineering	MS&E
Mechanical and Aerospace Engineering	M&AE
Nuclear Science and Engineering	NS&E
Operations Research and Industrial Engineering	OR&IE
Theoretical and Applied Mechanics	T&AM

ENGINEERING COMMON COURSES

Courses of General Interest

Courses in this category are of general interest and cover technical, historical, and social issues relevant to the engineering profession. These courses may also include seminar or tutorial type courses.

ENGRG 101 The Computer Age (also COM S 101)
Summer. 3 credits. Not offered every year. Credit is granted for both COM S 100 and 101 only if 101 is taken first.
An introduction to computer science and programming for students in nontechnical areas. The aims of the course are to acquaint the student with the major ideas in computer science and to develop an appreciation of algorithmic thinking. Topics may include the history of computation; microtechnology; the retrieval and transmission of information; scientific computing; computer graphics, art, and music; robotics, natural-language processing, and machine intelligence. Students become acquainted with the notion of an algorithm by writing several programs in Pascal or Scheme and testing them on microcomputers. The amount of programming is about half that taught in Engr 100.

ENGRG 102 Drawing and Engineering Design (also M&AE 102)
Fall, spring. 1 credit. Half-term course offered twice each semester. Enrollment limited to thirty students each half term. Recommended for students without previous mechanical drawing experience. S-U grades optional.
Introduction to sketching, drawing, and graphic techniques useful in design, analysis, and presentation of ideas. Use of computer-aided drafting software is introduced in the final design project.

ENGRG 150 Engineering Seminar
Fall. 1 credit. First-year students only. S-U grades only.
Weekly discussions with selected faculty advisers to give students information about the various fields of engineering and related career opportunities. Topics may include recent science and engineering developments, applications of engineering principles, and a view of campus resources. Visits to campus academic and research facilities may be included.

ENGRG 250 Technology in Western Society (also ELE E 250)
Fall. 3 credits. Meets liberal studies distribution requirement.
An investigation of the history of technology in Western society from ancient Egyptian times to the present, focusing on Western Europe up to the British industrial revolution in the late eighteenth century, and on the United States thereafter. Topics include the economic and social aspects of industrialization; the myths of heroic inventors like Morse, Edison, and Ford; the government's promotion and regulation of technology through such measures as the patent system, the funding of research and development, and regulatory legislation; the origins of modern systems of mass production; and the spread of the automobile and microelectronics cultures in the United States.

ENGRG 290 Engineering in Europe
Spring. 2 credits. Open only to participants in the Semester in Europe Program. S-U grades only.
A specially designed course for students in residence in Hamburg, Germany. Weekly seminars associated with approximately ten weekly field trips to engineering sites in and around Hamburg. Students will be required to maintain written journals of field trips, prepare memos to the record of field trips, assemble associated readings, as well as present oral reports on selected industries. A term paper is required. No unexcused absences.

ENGRG 298 The Electrical and Electronic Revolutions (also ELE E 298)
Spring. 3 credits. Approved for humanities distribution, not as field electives.
Explores the history of electricity in society from the 1830s to the present by considering the technical and social history of telecommunications, the electric-power industry, microelectronics, radio, television, and computers. Emphasis is placed on the changing relationship between science and technology, the institutional context of research and development, the economic aspects of innovation, and the social relations of this technology.

ENGRG 323 Engineering Economics and Management (also CEE 323)
Spring. 3 credits. Primarily for juniors and seniors. R. E. Schuler.
Introduction to engineering and business economics and to project management. Intended to give students a working knowledge of money management and how to make economic comparisons of alternative engineering designs or projects. The impact of inflation, taxation, depreciation, financial planning, economic optimization, project scheduling, and legal and regulatory issues are introduced and applied to economic investment and project-management problems.

ENGRG 356 Women in Engineering Career Planning Seminar
Spring. 1 credit. Limited to 25 students. S–U grades only. Open to juniors and seniors in engineering and related fields or permission of instructor.
Covers aspects of transition to the engineering profession and related issues especially of interest to women. Topics include career and life planning, the job-search process, interviewing strategies, juggling career and family, graduate education, sexual harassment and sexism in the workplace, professionalism, and networking. Corporate professionals and Cornell faculty and staff participate in class discussions.

ENGRG 360 Ethical Issues in Engineering
Spring. 3 credits. A social-science elective for engineering students. Open to juniors and seniors.
A discussion of ethical issues encountered in engineering practice, such as the rights of engineers in corporations, responsibility for harmful actions, whistleblowing, conflicts of interest, and decision making based on cost-benefit analysis. Codes of ethics of professional engineering societies and ethical theory will be used to help sort out conflicting obligations the engineer may feel toward public safety, professional standards, employers, colleagues, and family. Students will present a case study to the class, along the lines of the Space-Shuttle Challenger disaster, the Kansas City Hyatt-Regency Hotel walkway failure, or the Cornell computer "worm."

ENGRG 461 Engineering for Entrepreneurs
Fall. 3 credits.
Intent is to provide students with the tools and skills necessary to identify, evaluate, and undertake new business ventures. A major course project will be the development of a business plan for an innovative new venture and will require the detailing of manufacturing, support, and information systems as well as staffing and cost data. Intended for juniors and seniors in the College of Engineering, this course is open to all undergraduates.

ENGRG 501 Bioengineering Seminar
Fall, spring. 1 credit. Primarily for juniors, seniors, and graduate students. M. L. Shuler.
Broad survey of all aspects of bioengineering, including biomedical, bioprocess, biological, and bioenvironmental engineering and aspects of biotechnology. Sessions may be technical presentations or discussions.

Engineering Communications Courses

Courses in this category, offered by the Engineering Communications Program, develop writing and communications skills relevant to engineers.

ENGRC 233/433 Topics in Engineering Communications

TBA. 3 credits.

Topics vary as the need and interest arise. Offerings might include: introductory technical communications, graphic presentation of engineering material, desktop publishing, information technologies, advanced problems in engineering communications, technology and the law. Fulfills the college technical writing requirement.

ENGRC 234/434 Independent Study in Engineering Communications

TBA. Variable credits (1–3). Credit and course level (234 or 434) determined by the amount and intellectual level of the work.

Students work closely with a Communications Program instructor to pursue an aspect of professional communications not available through regular course work. Projects may involve writing technical documentation, creating user manuals, analyzing and producing technical graphics, or reading and writing about problems in engineering practice. Interested students should contact the Engineering Communications Program.

ENGRC 301 Writing in Engineering

TBA. 1 credit. Prerequisite: Permission of instructor. Can be used to satisfy requirements in expressive arts as a free or approved elective. *This course can only be taken in conjunction with a "writing-intensive" engineering class.*

Some "writing-intensive" engineering classes may require students to enroll in this supplementary course. Instructors from the Engineering Communications Program work with engineering faculty members to prepare students for writing assignments. Intended to strengthen understanding of the course content while enhancing communications skills. May be taken more than once, with different engineering courses.

ENGRC 350 Engineering Communications

Fall, spring, summer. 3 credits. Limited to 20 students per section.

Emphasizes technical and professional writing; also includes oral and visual presentation. Communications in real-life engineering contexts are analyzed, with case studies and assignments modeled on professional situations. Students learn to adapt language and formats—letters, memoranda, instructions, definitions, proposals, reports—to audiences having different needs and levels of technical expertise. Students also consider the social and ethical implications of the communications they encounter and produce. Taught as a workshop, with ample time for discussion. The goal throughout is clear, well-organized, responsible, and forceful professional communication. Lab fee will be charged to cover photocopying costs. Fulfills the college technical writing requirement.

ENGRC 435 Communications for Engineering Managers

Fall, spring. 3 credits. Limited to 20 students per section.

Guidance and practice in professional writing and in developing effective responses to case studies that replicate actual problems in industry. Learn techniques for planning and organizing action; controlling and monitoring progress; motivating, leading, coaching, and appraising co-workers; handling organizational power and politics; and managing conflict. Focus on issues such as writing successful proposals, managing engineering teams and projects, and communicating with lawyers, regulators, and the general public. Fulfills the college technical writing requirement. Lab fee will be charged to cover photocopying costs.

Introduction to Engineering Courses

Courses in this category are freshman-level courses intended to introduce students to various aspects of engineering. They have no prerequisites and are always cross-listed with a department.

ENGRI 110 The Laser and Its Applications in Science, Technology, and Medicine (also A&EP 110)

Fall, spring. 3 credits.

The principles of laser action, types of laser systems, elements of laser design, and applications of lasers in science, technology, and medicine are discussed. In the laboratory students build and operate a nitrogen laser and a tunable dye laser. Demonstration experiments with several types of lasers illustrate phenomena such as holography, laser processing of materials, and Raman spectroscopy.

ENGRI 111 Materials by Design (also MS&E 111)

Fall. 3 credits. E. P. Giannelis.

Explores the relationship between atomic structure and macroscopic properties of such diverse materials as metals, ceramics, polymers, and semiconductors. Hands-on project involves dissecting and analyzing various consumer products like a disposable camera or portable cassette player. Emphasis is placed on materials identification and their selection to perform an engineering function.

ENGRI 112 Introduction to Chemical Engineering (also CHEME 112)

Fall, spring. 3 credits. Limited to freshmen. T. M. Duncan, C. Cohen.

Design and analysis of processes involving chemical change. Strategies for design, such as creative thinking, conceptual blockbusting, and (re)definition of the design goal, in the context of contemporary chemical engineering. Methods for analyzing designs, such as mathematical modeling, empirical analysis by graphics, and dynamic scaling through dimensional analysis, to assess product quality, economics, safety, and environmental issues.

ENGRI 113 Environmental Systems Engineering (also CEE 113)

Fall. 3 credits. Not open (without instructor's permission) to upper-division engineering students, who should take CEE 120 instead. Staff.

Introduction to analysis, management, and modeling of environmental systems. Discussion of physical, chemical, and biological processes affecting environmental quality. Use of computers to simulate environmental phenomena. Examples include management of water resources, ecosystems concepts, solid waste management, and water quality in surface and ground waters.

ENGRI 114 An Introduction to Electrical Engineering Design

Spring. 3 credits.

An introduction to electrical engineering and electronic circuit design. Students work in small groups on a series of electric circuit projects leading to the team design of a working fiber optic transmitter-receiver system. The laboratories and lectures introduce the concepts and principles of electronic circuits and focus upon circuits useful in the design project. Laboratory fee required.

ENGRI 115 Engineering Application of Operations Research (also OR&IE 115)

Fall, spring. 3 credits.

An introduction to the problems and methods of Operations Research and Industrial Engineering focusing on problem areas (including inventory, network design, and resource allocation), the situations in which these problems can be found, and several standard solution techniques. In the computer laboratory, students will encounter problem simulations and use some standard software packages.

ENGRI 116 Modern Structures (also CEE 116)

Fall. 3 credits. A. R. Ingraffea.

An introduction to the basic principles of structural engineering and to structural forms. Emphasis is placed on how various types of structures carry loads. Concepts are illustrated by a series of case studies of major structures such as spacecraft, skyscrapers, bridges, shell structures, and dams. The philosophy of engineering design and lessons learned from structural failures and earthquakes are discussed. A semester project involves the design and construction of a small balsa-wood bridge.

ENGRI 117 Introduction to Mechanical Engineering (also M&AE 117)

Spring. 3 credits.

An introduction to topics of current interest in mechanical engineering. Specific topics vary from offering to offering. Students are urged to check in Upson 112 for details. In 1993, the course was "The Engine and the Atmosphere." This course discussed engines and their design including constraints imposed by the laws of thermodynamics, the combustion process, and the products of the exhaust. This led to a discussion of local and global environmental problems, including greenhouse warming. The dilemma of productivity versus environmental degradation and the engineer's role in this was also discussed. This offering was intended for students wishing to study mechanical engineering as well as environmental, chemical, and civil engineering.

ENGRI 118 Design Integration: A Portable CD Player (also MS&E 118)

Spring. 3 credits.

This course will examine the roles of various engineering disciplines on the design of a portable compact disc (CD) player. Students will be introduced to elements of mechanical, electrical, materials, environmental, manufacturing, and computer engineering as related to the CD player. Laboratory sessions and demonstrations will be used to illustrate the principles of design.

ENGRI 121 Fission, Fusion, and Radiation (also NS&E 121)
Spring. 3 credits.
A lecture, demonstration, and laboratory course on (1) the physical nature and biological effects of nuclear radiation; (2) the benefits and hazards of nuclear energy; (3) light-water reactors, breeder reactors, and fusion reactors; and (4) the uses of nuclear radiation in physical and biological research. The laboratory work and demonstrations involve criticality and the control of Cornell's two research reactors; detection of, and protection against, nuclear radiation; neutron activation analysis using gamma-ray spectroscopy; and plasma sources and devices.

ENGRI 122 Earthquake! (also Geology 122)
For description, see GEOL 122. L. Brown.

[ENGRI 123 Sensors and Actuators
Fall. 3 credits. Not offered 1995–96.]

ENGRI 181 Engineering in Context (also Science and Technology Studies 181)
Fall. 3 credits. No prerequisites. Illustrated lecs; multimedia lab.
Fundamental engineering principles designed to introduce engineering and other majors to the traditions and practices of the engineering profession and their effects on our culture. Technological literacy for non-engineers.) Development of scientific and engineering-design principles in a variety of technological contexts. Overview of the development of engineering as a profession and the evolution of the design process. The relationship between science, technology, and engineering. Civil, mechanical, electrical, chemical, and other engineering project case studies. The implications and uses of information technologies in society.

ENGRI 185 Art, Archaeology, and Analysis (also ARKEO 285, ART 272, CLASS 285, ENGL 285, MS&E 285, NS&E 285, PHYS 200)
Spring. 3 credits. 3 lecs. Does not meet liberal studies distribution requirements.
An interdepartmental course on the application of techniques of physical sciences and engineering to issues in cultural research. In each portion of the course, several archaeological artifacts or works of art will be discussed with a focus on the historical and technical aspects of their creation and on their analysis by modern methods including microscopic, infra-red, and x-ray examination and by techniques using neutrons. Determination of chemical composition and/or spatial patterns and images are used to identify pigments, inks, clays, etc., to deduce geographical origins; to date and authenticate the objects; and to assess their state for purposes of conservation.

Engineering Distribution Courses

Courses in this category are sophomore-level courses cross-listed with a department. These courses are intended to introduce students to more advanced concepts of engineering and may require pre- or co-requisites.

ENGRD 201 Introduction to the Physics and Chemistry of the Earth (also GEOL 201)
Spring. 3 credits. Prerequisites: Mathematics 191 and Physics 112. L. M. Cathles.
Formation of the solar system: accretion and evolution of the earth. The rock cycle: radioactive isotypes and the geological time scale, plate tectonics, rock and minerals, earth dynamics, mantle plumes. The hydrologic cycle: runoff, floods and sedimentation, groundwater flow, contaminant transport. Weathering cycle: chemical cycles, CO_2 (weathering), rock cycle, controls on global temperature (CO_2 or ocean currents), oil and mineral resources.

ENGRD 202 Mechanics of Solids (also T&AM 202)
Fall, spring. 3 credits.
Principles of statics, force systems, and equilibrium; frameworks; mechanics of deformable solids, stress, strain, statically indeterminate problems; mechanical properties of engineering materials; axial force, shearing force, bending moment, plane stress; Mohr's circle; bending and torsion of bars; buckling and plastic behavior.

ENGRD 203 Dynamics (also T&AM 203)
Fall, spring. 3 credits. Prerequisite: T&AM 202, coregistration in Mathematics 294, or permission of instructor.
Newtonian dynamics of a particle, systems of particles, a rigid body. Kinematics, motion relative to a moving frame. Impulse, momentum, angular momentum, energy. Rigid-body kinematics, angular velocity, moment of momentum, the inertia tensor. Euler equations, the gyroscope.

ENGRD 210 Introduction to Electrical Systems (also ELE E 210)
Fall, spring. 3 credits. Corequisites: Mathematics 294 and Physics 213.
Circuit elements and laws, analysis techniques, operational amplifiers. Response of linear systems, with an introduction to complex frequency and phasors, forced response, average power, transfer function, pole-zero concepts, and the frequency spectrum.

ENGRD 211 Computers and Programming
For description, see COM S 211.

ENGRD 212 Structure and Interpretation of Computer Programs
For description, see COM S 212.

ENGRD 219 Mass and Energy Balances (also CHEME 219)
Fall. 3 credits. Co-requisite: physical or organic chemistry or permission of instructor. C. Cohen.
Engineering problems involving material and energy balances. Batch and continuous reactive systems in the steady and unsteady states. Introduction to phase equilibria for multicomponent systems. Humidification processes.

ENGRD 221 Thermodynamics (also M&AE 221)
Fall, spring. 3 credits. Prerequisites: Mathematics 192 and Physics 112.
The definitions, concepts, and laws of thermodynamics. Applications to ideal and real gases, multiphase pure substances, gaseous reactions. Heat-engine and heat-pump cycles, with an introduction to energy-conversion systems.

ENGRD 222 Introduction to Scientific Computation
For description, see COM S 222.

ENGRD 230 Introduction to Digital Systems (also ELE E 230)
Fall, spring. 4 credits. Prerequisite: COM S 100.
An introduction to basic principles and design techniques for digital systems such as computers and communications systems. Includes Boolean algebra, switching circuits, finite state machines, and system design methodology.

ENGRD 241 Engineering Computation (also CEE 241)
Fall, spring. 3 credits. Prerequisites: COM S 100 and Math 293. Co-requisite: Math 294. J. R. Stedinger, P. L.-F. Liu.
This course introduces the discipline of numerical methods while developing programming and graphics proficiency with MATLAB and spreadsheets. Numerical analysis topics considered are accuracy, precision, Taylor-series approximations, truncation and round-off errors, condition numbers, operation counts, convergence, and stability. Included are numerical methods for solving engineering problems that entail roots of functions, simultaneous linear equations, regression, interpolation, numerical differentiation and integration, and ordinary differential equations. The context and solution of partial differential equations are broached. Applications are drawn from different areas of engineering.

ENGRD 261 Introduction to Mechanical Properties of Materials (also MS&E 261)
Fall. 3 credits. S. L. Sass.
The relationship of elastic deformation, plastic deformation, and fracture properties to structure and defects on a microscopic scale in metals, ceramics, polymers, and composite materials. Design and processing of materials to achieve high modulus, damping capacity, hardness, fracture strength, creep resistance, or fatigue resistance. Flaw-tolerant design methods using fracture mechanics.

ENGRD 262 Introduction to Electrical Properties of Materials (also MS&E 262)
Fall. 3 credits. Prerequisite: co-registration in PHYS 213 or electricity and magnetism in high school physics. M. O. Thompson.
Electrical and structural properties of semiconductors, the operation of p-n junctions and transistors, and the processing methods used to form modern integrated circuits. Electrical conduction in metal films, semiconductors, bipolar and field-effect transistors and light-emitting diodes. Diffusion, ion implantation, oxidation, metallization, and other process steps in fabricating semiconductor devices. Interplay between structural and electrical properties and their application to the design of semiconductor devices and integrated circuits.

ENGRD 264 Computerized Instrumentation Design (also A&EP 264)
Fall, spring. 3 credits. Prerequisites: Engr 100 or CS 100. 1 lec, 1 lab. Fall: T. Cool; spring: J. Brock.
This course covers the use of a small computer in an engineering or scientific research laboratory. Various experiments are performed using an IBM-AT style computer (80486) running MS-DOS. The experiments and devices to be investigated include: input and output ports, analog to digital converters (ADC), digital to analog converters (DAC), thermistors, optical sensors, digital temperature control, non-linear least squares curve fitting of experimental data, thermal diffusion,

and viscosity of fluids. A second goal of this course is to develop effective written communication skills in the context of science and engineering. A number of rhetorical principles will be presented that can produce clarity in communication without oversimplifying scientific issues. Students will prepare progress reports, technical reports, and formal articles based on the experiments.

ENGRD 270 Basic Engineering Probability and Statistics (also OR&IE 270)

Fall, spring. 3 credits. Prerequisite: first-year calculus.

This course should give students a working knowledge of basic probability and statistics and their application to engineering. Computer analysis of data and simulation are emphasized. Topics include random variables, probability distributions, expectation, estimation, testing, experimental design, quality control, and regression.

AGRICULTURAL AND BIOLOGICAL ENGINEERING

Courses in agricultural and biological engineering will be found in the section listing the offerings of the College of Agriculture and Life Sciences.

APPLIED AND ENGINEERING PHYSICS

A&EP 110 The Laser and Its Applications in Science, Technology, and Medicine (also ENGRI 110)

Fall, spring. 3 credits. This is a course in the Introduction to Engineering series.

For description see Engineering Common Courses.

A&EP 264 Computer-Instrumentation Design (also ENGRI 264)

Fall, spring. 3 credits. Prerequisites: Engr 100 or COM S 100.

For description see Engineering Common Courses.

A&EP 303 Introduction to Nuclear Science and Engineering I (also NS&E 303)

Fall. 3 credits. Prerequisite: Physics 214 or Mathematics 294.

For description see NS&E 303.

A&EP 320 Engineering Biophysics: The Physics of Life

Spring. 3 credits. Prerequisites: freshman and sophomore chemistry, physics, math.

Introduction to biophysics for engineers to students interested in bioengineering.

A&EP 321 Mathematical Physics I

Fall, summer. 4 credits. Prerequisite: Math 294. Intended for upper-level undergraduates in the physical sciences.

Review of vector analysis; complex variable theory, Cauchy-Rieman conditions, complex Taylor and Laurent series, Cauchy integral formula and residue techniques, conformal mapping; Fourier Series; Fourier and Laplace transforms; ordinary differential equations; separation of variables. Texts: *Mathematical Methods for Physicists*, by Arfken; *Mathematical Physics*, by Butkov.

A&EP 322 Mathematical Physics II

Spring. 4 credits. Prerequisite: A&EP 321. Second of the two-course sequence in mathematical physics intended for upper-level undergraduates in the physical sciences.

Partial differential equations, Bessel functions, spherical harmonics, separation of variables, wave and diffusion equations, Laplace, Helmholtz and Poisson's Equations, transform techniques, Green's functions; integral equations, Fredholm equations, kernals; complex variables, theory, branch points and cuts, Riemann sheets, method of steepest descent; tensors, contravariant and covariant representations; group theory, matrix representations, class and character. Texts: *Mathematical Methods for Physicists*, by Arfken; *Mathematical Physics*, by Butkov.

A&EP 330 Modern Experimental Optics (see also PHYS 330)

Fall. 4 credits. Enrollment limited. Prerequisites: Physics 214 or equivalent. Lec M 2:30–3:20; lab T W 1:25–4:25. E. Bodenschatz.

A practical laboratory course in basic and modern optics. The various projects cover a wide range of topics from geometrical optics to classical wave properties such as interference, diffraction, and polarization. Each experimental setup is equipped with standard, off-the-shelf optics and opto-mechanical components to provide the students with hands-on experience in practical laboratory techniques currently employed in physics, chemistry, biology and engineering. The students will also be introduced to digital imaging and image processing techniques.

A&EP 333 Mechanics of Particles and Solid Bodies

Fall, summer. 4 credits. Prerequisites: Physics 112 or 116 and coregistration in A&EP 321 or equivalent or permission of instructor.

Newton's mechanics; constants of the motion; many-body systems; linear oscillations; variational calculus; Lagrangian and Hamiltonian formalism for generalized coordinates; non-inertial reference systems; central-force motion; motion of rigid bodies; small vibrations in multi-mass systems; nonlinear oscillations; basic introduction to relativistic mechanics. Emphasis on mathematical treatments, physical concepts, and applications. (On the level of *Classical Dynamics*, by Marion and Thorton).

A&EP 355 Intermediate Electromagnetism

Fall, summer. 4 credits. Prerequisites: PHYS 214 or 217 and coregistration in A&EP 321 or equivalent, or permission of instructor.

Topics: vector calculus, electrostatics, analytic and numerical solutions to Laplace's equation in various geometries, electric and magnetic multipoles, electric and magnetic materials, energy in fields, quasistatics and magnetic circuit design. Emphasis is on developing proficiency with analytical and numerical solution techniques in order to solve real-world design problems.

A&EP 356 Intermediate Electrodynamics

Spring. 4 credits. Prerequisite: A&EP 355 and coregistration in A&EP 322 or equivalent, or permission of instructor.

Topics: electromagnetic waves, waveguides, transmission lines, dispersive media, radiation, special relativity, interference phenomena. Emphasis on physical concepts and developing ability to design/analyze microwave circuits and antenna arrays.

A&EP 360 Electronic Circuits (also A&EP 363)

Fall, spring. 4 credits. Prerequisites: Physics 208 or 213 or permission of the instructor. No previous experience with electronics assumed, however the course moves quickly through some introductory topics such as basic DC circuits. Fall term usually less crowded. 1 lec, 2 labs. Fall: E. Kirkland; spring: J. Alexander.

Analyze, design, build and experimentally test circuits used in scientific and engineering instrumentation (with discrete components and integrated circuits). Analog circuits: resistors, capacitors, operational amplifiers (linear amplifiers with feedback, oscillators, comparators), filters, diodes and transistors. Digital circuits: combinatorial (gates) and sequential (flip-flops, counters, shift registers) logic. Computer interfacing introduced and used to investigate digital to analog (DAC) and analog to digital conversion (ADC) and signal averaging.

A&EP 361 Introductory Quantum Mechanics

Spring. 4 credits. Prerequisites: A&EP 333 or Physics 318; coregistration in A&EP 322 or equivalent and in A&EP 356 or Physics 326.

A first course in the systematic theory of quantum phenomena. Topics include the harmonic oscillator, the Dirac formalism, angular momentum, the hydrogen atom, and perturbation theory.

A&EP 363 Electronic Circuits

Fall, spring. 4 credits. Prerequisites: Physics 208 or 213 or permission of the instructor. No previous experience with electronics assumed; however, the course moves quickly through some introductory topics such as basic DC circuits. Fall term usually less crowded. 1 lec, 2 labs. Fall: E. Kirkland; spring: J. Alexander.

Analyze, design, build and experimentally test circuits used in scientific and engineering instrumentation (with discrete components and integrated circuits). Analog circuits: resistors, capacitors, operational amplifiers (linear amplifiers with feedback, oscillators, comparators), filters, diodes and transistors. Digital circuits: combinatorial (gates) and sequential (flip-flops, counters, shift registers) logic. Computer interfacing introduced and used to investigate digital to analog (DAC) and analog to digital conversion (ADC) and signal averaging.

A&EP 423 Statistical Thermodynamics

Fall. 4 credits. Prerequisite: Introductory three-semester physics sequence plus one year of junior-level mathematics.

Quantum statistical basis for equilibrium thermodynamics, microcanonical, canonical and grand canonical ensembles, and partition functions. Classical and quantum ideal gases, paramagnetic and multiple-state systems. Maxwell-Boltzmann, Fermi-Dirac, and Bose-Einstein statistics and applications. Introduction to systems of interacting particles. At the level of *Thermal Physics*, by Kittel and Kroemer, and *Statistical Physics*, by Rosser.

A&EP 434 Continuum Physics
Spring. 4 credits. Prerequisites: A&EP 333 and 356 or equivalent.
Elasticity and Fluid Mechanics: Basic phenomena of elasticity, simple beams, stress and strain tensors, materials equations, equations of motion, general beam equations, waves; Fluids: basic phenomena, Navier Stokes equation, scaling laws, Reynolds and Froude numbers, Poisseuille flows, Stokes drag on sphere, boundary layers, invicid and incompressible flows, potential flow, conservation laws, Bernoulli equation, vorticity and circulation, life of wings, jets, instabilities, introduction to turbulence. Projects in combination with AEP 438 possible. At the level of Lai, Rubin and Krempl, *Continuum Mechanics,* and Tritton, *Introduction to Fluid Mechanics.*

A&EP 438 Computational Engineering Physics
Spring. 3 credits. Prerequisites: COM S 100, A&EP 321, 333, 355, 361, or equivalent, or permission of instructor; co-registration in 361 permitted.
Numerical computation (derivatives, integrals, differential equations, matrices, boundary-value problems, relaxation, Monte Carlo methods, etc.) will be introduced and applied to engineering physics problems that cannot by solved analytically (three-body problem, electrostatic fields, quantum energy levels, etc.). Computer programming required (in C or optionally C++, FORTRAN, or Pascal). Some prior exposure to programming assumed but no previous experience with C assumed.

A&EP 440 Quantum and Nonlinear Optics
Spring. 4 credits. Prerequisites: A&EP 356, A&EP 361 or equivalent.
An introduction to the fundamentals of the interaction of laser light with matter. Topics include the propagation of laser beams in bulk media and in guided-wave structures, the origins of optical nonlinearities, harmonic generation, self-focusing, optical bistability, propagation of ultrashort pulses, solitons, optical phase conjugation, optical resonance and two-level atoms, atom cooling and trapping, multiphoton processes, spontaneous and simulated scattering, ultra-intense laser-matter interactions.

A&EP 484 Introduction to Controlled Fusion: Principles and Technology (also ELE E 484, M&AE 559, and NS&E 484)
Spring. 3 credits. Not offered every year. Prerequisites: Physics 112, 213, and 214, or equivalent background in electricity and magnetism and mechanics, and permission of instructor. Intended for seniors and graduate students.
For description see NS&E 484.

A&EP 490 Independent Study in Engineering Physics
Credit to be arranged.
Laboratory or theoretical work in any branch of engineering physics under the direction of a member of the faculty. The study can take a number of forms; for example, design of laboratory apparatus, performance of laboratory measurements, computer simulation or software developments, theoretical design and analysis. Details to be arranged with respective faculty member.

A&EP 606 Introduction to Plasma Physics
For description, see ELE E 581.

A&EP 607 Advanced Plasma Physics
For description, see ELE E 582.

[A&EP 609 Low-Energy Nuclear Physics
Fall. 4 credits. Prerequisite: an introductory course in modern physics, including quantum mechanics. Offered alternate years. Not offered 1995–96.
The nuclear interaction. Properties of ground and excited states of nuclei; models of nuclear structure; alpha, beta, gamma radioactivity; low-energy nuclear reactions—resonant and nonresonant scattering, absorption, and fission. At the level of *Introduction to Nuclear Physics*, by Enge.]

A&EP 612 Nuclear Reactor Theory
Fall. 4 credits. Prerequisites: a year of advanced calculus and some nuclear physics.
Physical theory of fission reactors. Fission and neutron interactions with matter; theory of neutron diffusion; slowing down and thermalization; calculations of criticality and neutron-flux distribution in nuclear reactors. Reactor kinetics. At the level of *Nuclear Reactor Theory*, by Lamarsh.

A&EP 615 Molecular Biophysics of Cell Dynamics
To be arranged. 3 credits. Prerequisite: Graduate or senior level in science or engineering.
Physical mechanisms in cellular function: statistical thermodynamics of ion channel molecules, single channel recording, receptor signaling, molecular motility and mobility. Intermolecular forces, spontaneous self-assembly of mesoscopic structures, molecular mechanisms of secretion, supramolecular mechanisms in memory and development.

A&EP 633 Nuclear Engineering
Fall. 4 credits. Prerequisite: introductory course in nuclear engineering.
The fundamentals of nuclear reactor engineering, reactor siting and safety, fluid flow and heat transfer, control, environmental effects, and radiation protection.

A&EP 634 Nuclear Engineering Design Seminar
Spring. 4 credits. Prerequisite: A&EP 633.
A group design study of a selected nuclear system. Emphasis is on safety, siting, and radiation protection in the design of nuclear systems.

A&EP 638 Intense Pulsed Electron and Ion Beams: Physics and Technology
Spring. 2 credits. Prerequisites: A&EP 606 (ELE E 581) and 607 (ELE E 582) or equivalent, or permission of instructor. Offered when demand warrants.
Topics include (1) theoretical aspects of intense electron and ion beams, such as equilibria and stability; (2) technology of intense beam production, such as pulsed-power generator principles, and electron and ion diode operation; and (3) applications of intense beams, such as to controlled fusion, microwave generation, and laser pumping. Extensive discussion of experimental results.

A&EP 651 Nuclear Measurements Laboratory
Spring. 4 credits. Prerequisite: A&EP 609 or equivalent. Primarily for graduate students in nuclear fields. A less-intensive related course, NS&E 551, is intended for students in non-nuclear fields in which nuclear methods are used.
Lectures on interaction of radiation with matter, radiation protection, and nuclear instruments and methods. About fifteen experiments are available in radiation detection, attenuation, and measurement; electronic instrumentation, including computerized systems; activation analysis; neutron radiography; neutron moderation and reactor physics; neutron diffraction; and low-energy nuclear physics with neutron beams. The TRIGA reactor and the Zero Power Reactor critical facility are used. Students select seven or eight experiments to meet their interests and needs. At the level of *Radiation Detection and Measurement,* by Knoll.

A&EP 661 Microcharacterization
Fall. 3 credits. Prerequisites: introductory three-semester physics sequence or an introductory course in modern physics. At the senior/first-year graduate level.
The basic physical principles underlying the many modern microanalytical techniques available for characterizing materials from volumes less than a cubic micron. Discussion centers on the physics of the interaction process by which the characterization is performed, the methodology used in performing the characterization, the advantages and limitations of each technique, and the instrumentation involved in each characterization method.

A&EP 662 Micro/Nano-fabrication and Processing
Spring. 3 credits.
An introduction to the fundamentals of micro and nano-fabricating and patterning thin-film materials and surfaces, with emphasis on electronic materials, with emphasis on electronic and optical materials, micromechanics, and other applications. Vacuum and plasma thin-film deposition processes. Photon, electron, X-ray, and ion-beam lithography. Techniques for pattern replication by plasma and ion processes. Emphasis is on understanding the physics and materials science that define and limit the various processes. At the level of Brodie and Muray.

A&EP 681–689 Special Topics in Applied Physics
Topics, instructors, and credits to be announced each term. Typical topics include quantum superconducting devices, physics of submicron conductors, nonlinear fluctuators, biophysical processes, molecular fluorescence.

A&EP 711 Principles of Diffraction (also MS&E 610)
Spring. 4 credits. Offered alternate years.
Introduction to diffraction phenomena as applied to solid-state problems. Scattering and absorption of neutrons, electrons, and X-ray beams, with particular emphasis on synchrotron radiation X-ray sources. Diffraction from two- and three-dimensional periodic lattices. Fourier representation of scattering centers and the effect of thermal vibrations. Diffraction from almost periodic structures, surface layers, gases, and amorphous materials. Survey of dynamical diffraction from perfect and imperfect lattices. Several laboratory experiments will be conducted.

A&EP 751/752 Project
751, fall and spring. 6–12 credits to be arranged. Required for candidates for the M.Eng. (Engineering Physics) degree.
Independent study under the direction of a member of the university faculty. Students participate in an independent research project through work on a special problem related to their field of interest. A formal and complete research report is required.

A&EP 753 Special Topics Seminar in Applied Physics
Fall. 4 credits. Prerequisite: undergraduate physics. Required for candidates for the M.Eng. (Engineering Physics) degree and recommended for seniors in engineering physics.
Special topics in applied science, with focus on areas of applied physics and engineering that are of current interest. Subjects chosen are researched in the library and presented in a seminar format by the students. Effort is made to integrate the subjects within selected subject areas such as atomic, biological, computational, optical, plasma, and solid-state physics, or microfabrication technology, as suggested by the students and coordinated by the instructor.

CHEMICAL ENGINEERING

CHEME 101 Nonresident Lectures
Spring. 1 credit. F. Rodriguez.
Given by lecturers invited from industry and from selected departments of the university to assist students in their transition from college to industrial life.

CHEME 112 Introduction to Chemical Engineering (also ENGRI 112)
Fall, spring. 3 credits. Limited to freshmen. T. M. Duncan, C. Cohen.
For description see Engineering Common Courses.

CHEME 219 Mass and Energy Balances (also ENGRD 219)
Fall. 3 credits. Corequisite: physical or organic chemistry or permission of instructor. C. Cohen.
For description see Engineering Common Courses.

CHEME 313 Chemical Engineering Thermodynamics
Fall. 4 credits. Corequisite: physical chemistry. A. Z. Panagiotopoulos.
A study of the first and second laws, with application to batch and flow processes. Thermodynamic properties of fluids; applications of thermodynamics to compressors, power cycles, refrigeration; thermodynamic analysis of processes. Thermodynamics of mixtures, phase equilibria and phase diagrams. Estimation methods. Heat effects, chemical equilibria.

CHEME 323 Fluid Mechanics
Fall. 3 credits. Prerequisites: CHEME 219 and engineering mathematics sequence. W. B. Streett.
Fundamentals of fluid mechanics. Macroscopic and microscopic balances. Applications to problems involving viscous flow.

CHEME 324 Heat and Mass Transfer
Spring. 3 credits. Prerequisite: CHEME 323. D. A. Hammer.
Fundamentals of heat and mass transfer. Macroscopic and microscopic balances. Applications to problems involving conduction, convection, and diffusion.

CHEME 332 Analysis of Separation Processes
Spring. 4 credits. Prerequisites: CHEME 313 and 323. W. B. Streett.
Analysis of separation processes involving phase equilibria and mass transfer; some use of the digital computer. Phase equilibria; binary and multicomponent distillation; liquid-liquid extraction; gas absorption, absorption, membrane separations.

CHEME 390 Reaction Kinetics and Reactor Design
Spring. 3 credits. Prerequisites: CHEME 313 and 323. R. P. Merrill.
A study of chemical reaction kinetics and principles of reactor design for chemical processes.

CHEME 432 Chemical Engineering Laboratory
Fall. 4 credits. Prerequisites: CHEME 323, 324, 332, and 390. Staff.
Laboratory experiments in fluid dynamics, heat and mass transfer, kinetics, other operations. Correlation and interpretation of data. Technical report writing.

CHEME 462 Chemical Process Design
Spring. 4 credits. Prerequisite: CHEME 432. Staff.
A consideration of process and economic alternatives in selected chemical processes; design and assessment.

CHEME 472 Process Control
Fall. 3 credits. Prerequisites: CHEME 324 and 390. J. R. Engstrom.
Analysis of the dynamics of chemical processes and design of feedback and feedforward control systems. Laplace transform techniques; stability analysis; frequency-response analysis. An introduction to multivariable control. The laboratory includes experiments on transient response, frequency response, controller tuning, and discussions of typical process instrumentation.

CHEME 481 Biomedical Engineering
Fall. 3 credits. Prerequisite: CHEME 324 or equivalent or permission of instructor. D. A. Hammer.
Special topics in biomedical engineering, including cell separations, blood flow, design of artificial devices, biomaterials, image analysis, biological transport phenomena, pharmacokinetics and drug delivery, biomedical transducers (ECG and pace makers), and analysis of physiological processes such as adhesion, mobility, secretion, and growth.

CHEME 490 Undergraduate Projects in Chemical Engineering
Fall, spring. Variable credit.
Research or studies on special problems in chemical engineering.

CHEME 491 Undergraduate Teaching in Chemical Engineering
Fall, spring. 1 credit.
Methods of instruction in chemical engineering acquired through discussions with faculty and by assisting with the instruction of freshmen and sophomores.

CHEME 520 Chemical, Pharmaceutical, and Food Processing
Spring. Variable to 3 credits. Prerequisite: seniors or M.Eng. students with one term of college chemistry, C. Cohen, R. Finn, and S. Mulvaney.
This course consists of three equal parts, each worth one credit. The chemical part is open to non-chemical engineers only and covers process fundamentals, design, and control of continuous large-scale chemical processes. Pharmaceutical processing covers fermentation, purification, and sterilization. Food processing emphasizes food preservation principles and technology.

CHEME 562 Managing Chemical Process Design
Spring. 1 or 2 credits. Prerequisite: CHEME 462. Staff.
Guidance and evaluation of chemical process designs developed by teams of chemical engineers.

CHEME 564 Design of Chemical Reactors
Spring. 3 credits. Prerequisite: CHEME 390 or equivalent. Not offered spring 1996 and 1998; next offered spring 1997. P. Harriott.
Design, scale-up, and optimization of chemical reactors with allowance for heat and mass transfer and nonideal flow patterns. Homework problems feature analysis of published data for gas-solid, gas-liquid, and three-phase reaction systems.

CHEME 565 Design Project
Fall, spring. 3 or 6 credits. Required for students in the M.Eng.(Chemical) program.
Design study and economic evaluation of a chemical processing facility, alternative methods of manufacture, raw-material preparation, food processing, waste disposal, or some other aspect of chemical processing.

[CHEME 566 Systematic Methods for Process Design
Spring. 3 credits. Prerequisite: CHEME 332 or equivalent. Not offered 1995–96.
An introduction to the synthesis and use of computer systems for steady-state simulation of chemical processes. Systematic design methods for vapor-liquid processes, including synthesis methods for separation systems and heat exchanger networks.]

CHEME 590 Special Projects in Chemical Engineering
Fall, spring. Variable credit. Limited to graduate students.
Non-thesis research or studies on special problems in chemical engineering.

CHEME 640 Polymeric Materials
Fall. 3 credits. F. Rodriguez.
Chemistry and physics of the formation and characterization of polymers. Principles of fabrication.

CHEME 642 Polymeric Materials Laboratory
Spring. 2 or 3 credits. Prerequisite: CHEME 640. F. Rodriguez.
Experiments in the formation, characterization, fabrication, and testing of polymers.

CHEME 643 Introduction to Bioprocess Engineering
Spring. 3 credits. Prerequisite: CHEME 390 or permission of instructor. No prior background in the biological sciences required. M. L. Shuler.

A discussion of principles involved in using microorganisms, tissue cultures, and enzymes for processing. Application to food, fermentation, and pharmaceutical industries and to biological waste treatment.

CHEME 645 Advanced Concepts in Biological Engineering
Spring. 3 credits. Prerequisite: CHEME 643 or equivalent or permission of instructor. Not offered spring 1997; next offered spring 1996. D. A. Hammer.
Fundamentals of biochemical and biomedical engineering, with additional emphasis on cell and membrane biophysics. Topics include cell-surface receptor phenomena, protein diffusion, cell adhesion, membrane biophysics, cell motility and growth, mathematical immunology, virus binding and infection, enzyme catalysis, bioseparation, and genetically modified organisms.

[CHEME 648 Polymers in Electronics and Related Areas
Spring. 3 credits. Prerequisite: 640 or permission of instructor. Not offered 1995–96. F. Rodriguez.
Applications of polymers as resists for microlithography, as insulators, and as conductors. Radiation effects, polymer synthesis, and surface characterization. Additional special topics may be covered.]

[CHEME 656 Separations Using Membranes or Porous Solids
Spring. 3 credits. Prerequisites: ChemE 324 and 332. Not offered spring 1996 and 1998; next offered spring 1997. P. Harriott.
Diffusion of small molecules in gases, liquids, and solids. Membrane separation processes including gas separation, pervaporation, reverse osmosis, and ultrafiltration. Purification of gases and liquids by adsorption, ion exchange, and chromatography.]

CHEME 661 Air Pollution Control
Fall. 3 credits. P. Harriott.
Origin of air pollutants, U.S. emission standards, dispersion equations. Design of equipment for removal of particulate and gaseous pollutants formed in combustion and chemical processing.

CHEME 673 Adsorption and Reactions on Chemically Reactive Solids
Fall. 3 credits. R. P. Merrill.
The physics and chemistry of reactions at solid surfaces are presented in molecular detail. The emphasis is on the use of modern spectroscopic techniques to determine the geometric structure, electronic properties, and reaction sequences on well-defined surfaces. Examples from the preparation of optoelectronic materials and from catalysis will be given to illustrate the concepts and principles presented.

CHEME 675 Synthetic Polymer Chemistry (also MS&E 671 and Chemistry 671)
Fall. 4 credits. Prerequisites: Chem 359–360 or equivalent or permission of instructor. MS&E 620 is recommended.
For description see Chemistry 671.

[CHEME 681 Dynamics of Colloidal Systems
Fall. 3 credits. Prerequisite: basic understanding of thermodynamics and fluid dynamics. Offered alternate years. Not offered fall 1995 and fall 1997; next offered fall 1996. A. Z. Panagiotopoulos.
Fundamental descriptions of colloidal systems under equilibrium and non-equilibrium conditions. Phase equilibria of surfactant systems, thermodynamics of micelle formation, forces between colloidal particles, electrokinetic phenomena, flocculation and aggregation, transport of surfactant in interfacial systems, stability of emulsions, and dynamics of thin films. Open to advanced undergraduates and graduate students from all fields.]

CHEME 711 Advanced Chemical Engineering Thermodynamics
Fall. 3 credits. Prerequisite: CHEME 313 or equivalent. K. E. Gubbins.
Postulatory approach to thermodynamics. Legendre transformations. Equilibrium and stability of general thermodynamic systems. Applications of thermodynamic methods to advanced problems in chemical engineering. Introduction to statistical mechanical ensembles, phase transitions, Monte Carlo methods, and theory of liquids.

CHEME 713 Chemical Kinetics and Dynamics
Spring. 3 credits. Prerequisite: CHEME 390 or equivalent. J. R. Engstrom.
Microscopic and macroscopic viewpoints. Connections between phenomenological chemical kinetics and molecular reaction dynamics. Reaction cross sections, potential energy surfaces, and dynamics of bimolecular collisions. Molecular beam scattering. Transition state theory. Unimolecular reaction dynamics. Complex chemically reacting systems: reactor stability, multiple steady states, oscillations, and bifurcation. Reactions in heterogeneous media. Free-radical mechanisms in combustion and pyrolysis.

CHEME 721 Thermodynamics and Phase Change Heat Transfer (also M&AE 652)
Spring. 4 credits. Prerequisite: graduate standing or permission of instructor.
For description see M&AE 652.

CHEME 731 Advanced Fluid Mechanics and Heat Transfer
Fall. 3 credits. Prerequisites: CHEME 323 and 324 or equivalent. D. L. Koch.
Derivation of the equations of motion for Newtonian fluids. Low Reynolds number fluid dynamics, lubrication theory, inviscid fluid dynamics. Boundary layer theory. Convective and conductive heat transfer.

CHEME 732 Diffusion and Mass Transfer
Spring. 2 credits. Prerequisite: CHEME 731 or equivalent. D. L. Koch.
Conservation equations in multicomponent systems, irreversible thermodynamics, dispersion, and Brownian diffusion. Mass transfer for convective diffusion in liquids. Application to a variety of problems such as coagulation of aerosols, diffusion through films and membranes, liquid-liquid extraction, chemical vapor deposition, polymer rheology and diffusion, and reaction-diffusion systems.

CHEME 741 Selected Topics in Biochemical Engineering
Fall. 1 credit (may be repeated for credit). Prerequisite: CHEME 643 or permission of instructor. M. L. Shuler.
Discussion of current topics and research in biochemical engineering for graduate students.

[CHEME 745 Physical Polymer Science I
Fall. 3 credits. Prerequisite: CHEME 711 or equivalent. Not offered fall 1995 and 1997; next offered fall 1996. C. Cohen.
Thermodynamic properties of dilute, semidilute, and concentrated solutions from both classical and scaling approaches. Characterization techniques of dilute solutions: osmometry, light scattering, viscometry, and sedimentation. Rubber elasticity; mechanical and thermodynamic properties of gels. Polymer melts: equations of state and glass transition phenomena.]

CHEME 751 Mathematical Methods of Chemical Engineering Analysis
Fall. 4 credits. A. B. Anton.
Application of advanced mathematical techniques to chemical engineering analysis. Mathematical modeling, scaling, regular and singular perturbation, multiple scales, asymptotic analysis. Linear and nonlinear ordinary differential equations, partial differential equations.

[CHEME 753 Analysis of Nonlinear Systems: Stability, Bifurcation, and Continuation
Fall. 3 credits. Prerequisite: CHEME 751 or equivalent. Offered alternate years. Not offered 1996. P. H. Steen.
Elements of stability and bifurcation theory. Branch-following techniques. Stability of discrete and continuous systems. Application to elasticity, reaction-diffusion, and hydrodynamic systems using software for continuation problems.]

[CHEME 772 Theory of Molecular Liquids
Spring. 3 credits. Prerequisite: CHEME 711 or equivalent. Not offered 1996 or 1998; next offered 1997.
Theory of intermolecular forces, and equilibrium statistical mechanics for nonspherical molecules. Distribution functions. Applications to thermodynamics of such fluids using integral equation and perturbation theory techniques. Mixture properties, phase diagrams for mixtures with polar or quadrupolar components. Surface properties.]

CHEME 774 Atomistic Simulation of Materials
Spring. 3 credits. Prerequisite: Competence in FORTRAN, PASCAL, or C. Prior knowledge of statistical mechanics helpful. Offered alternate years. A. Z. Panagiotopoulos.
The statistical mechanical theory behind Monte-Carlo and Molecular-Dynamics computer-simulation techniques. Strong emphasis is placed on students writing their own MC and MD code. Calculation of distribution functions, thermodynamic, kinetic and structural properties. Introduction to the application of computer graphics to simulation. Interparticle forces and application of atomistic simulation of systems containing metals, semiconductors, and biological materials. Issues of code efficiency and vectorization.

CHEME 790 Seminar
Fall, spring. 1 credit each term.
General chemical engineering seminar required of all graduate students in the Field of Chemical Engineering.

CHEME 792 Advanced Seminar in Thermodynamics
Fall, spring. 1 credit.
A forum for talks by graduate students and faculty members on topics of current interest in thermodynamics and statistical mechanics.

CHEME 890 Thesis Research
Fall, spring. Variable credit.
Thesis research for the M.S. degree in chemical engineering.

CHEME 990 Thesis Research
Fall, spring. Variable credit.
Thesis research for the Ph.D. degree in chemical engineering.

CIVIL AND ENVIRONMENTAL ENGINEERING

General

CEE 113 Environmental Systems Engineering (also ENGRI 113)
Fall. 3 credits. Staff.
For description see Engineering Common Courses.

CEE 116 Modern Structures (also ENGRI 116)
Fall. 3 credits. A. R. Ingraffea.
For description see Engineering Common Courses.

CEE 120 Readings on the Environment
Spring. 1 credit.
A reading course from an introductory environmental text. Topics include structure and dynamics of ecosystems, water habitats and communities, water resources, toxic-waste pollution of surface and groundwater, international water-pollution problems, energy resources, nuclear-waste disposal, hydroelectric power, environmental carcinogens. Not available to students receiving credit for ENGRI 113 or Natural Resources 201.

CEE 241 Engineering Computation (also ENGRD 241)
Fall or spring. 3 credits. Prerequisites: COM S 100 and Math 293. Corequisite: Math 294. J. R. Stedinger, P. L.-F. Liu.
For description see Engineering Common Courses.

CEE 304 Uncertainty Analysis in Engineering
Fall. 4 credits. Prerequisite: first-year calculus. M. Grigoriu.
An introduction to probability theory and statistical techniques, with examples from civil, environmental, agricultural, and related disciplines. The course covers data presentation, probability theory, commonly used probability distributions, parameter estimation, probability plotting and normality tests, confidence intervals, hypothesis testing, simple linear regression, and nonparametric statistics. Examples include structural reliability, models of vehicle arrivals, and distributions describing wind speeds, floods, pollutant concentrations, and soil and material properties. Total quality management employed.

CEE 309 Special Topics in Civil and Environmental Engineering
Fall, spring. 1–6 credits. Staff.
Supervised study by individuals or groups of upper-division students on an undergraduate research project or on specialized topics not covered in regular courses.

CEE 400 Senior Honors Thesis
Fall, spring. Variable credits. Staff.
Available to students admitted to the CEE Honors Program. Supervised research or project work resulting in an honors thesis.

CEE 501 Civil and Environmental Engineering Design Project I
Fall. 3 credits. Required for students in the M.Eng.(Civil) program. Staff.
Design of major civil engineering project. Planning and preliminary design in fall term; final design in January intersession (CEE 502).

CEE 502 Civil and Environmental Engineering Design Project II
Spring (work required during January intersession). 3 credits. Required for students in the M.Eng.(Civil) program. Prerequisite: CEE 501. Staff.
A continuation of CEE 501.

CEE 503 Professional Practice in Engineering
Spring. 3 credits. Required for and limited to students in the M.Eng.(Civil) program. Staff.
Financial, legal, regulatory, ethical, and business aspects of engineering practice are examined in detail. Students are expected to develop their understanding of the interrelations among the physical, social, economic, and ethical constraints on engineering design.

CEE 601 Water Resources and Environmental Engineering Seminar
Fall. 1 credit.
Presentation of topics of current interest.

Remote Sensing

[CEE 411 Remote Sensing: Environmental Applications (also SCAS 461)
Spring. 3 credits. Prerequisite: permission of instructor. Not offered 1995–96. Offered 1996–97 and 1997–98. Staff.
A survey of how remote sensing is applied in various environmental disciplines. Laboratory emphasis is on using aircraft and satellite imagery for inventorying and monitoring surface features in engineering, planning, agriculture, and natural resource assessments.]

CEE 610 Remote Sensing Fundamentals (also Agronomy 660)
Fall. 3 credits. Prerequisite: permission of instructor. W. D. Philpot.
An introduction to equipment and methods used in obtaining information about earth resources and the environment from aircraft or satellite. Coverage includes sensors; sensor and ground-data aquisition; data analysis and interpretation; and project design.

CEE 615 Digital Image Processing
Spring. 3 credits. Prerequisites: facility with algebra and trigonometry (e.g., Math 109) and statistics (e.g., CEE 304 or Agricultural Economics 310), or permission of instructor. W. D. Philpot.
An introduction to digital image-processing concepts and techniques, with emphasis on remote-sensing applications. Topics include image acquisition, enhancement procedures, spatial and spectral feature extraction, and classification. Assignments will require the use of image-processing software and graphics.

CEE 617 Project—Remote Sensing
On demand. 1–6 credits. W. D. Philpot.
Students may elect to undertake a project in remote sensing. The work is supervised by a professor in this subject area.

CEE 618 Special Topics—Remote Sensing
On demand. 1–6 credits. W. D. Philpot.
Supervised study in small groups on one or more special topics not covered in the regular courses. Special topics may be of a theoretical or applied nature.

CEE 619 Seminar in Remote Sensing (also SCAS 662)
Spring. 1 credit. S-U grades only.
Lectures on current developments in assessing earth resources or the environment. Each week a different topic on remote sensing or geographic information systems is presented by specialists from government, industry, Cornell, or other research or academic institutions.

CEE 710 Research—Remote Sensing
On demand. 1–6 credits. W. D. Philpot.
For students who want to study one particular area in depth. The work may take the form of laboratory investigation, field study, theoretical analysis, or development of design procedures.

CEE 810 Thesis—Remote Sensing
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. W. D. Philpot.
A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

Environmental and Public Systems

See also CEE 120.

CEE 323 Engineering Economics and Management (also ENGRG 323)
Spring; usually offered in summer for Engineering Co-op Program. 3 credits. Primarily for juniors and seniors. R. E. Schuler.
For description see Engineering Common Courses.

CEE 422 The Economics of Infrastructure and a Sustainable Environment (also ECON 422)
Fall. 4 credits. Prerequisite: Mathematical version of intermediate micro-economics (CEE 321 or ECON 203 or 313). R. E. Schuler.
Analysis of the broad economic, technological, and ecological environments in which products, projects and engineered systems are implemented. Infrastructure includes public physical capital (roads, utilities, water, and sewer), human capital (education and R&D), and biological capital (biodiversity, resources, and the natural environment). Market failures that must be resolved include the environment, public goods, renewable resources, scale economies, urbanization, demographics and technological innovation. Planning tools presented include methods for assessing project demand, cost-benefit analysis, choosing proper discount rate, dealing with uncertainty, financial constraints, and when and how to price. Also discussed are problems of sustainability, the allocation of scarce and previously nonmarketed resources, and the planning and management of activities with uncertain environmental consequences.

CEE 423 Environmental Quality Systems Analysis
Spring. 3 credits. Prerequisites: Math 294 and systems (CEE 323). Intended for undergraduates who have not taken OR&IE 320 or ABEN 475. Most lectures concurrent with CEE 623.
C. A. Shoemaker.
Applications of optimization and simulation methods to the development of plans and the design and operation of facilities for managing environmental quality. Algorithms for nonlinear programming, linear programming, and sensitivity analysis. See description of CEE 623 for water quality applications.

CEE 529 Water and Environmental Resources Problems and Policies
Fall. 3 credits. Intended primarily for graduate engineering and non-engineering students but open to qualified upperclass students. Prerequisite: permission of instructor. D. J. Allee and L. B. Dworsky.
Evaluation, appraisal, and prospects for problems involving water and environmental resources. Organization and public policies in the federal system.

[CEE 620 Water-Resources Systems I
Fall. 3 credits. Prerequisite: CEE 323 or equivalent. Not offered 1995–96. Offered 1996–97 and 1997–98.
Development and application of deterministic and stochastic optimization and simulation models for water-resources planning and management. River-basin modeling, including reservoir design and operation, irrigation planning and operation, hydropower-capacity development, flow augmentation, flood control and protection, and water-quality prediction and control.]

CEE 621 Water-Resources Systems II: Stochastic Hydrology
Spring. 3 credits. Prerequisites: CEE 304 and 620 or permission of instructor. Offered 1995–96 and 1997–98. Not offered 1996–97. J. R. Stedinger.
Course examines statistical, time series, and stochastic optimization methods used to address water resources problems. Statistical issues include properties of moments and other statistical estimators; maximum likelihood, method of moments, and method of L-moments estimation; censored datasets and historical information; probability plotting; Bayesian inference and index flood methods; ARMA and Box-Jenkins models; and disaggregation and multivariate stochastic streamflow models. Course also addresses Monte Carlo methods, stochastic simulation of water resource systems, and stochastic reservoir-operation optimization models.

CEE 623 Environmental Quality Systems Analysis
Spring. 3 credits. Prerequisites: Math 294 and optimization (ABEN 475, CEE 593, or OR&IE 320/520 or permission of instructor). C. A. Shoemaker.
Applications of optimization, simulation methods, and uncertainty analysis to the design and operation of facilities for managing the quality of surface- and groundwater. Applications include location of wastewater, solid waste, and hazardous-waste facilities, restoration of dissolved oxygen levels in rivers, and reclamation of contaminated aquifers. Optimization applications use linear programming, and integer, dynamic, and nonlinear programming.

CEE 628 Environmental and Water Resources Systems Analysis Seminar
Spring. 1 credit. Prerequisite: permission of instructor. Staff.
Graduate students and faculty members give informal lectures on various topics related to ongoing research in environmental or water resources systems planning and analysis.

CEE 722 Environmental and Water Resources Systems Analysis Research
On demand. Variable credit. Prerequisite: permission of instructor. Preparation must be suitable to the investigation to be undertaken. Staff.
Investigations of particular environmental or water resources systems problems.

CEE 729 Special Topics in Environmental or Water Resources Systems Analysis
On demand. Variable credit. Staff.
Supervised study, by individuals or small groups, of one or more specialized topics not covered in regular courses.

CEE 820 Thesis—Environmental and Water Resource Systems
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.
A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

Fluid Mechanics and Hydrology

CEE 331 Fluid Mechanics
Fall; usually offered in summer for Engineering Co-op Program. 4 credits. Prerequisite: Engr 202 (may be taken concurrently). W. H. Brutsaert.
Hydrostatics, the basic equations of fluid flow, potential flow and dynamic pressure forces, viscous flow and shear forces, steady pipe flow, turbulence, dimensional analysis, open-channel flow. Elements of design in water supply systems, canals, and other hydraulic schemes.

CEE 332 Hydraulic Engineering
Spring. 4 credits. Prerequisite: CEE 331. P. L.-F. Liu.
Application of fluid-mechanical principles to problems of engineering practice and design: hydraulic machinery, water-distribution systems, open-channel design, river engineering, groundwater flow, and pollutant dispersal. Lectures supplemented by laboratory work and a design project.

[CEE 431 Geohydrology (also ABEN 471 also GEOL 445)
For description, see GEOL 445. Not offered 1995–96 and 1996–97; offered 1997–98.]

CEE 432 Hydrology
Spring. 3 credits. Prerequisite: CCE 331. Intended for undergraduates. Lectures concurrent with CEE 632. W. H. Brutsaert.
Introduction to hydrology as a description of the water cycle and the role of water in the natural environment, and other issues for environmental engineers. Physical and statistical prediction methods for design related to hydrologic processes. Hydrometeorology and evaporation. Infiltration and base flow. Surface runoff and channel routing. Linear and nonlinear hydrologic systems. Storage routing and unit hydrograph methods.

CEE 433 Pollutant Transport and Transformation in the Environment
Fall. 3 credits. Prerequisite: CEE 331. Intended for undergraduates. Lectures concurrent with CEE 655. J. J. Bisogni.
Introduction to the physical transport and chemical and biochemical transformation processes that govern the fate and distribution of pollutants in the environment. See description for CEE 655.

CEE 435 Coastal Engineering
Spring. 4 credits. Prerequisite: CEE 331. P. L.-F. Liu.
Introduction to water wave phenomena, including wave generation, shoaling, refraction, diffraction, and breaking. Applications of wave theories to engineering design problems such as forces on coastal structures and beach erosion in coastal zones. Lectures supplemented by four laboratory assignments and a design project.

[CEE 630 Advanced Fluid Mechanics
Fall. 3 credits. Prerequisite: CEE 331. Not offered 1995–96 and 1996–97; offered 1997–98.
Introduction to tensor analysis; conservation of mass, momentum, and energy. Rigorous treatment includes study of exact solutions of the Navier-Stokes equations. Asymptotic approximations at low and high Reynolds numbers. Similitude and modeling. Laminar diffusion of momentum, mass, and heat.]

[CEE 631 Flow and Contaminant Transport Modeling in Groundwater
Spring. 3 credits. Prerequisites: Mathematics 294 or equivalent, Engr 241 or experience in numerical methods and programming, and elementary fluid mechanics. Not offered 1995–96 and 1996–97; offered 1997–98.
Potential flows and their calculation. Numerical methods include finite difference, finite elements, and boundary elements. Fundamental equations of saturated and unsaturated flow in porous media. Flow in fractured media. Numerical modeling of transport in porous media. Diffusion and advective diffusion in one, two, and three dimensions. Anisotropy. Additional terms for reactive substances. The course will include the use of computer programs.]

CEE 632 Hydrology
For description, see CEE 432. W. H. Brutsaert.

[CEE 633 Flow in Porous Media and Groundwater
Fall. 3 credits. Prerequisite: CEE 331. Not offered 1995–96 and 1997–98; offered 1996–97.
Fluid mechanics and equations of single-phase and multiphase flow; methods of solution. Applications involve aquifer hydraulics, pumping wells; drought flows; infiltration, groundwater recharge; land subsidence; seawater intrusion, miscible displacement; transient seepage in unsaturated materials.]

[CEE 634 Boundary Layer Meteorology
Fall. 3 credits. Prerequisite: CEE 331 or permission of instructor. Not offered 1995–96 and 1997–98; offered 1996–97.
Physical processes in the lower atmospheric environment: turbulent transport in the atmospheric boundary layer, surface-air interaction, disturbed boundary layers, radiation. Applications include sensible and latent heat transfer from lakes, plant canopy flow and evapotranspiration, turbulent

diffusion from chimneys and cooling towers, and related design issues.]

[CEE 635 Small and Finite Amplitude Water Waves

Fall. 3 credits. Prerequisite: CEE 435 or equivalent. Not offered 1995–96 and 1997–98; offered 1996–97. P. L.-F. Liu.

Review of linear and nonlinear theories of ocean waves. Discussion on the applicability of different wave theories to engineering problems.]

[CEE 636 Environmental Fluid Mechanics

Spring. 3 credits. Prerequisite: CEE 655 or permission of instructor. Offered alternate years. Not offered 1995–96 and 1996–97; offered 1997–98.

Mass- and heat-transport processes in the environment and their interaction with pollutant discharges. Mechanics of discretely and continuously stratified fluids, internal waves, density currents, selective withdrawal, and baroclinic motions. Flow stability, mixing, and turbulence. Turbulent diffusion and shear flow dispersion, including effects of buoyancy. Convective instabilities and mixed-layer dynamics. Concentrated sources of momentum and buoyancy: jets and plumes and their behavior in the environment. Applications to mixing processes in rivers, lakes, the ocean, and the atmosphere.]

CEE 638 Hydraulics Seminar

Spring. 1 credit. Open to undergraduates and graduates and required of graduate students majoring in hydraulics or hydraulic engineering. Staff.

Topics of current interest in fluid mechanics, hydraulic engineering, and hydrology.

CEE 639 Special Topics in Hydraulics

On demand. Variable credit. Staff.

Special topics in fluid mechanics, hydraulic engineering, or hydrology.

[CEE 732 Computational Hydraulics

Fall. 3 credits. Prerequisite: elementary fluid mechanics or permission of instructor. Offered alternate years. Not offered 1995–96 amd 1996–97; offered 1997–98. J. A. Liggett.

Numerical methods for solving hydraulics and fluid-mechanics problems. Solutions for elliptic, parabolic, and hyperbolic equations. Finite-difference, finite-element, and boundary-integral methods.]

CEE 735 Research in Hydraulics

On demand. Variable credit. Staff.

The student may select an area of investigation in fluid mechanics, hydraulic engineering, or hydrology. The work may be either experimental or theoretical in nature. Results should be submitted to the instructor in charge in the form of a research report.

CEE 830 Thesis—Fluid Mechanics and Hydrology

Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.

A thesis resarch topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

Geotechnical Engineering

CEE 341 Introduction to Geotechnical Engineering

Spring. 4 credits. H. A. Stewart.

Soil as an engineering material. Chemical and physical nature of soil. Engineering properties of soil. Stresses and stress analysis of soil. Basic theory and design for water flow in soil, one-dimensional consolidation of clay and silts, and shear-strength problems. Introduction to slope stability, earth pressure, geosynthetics, and landfill and waste-containment issues. Introduction to laboratory testing. Synthesis of soil analysis and laboratory-test results for the design of engineering structures.

CEE 640 Foundation Engineering

Fall. 3 credits. Prerequisite: CEE 341. F. H. Kulhawy.

Soil exploration, sampling, and in-situ testing techniques. Bearing capacity, stress distribution, and settlement. Design of shallow and deep foundations. Compaction and site preparation. Seepage and dewatering of foundation excavations.

CEE 641 Retaining Structures and Slopes

Spring. 3 credits. Prerequisite: CEE 341. T. D. O'Rourke.

Earth pressure theories. Design of rigid, flexible, braced, tied-back, slurry, and reinforced soil structures. Stability of excavation, cut, and natural slopes. Design problems stressing application of course material under field conditions of engineering practice.

CEE 643 Pavement Engineering (also ABEN 692)

Spring. 4 credits. Limited to engineering seniors and graduate students. Prerequisite: CEE 341 and 642. L. H. Irwin.

For description see ABEN 692.

CEE 648 Seminar in Geotechnical Engineering

Fall, spring. 1 credit. Staff.

Presentation and discussion of topics in current research and practice in geotechnical engineering.

CEE 649 Special Topics in Geotechnical Engineering

On demand. 1–6 credits. Staff.

Supervised study of special topics not covered in the formal courses.

CEE 740 Engineering Behavior of Soils

Fall. 4 credits. Prerequisite: CEE 341. H. A. Stewart.

Detailed study of the physiochemical nature of soil. Stress states due to geostatic loading and stress-history effects. In-depth evaluation of stress-strain-strength, compressibility, and hydraulic conductivity of natural soils. Field-testing methods for determining properties based on laboratory testing. Laboratory sessions include in-situ field testing, simple index tests, and complete laboratory characterization of important soil properties.

CEE 741 Rock Engineering

Fall. 3 credits. Prerequisite: CEE 341 or permission of instructor. Recommended: introductory geology. T. D. O'Rourke.

Geological and engineering classifications of intact rock, discontinuities, and rock masses. Laboratory and field evaluation of properties. Stress states and stress analysis. Design of foundations on, and openings in, rock masses. Analysis of the stability of rock slopes.

CEE 744 Advanced Foundation Engineering

Spring. 2 credits. Prerequisite: CEE 640. Offered 1995–96 and 1997–98; not offered 1996–97. F. H. Kulhawy.

A continuation of CEE 640, with detailed emphasis on special topics in soil-structure interaction. Typical topics include lateral and pullout loading of deep foundations, pile group behavior, foundations for offshore structures, foundations for special structures.

CEE 745 Soil Dynamics

Spring. 4 credits. Prerequisite: permission of instructor. H. A. Stewart.

Study of soil behavior under dynamic loading conditions. Foundation design for vibratory loadings. Introductory earthquake engineering including field and laboratory techniques for determining dynamic soil properties and liquefaction potential. Design of embankments and retaining structures under dynamic loading conditions. Laboratory experiments and demonstrations using resonant column and a range of cyclic testing equipment.

[CEE 746 Embankment Dam Engineering

Spring. 2 credits. Prerequisites: CEE 641 and 741, or permission of instructor. Not offered 1995–96 and 1997–98; offered 1996–97. F. H. Kulhawy.

Principles of analysis and design for earth and rockfill dams. Materials, construction methods, internal and external stability, seepage and drainage, performance monitoring, abutment and foundation evaluation. Introduction to tailings dams.]

CEE 749 Research in Geotechnical Engineering

On demand. 1–6 credits. Staff.

For the student who wants to pursue a particular geotechnical topic in considerable depth.

CEE 840 Thesis—Geotechnical Engineering

Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.

A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

Environmental Engineering

CEE 351 Environmental Quality Engineering

Spring; usually offered in summer for Engineering Co-op Program. 3 credits. L. W. Lion.

Introduction to engineering aspects of environmental quality control. Quality parameters, criteria, and standards for water and wastewater. Emphasis on water-quality control concepts, theory, and methods. Elementary analysis pertaining to the modeling of pollutant reactions in natural systems, and introduction to design of unit processes for water and wastewater treatment.

CEE 352 Water Supply Engineering

Fall. 3 credits. Prerequisite: CEE 351. R. I. Dick.

Analysis of contemporary threats to human health from water supply systems. Criteria and standards for potable-water quality. Water-quality control theory. Design of water supply facilities.

CEE 453 Laboratory Research in Environmental Engineering
Fall. 2 credits. Prerequisites: CEE 351, CEE 352. Enrollment limited to 12. J. J. Bisogni Jr. and M. L. Weber-Shirk.
Laboratory investigations reflecting faculty research on current environmental problems. Laboratory exercises will change from year to year. Possible topics include: Acid rain/lake chemistry; contaminated soil-site assessment, risk assessment, and remediation; packed tower air stripping treatment of contaminated groundwater; pollutant dispersion/transport in rivers; drinking water filtration for pathogen removal; oxygen sag in rivers; and biodegradation in landfills.

CEE 651 Microbiology for Environmental Engineering
Fall. 2 credits. Prerequisite: one semester of college chemistry. J. M. Gossett.
A self-paced autotutorial introduction to fundamental aspects of microbiology, organic chemistry, and biochemistry pertinent to environmental engineering. Course work consists of assigned readings, study questions, and brief exams.

CEE 653 Water Chemistry for Environmental Engineering
Fall. 3 credits. Prerequisite: one semester of college chemistry or permission of instructor. L. W. Lion.
Principles of chemistry applicable to the understanding, design, and control of water and wastewater treatment processes and to reactions in receiving waters. Topics include chemical thermodynamics, reaction kinetics, acid-base equilibria, mineral precipitation/dissolution, and electrochemistry. The focus of the course is on the mathematical description of chemical reactions relevant to engineered processes and natural systems, and the numerical or graphical solution of these problems.

CEE 654 Aquatic Chemistry
Spring. 3 credits. Prerequisite: CEE 653 or Chemistry 287–288. J. J. Bisogni.
Concepts of chemical equilibria applied to natural aquatic systems. Topics include acid-base reactions, buffer systems, mineral precipitation, coordination and redox reactions, Eh-pH diagrams adsorption phenomena, humic acid chemistry, and chemical-equilibria computational techniques. In-depth coverage of topics covered in CEE 653.

CEE 655 Pollutant Transport and Transformation in the Environment
For description, see CEE 433. J. J. Bisogni.

CEE 658 Sludge Treatment, Utilization, and Disposal
Spring. 3 credits. Prerequisite: CEE 352 or permission of instructor. R. I. Dick.
Analysis of the quantity and quality of residues produced from municipal and industrial water-supply and pollution-control facilities and other residue-producing processes as functions of process design and operational variables. Alternatives for reclaiming or disposing of hazardous and nonhazardous residues with assessment of potential environmental impacts. Fundamental factors influencing performance of treatment processes for removing water from sludges and for altering sludge properties prior to reuse or ultimate disposal. Considerations in selecting and integrating of sludge-management processes to approach optimal design.

CEE 659 Environmental Quality Engineering Seminar
Spring. 1 credit. Prerequisite: enrollment as graduate student in environmental engineering. Staff.
Presentation and discussion of current research and design projects in environmental engineering.

CEE 750 Research in Environmental Engineering
On demand. 1–6 credits. Staff.
For students who want to study a particular area in depth. The work may take the form of laboratory investigation, field study, theoretical analysis, or development of design and analysis procedures.

CEE 755 Environmental Engineering Processes I
Fall. 3 credits. Prerequisite: Previous or concurrent enrollment in CEE 653 or permission of instructor. J. M. Gossett.
Theoretical and engineering aspects of chemical and physical phenomena and processes applicable to the removal of impurities from water, wastewater, and industrial wastes and to their transformation in receiving waters. Analysis and design of treatment processes and systems.

CEE 756 Environmental Engineering Processes II
Spring. 3 credits. Prerequisites: CEE 651 and 755, or permission of instructor. J. M. Gossett.
Theoretical and engineering aspects of biological phenomena and processes applicable to the removal of impurities from water, wastewater, and industrial wastes and to their transformation in receiving waters. Biokinetic analysis and design of biological treatment process.

CEE 757 Environmental Engineering Processes Laboratory I
Fall. 2 credits. Prerequisite: concurrent enrollment in CEE 653 and CEE 755. J. J. Bisogni.
Laboratory studies of aquatic chemistry and physical/chemical processes of environmental engineering. Topics include gravimetric analyses; acids/bases; alkalinity; gas chromatography; UV-visible and atomic absorption spectrophotometry; adsorption; filtration; ion exchange; gas transfer; sedimentation; characterization of reactor mixing regimes; coagulation.

CEE 758 Environmental Engineering Processes Laboratory II
Spring. 2 credits. Prerequisite: CEE 651 and concurrent enrollment in CEE 756. J. M. Gossett.
Laboratory studies of microbiological phenomena and environmental engineering processes. Topics include microscopy; biochemical and chemical oxygen demand; biological treatability studies; enumeration of bacteria.

CEE 759 Special Topics in Environmental Engineering
On demand. Variable credit. Staff.
Supervised study in special topics not covered in formal courses.

CEE 850 Thesis—Environmental Engineering
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.
A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

Transportation

CEE 361 Introduction to Transportation Engineering
Spring; usually offered in summer for Engineering Co-op Program. 3 credits. A. H. Meyburg.
Introduction to technological, economic, and social aspects of transportation. Emphasis on design and functioning of transportation systems and their components. Supply-demand interactions; system planning, design, and management; traffic flow and control intersection and network analysis. Institutional and energy issues; environmental impact.

CEE 362 Highway Engineering (also ABEN 491)
Fall. 3 credits. Prerequisites: Fluid mechanics (may be taken concurrently) and junior standing in engineering. L. H. Irwin.
For description, see ABEN 491.

CEE 463 Transportation and Information Technology
Fall. 3 credits. Prerequisite: CEE 361 or permission of the instructor. L. K. Nozick.
Focuses on shift from building new infrastructure to improving the utilization of current facilities. Reviews major legislation that solidifies this shift and examines the role of computer and telecommunications technology. Technologies to be considered include tags and readers, weigh-in-motion, cellular communication technology, the global positioning system, on-board navigation systems, databases, and distributed databases.

CEE 664 Transportation Systems Design
Spring. 3 credits. Prerequisite: CEE 361. Staff.
Advanced techniques for physical and operational design of transportation systems, including analytical modeling techniques underlying design criteria. Evaluation of alternative designs. Management and operating policies, including investment strategies. Facility location decisions, networks, and passenger and freight terminals.

CEE 762 Transportation Research
On demand. Variable credit. Staff.
In-depth investigation of a particular transportation planning or engineering problem mutually agreed upon between the student and one or more faculty members.

CEE 764 Special Topics in Transportation
On demand. Variable credit. Staff.
Advanced subject matter not covered in depth in other regular courses.

CEE 860 Thesis—Transportation Engineering
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.
A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

Structural Engineering

See also CEE 116.

CEE 371 Structural Behavior
Spring. 4 credits. Prerequisite: Engr 202. A. R. Ingraffea.
Fundamental concepts of structural engineering: behavior, analysis, and design. Loads, structural materials, structural form, statically determinate analysis, approximate analysis of indeterminate systems. Use of interactive graphical analysis programs. Fundamentals of behavior of steel and concrete members. Introduction to limit states design.

CEE 372 Structural Analysis
Fall; usually offered in summer for Engineering Co-op Program. 4 credits. Prerequisite: CEE 371. J. F. Abel.
Fundamentals of statically indeterminate structures. Moment-area and virtual-work methods of displacement computation. Matrix flexibility and stiffness methods. Moment distribution analysis. Influence lines. Computer applications to practical structures. Role and limitations of analysis in design. The art of structural modeling for analysis and design.

CEE 373 Design of Concrete Structures
Fall. 4 credits. Prerequisites: CEE 372 or permission of instructor. P. Gergely.
Behavior and design of reinforced concrete and prestressed concrete structures. Design project.

CEE 374 Design of Steel Structures
Spring. 4 credits. Prerequisite: CEE 372 or permission of instructor. T. Peköz.
Behavior and design of steel members, connections, and structures. Discussion of structural systems for buildings and bridges.

CEE 376 Civil Engineering Materials
Spring. 3 credits. K. C. Hover.
Engineering properties of concrete, steel, wood, masonry, and other structural materials. Design characteristics and significance of test results of materials used in engineering works. Developing QA/QC programs and writing specifications. Extensive laboratory testing and report writing.

CEE 671 Random Vibration
Spring. 3 credits. Prerequisites: M&AE 326, CEE 779, and OR&IE 260; or equivalent and permission of instructor. Offered 1995–96 and 1997–98. Not offered 1996–97. M. D. Grigoriu.
Review of random-process theory, simulation, and first-passage time. Linear random vibration: second-moment response descriptors and applications from fatigue; seismic analysis; and response to wind, wave, and other non-Gaussian load processes. Nonlinear random vibration: equivalent linearization, perturbation techniques, Fokker-Planck and Kolmogorov equations, Itô calculus, and applications from chaotic vibration, fatigue, seismic analysis, and parametrically excited systems.

CEE 672 Fundamentals of Structural Mechanics
Spring. 3 credits. Staff.
Theory of elasticity, energy principles, plate flexure, failure theories for structural design, beams on elastic foundation, finite-difference method, plate theory, energy principles, introduction to finite-element method.

CEE 673 Advanced Structural Analysis
Fall. 3 credits. Prerequisites: CEE 372 and computer programming. A. R. Ingraffea.
Matrix analysis of structures, computer programming of displacement (stiffness) method, use of interactive graphical analysis programs, solution methods, errors and accuracy, special analysis procedures, virtual work in matrix analysis, and introduction to nonlinear analysis and finite-element methods.

[CEE 675 Concrete Materials and Construction
Spring. 3 credits. Prerequisite: CEE 376 or equivalent. Offered alternate years. Not offered 1995–96 and 1997–98; offered 1996–97. K. C. Hover.
Materials science, structural engineering, and construction technology involved in the materials aspects of the use of concrete. Cement chemistry and physics, mix design, admixtures, engineering properties, testing of fresh and hardened concrete, and the effects of construction techniques on material behavior. Lab assignments.]

[CEE 677 Stochastic Mechanics
Spring. 3 credits. Prerequisite: permission of instructor. Offered alternate years. Not offered 1995–96 and 1997–98; offered 1996–97. M. D. Grigoriu.
Review of concepts of probability theory, random processes, and random fields. Analytical and numerical methods for reliability analysis. Methods for solution of random eigenvalue problems, equilibrium of uncertain systems and systems with random imperfections, and propagation problems in stochastic systems. Applications include stochastic finite elements, probabilistic fracture mechanics, and dynamic Daniels systems.]

CEE 680 Structural Engineering Seminar
Fall, spring. 1 credit. Limited to qualified seniors and graduate students. Staff.
Presentation of topics of current interest in the field of structures.

[CEE 770 Engineering Fracture Mechanics
Fall. 3 credits. Prerequisite: CEE 772 or permission of instructor. Offered alternate years. Not offered 1995–96 and 1997–98; offered 1996–97. A. R. Ingraffea.
Fundamentals of fracture-mechanics theory. Energy and stress-intensity approaches to fracture. Mixed-mode fracture. Fatigue-crack propagation. Finite- and boundary-element methods in fracture mechanics. Introduction to elastic-plastic fracture mechanics. Interactive computer graphics for fracture simulation. Laboratory techniques for fracture-toughness testing of metals, concrete, and rock.]

CEE 772 Finite Element Analysis
Spring. 3 credits. Prerequisites: CEE 672 and 673, or permission of instructor. J. F. Abel.
Conceptual, theoretical, and practical bases for finite-element analysis in structural mechanics and other disciplines. Development and evaluation of formulations for one-, two-, and three-dimensional elements. Introduction to boundary-element analysis. Interactive computer graphics for finite- and boundary-element analysis.

CEE 773 Structural Reliability
Fall. 3 credits. Prerequisite: permission of instructor. Offered alternate years. Offered 1995–96 and 1997–98; not offered 1996–97. M. D. Grigoriu.
Review of probability theory, practical measures for structural reliability, second-moment reliability indices, probability models for strength and loads, probability-based design codes, reliability of structural systems, imperfection-sensitive structures, fatigue, stochastic finite-element techniques, elementary concepts of probabilistic fracture mechanics.

CEE 774 Advanced Concrete Structures I
Fall. 3 credits. Prerequisite: undergrad course in concrete structures. R. N. White.
Role of material properties in structural performance; design code philosophies; behavior and design of reinforced and prestressed concrete flexural sections; deflection control for RC and PC structures including load balancing for PC structures; continuity effects; serviceability issues; behavior and design of RC and PC slab systems; plastic truss (strut-and-tie) approach for torsion, deep beams, and shear; vertical framing systems.

CEE 775 Advanced Concrete Structures II
Spring. 3 credits. Prerequisite: CEE 774 or equivalent. R. N. White.
Ductility and its enhancement; prestress loss calculations; short-term and long-term deflection predictions; shrinkage and temperature effects and their control; extension of plastic truss approach to corbels, brackets, and connections; slender columns and biaxial bending; composite construction; anchorage region behavior in PC beams; strip method for design of slabs with unusual geometry; shear walls; bridges; directions of design codes.

CEE 776 Advanced Design of Metal Structures
Fall. 3 credits. Prerequisite: CEE 374 or equivalent. T. Peköz.
Preliminary design of structural systems. Design of members and connections. Behavior and computer-aided design of building frames. Design of composite members.

[CEE 777 Advanced Behavior of Metal Structures
Spring. 3 credits. Prerequisite: CEE 374 or equivalent. Not offered 1995–96 and 1996–97; offered 1997–98. T. Peköz.
Analysis of elastic and inelastic stability. Behavior and design of hot-rolled and cold-rolled steel and aluminum members, elements, and frames. Critical review of design specifications.]

CEE 779 Structural Dynamics and Earthquake Engineering
Spring. 3 credits. P. Gergely.
Modal analysis, numerical methods, and frequency-domain analysis. Introduction to earthquake-resistant design.

[CEE 780 Advanced Concrete Material Science
Fall. 3 credits. Prerequisites: CEE 376 or equivalent and CEE 675. Not offered 1995–96 and 1997–98; offered 1996–97. K. C. Hover.
Advanced study of the chemistry, physics, and microstructure of cement and concrete. Investigation of cement manufacture and chemistry, hydration reactions and effect of admixtures. Study of microstructure with scanning electron microscopy, and porosimetry. Engineering properties and behavior include failure mechanisms and elastic and viscoelastic behavior. Durability. Student presentations.]

CEE 783 Civil and Environmental Engineering Materials Project
On demand. 1–3 credits. K. C. Hover.
Individual projects or reading and study assignments involving engineering materials.

CEE 785 Research in Structural Engineering
On demand. Variable credit. Staff.
Pursuit of a branch of structural engineering beyond what is covered in regular courses. Theoretical or experimental investigation of suitable problems.

CEE 786 Special Topics in Structural Engineering
On demand. Variable credit. Staff.
Individually supervised study or independent design or research in specialized topics not covered in regular courses. Occasional offering of such special courses as Shell Theory and Design, and Advanced Topics in Finite Element Analysis.

CEE 880 Thesis—Structural Engineering
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.
A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

Engineering Management

CEE 590 Engineering Management Practice
Fall. 3 credits. Prerequisite: permission of instructor. M. A. Turnquist.
An introduction to the work and skills of management, especially for the management of projects. Planning, organizing, communicating, scheduling, controlling, and correcting will be covered in combination of lectures, readings, outside assignments, and in-class role-playing exercises.

CEE 591 Engineering Management Project
Fall. 3 credits. Prerequisite: permission of instructor. M. A. Turnquist and L. K. Nozick.
An intensive evaluation of the management aspects of a major engineering project or system. Most students will work on a large group project in the area of project management, but students may also work singly or in small groups on an engineering management topic of special interest to them.

CEE 592 Engineering Management Project
Spring. 3 credits. Prerequisite: permission of instructor. M. A. Turnquist and L. K. Nozick.
A continuation of CEE 591.

CEE 593 Engineering Management Methods I: Data, Information, and Modeling
Fall. 3 credits. Prerequisites: OR&IE 320 and OR&IE 270 or CEE 304 or equivalent. L. K. Nozick.
Methods for managing data and transforming data into information. Modeling as a means to synthesize information into knowledge that can form the basis for decisions and actions. Application of statistical methods and optimization to managerial problems in project scheduling, quality control, forecasting, and resource allocation.

CEE 594 Engineering Management Methods II: Managing Uncertain Systems
Spring. 3 credits. Prerequisite: CEE 593 or permission of instructor.
M. A. Turnquist.
Modeling and managing systems in which uncertainty is a major determinant of system behavior. Systems which are subject to breakdown, deterioration and queuing. Simulation as a tool for analyzing uncertain systems. Projects and case studies to illustrate application of the methods.

CEE 595 Construction Planning and Operations
Fall. 3 credits. Prerequisite: permission of instructor. K. C. Hover.
A course on the fundamentals of construction planning: organization of the worksite, construction planning, scheduling, and cost estimating, bidding, design of falsework and shoring systems, construction loadings, materials handling for construction, optimization of construction processes, applications of computer methods.

CEE 597 Risk Analysis and Management
Spring. 3 credits. Prerequisite: CEE 304 or OR&IE 270 or equivalent.
J. R. Stedinger.
Course develops a working knowledge of risk terminology, analytic tools used to analyze environmental and technological risks, and social and psychological risk issues. Discussions address life risks in the U.S., transportation risks, transportation of hazardous materials, waste incineration and remediation, public health risks such as AIDS, regulatory policy, risk communication, environmental risk issues in the media, and risk management.

CEE 692 Special Topics in Engineering Management
On demand. 1–6 credits. Staff.
Individually supervised study of one or more specialized topics not covered in regular courses.

CEE 694 Research in Engineering Management
On demand. 1–6 credits. Staff.
The student may select an area of investigation in engineering management. Results should be submitted to the instructor in charge in the form of a research report.

COMPUTER SCIENCE

The Department of Computer Science is part of both the College of Arts and Sciences and the College of Engineering.

COM S 099 Fundamental Programming Concepts
Fall. 2 credits. No prerequisites. S-U grades only.
This course is designed for students who intend to take COM S 100 but are not adequately prepared for that course. Students who do not intend to take COM S 100 but want some introduction to computers and programming should take COM S 101 instead. Students cannot receive credit for both COM S 101 and COM S 099. Basic programming concepts and problem analysis are studied. The programming language used is Pascal. Students with previous programming experience should not take this course.

COM S 100 Introduction to Computer Programming
Fall, spring, summer. 4 credits. Students who plan to take COM S 101 and also 100 must take 101 first.
An introduction to elementary computer programming concepts. Emphasis is on techniques of problem analysis and the development of algorithms and programs. The subject of the course is programming, not a particular programming language. The principal programming language is C. The course does not presume previous programming experience. Programming assignments are tested and run on interactive, stand-alone microcomputers. During most semesters, two versions of COM S 100 are available as described below.

COM S 100a Introduction to Computer Programming
Standard version of COM S 100. No college-level mathematics is assumed. Register for COM S 100.

COM S 100b Introduction to Computer Programming
Prerequisite: MATH 111, 191 or equivalent. Offered fall only.
Alternative version of COM S 100, emphasizing examples and applications involving continuous mathematics, including trigonometry and calculus. Register for COM S 100. COM S 100b is not always available at all COM S 100 lecture hours.

COM S 101 The Computer Age (also ENGRG 101)
Summer. 3 credits. Credit is granted for both COM S 100 and 101 only if 101 is taken first.
An introduction to computer science and programming for students in nontechnical areas. The aims of the course are to acquaint the student with the major ideas in computer science and to develop an appreciation of algorithmic thinking. Topics may include the history of computation; microtechnology; the retrieval and transmission of information; scientific computing; computer graphics, art, and music; robotics, natural-language processing, and machine intelligence. Students become acquainted with the concept of an algorithm by writing several programs in Pascal or Scheme and testing them on microcomputers. The amount of programming is about half that taught in COM S 100.

COM S 211 Computers and Programming (also ENGRD 211)
Fall, spring, summer. 3 credits. Credit will not be granted for both COM S 211 and 212. Prerequisite: COM S 100 or equivalent programming experience.
Intermediate programming in a high-level language and introduction to computer science. Topics include program development, proofs of program correctness, program structure, recursion, abstract data types, object-oriented programming, data structures, and analysis of algorithms. Pascal is the principal programming language.

COM S 212 Structure and Interpretation of Computer Programs (also ENGRD 212)
Fall, spring. 4 credits. Credit will not be granted for both COM S 211 and 212. Prerequisite: COM S 100 or equivalent programming experience.
A challenging introduction to programming languages and computer science that emphasizes alternative modes of algorithmic

expression. Topics include recursive and higher-order procedures, performance analysis of algorithms, proofs of program correctness, probabilistic algorithms, symbolic hierarchical data, abstract data types, polymorphic functions, object-oriented programming, infinite data types, simulation, and the interpretation of programs. Programs are written in Scheme, a dialect of LISP.

COM S 212 emphasizes a varied collection of advanced programming concepts and techniques available in a modern functional programming language. In contrast, COM S 211 focuses on perfecting programming skills in a conventional imperative programming language. Corrective transfers between COM S 211 and 212 (in either direction) are encouraged during the first few weeks of instruction.

COM S 214 A Taste of UNIX and C
Fall, spring. 1–2 credits. Prerequisite: COM S 211 or equivalent programming experience. S-U grades only. Will not be offered after 1995–96.
A brief introduction to the UNIX operating system and the C programming language. Recommended for students who intend to pursue the computer science major. Taught in the first four to eight weeks of the semester. The 2-credit version involves an implementation project.

COM S 222 Introduction to Scientific Computation (also ENGRD 222)
Spring. 3 credits. Prerequisites: COM S 100 and pre/corequisite of MATH 221 or MATH 293.
An introduction to elementary numerical analysis and scientific computation. Topics include interpolation, quadrature, linear and nonlinear equation solving, least-squares fitting, and ordinary differential equations. The Matlab computing environment is used. Vectorization, efficiency, reliability, and stability are stressed. Special lectures on parallel computation and high-performance Fortran.

COM S 280 Discrete Structures
Fall, spring. 4 credits. Prerequisite: COM S 211 or 212 or permission of instructor.
Covers mathematical aspects of programming and computing. Topics will be chosen from the following: mathematical induction; logical proof; propositional and predicate calculus; combinatorics and discrete mathematics covering manipulation of sums, recurrence relations, and generating-function techniques; basic number theory; sets, functions, and relations; partially ordered sets; graphs.

COM S 314 Introduction to Digital Systems and Computer Organization
Fall, spring, summer. 4 credits. Prerequisite: COM S 211, 212, or equivalent.
Introduction to computer organization. Topics include representation of information, machine-assembly languages, processor organization, interrupts and I/O, memory hierarchies, combinatorial and sequential circuits, data path and control unit design, RTL, and microprogramming.

COM S 381 Introduction to Theory of Computing
Fall. 4 credits. Prerequisite: COM S 280 or permission of instructor. Credit will not be granted for both COM S 381 and COM S 481. Collective transfers between COM S 381 and COM S 481 (in either direction) are encouraged during the first few weeks of instruction.
An introduction to modern theory of computing: automata theory, formal languages, and effective computability.

[COM S 400 The Science of Programming
Spring. 4 credits. Prerequisite: COM S 280 or equivalent. Not offered spring 1996; next offered spring 1997.
The practical development of correct programs based on the conscious application of principles that are derived from a mathematical notion of program correctness. Besides dealing with conventional sequential programs, the course covers implementations of abstract data types and contains an introduction to problems with concurrency. Issues in programming-language design that arise from program correctness are discussed. Programs are written but not run on a computer.]

COM S 401 Software Engineering: Technology and Technique
Fall. 4 credits. Prerequisite: COM S 410 and knowledge of the C programming language.
An introduction to the programming languages, tools, and methods used in modern software development. Programming methodologies: modularity, data abstraction, object-oriented programming. Effective use of C++. Programming tools, software libraries, and interface definition languages. General techniques will be complemented with programming experience.

COM S 410 Data Structures
Fall, spring, summer. 4 credits. Prerequisite: COM S 280 or permission of instructor.
Lists, trees, graphs, arrays, and other forms of data structure and their implementation. Relationship between language and data structure, emphasizing abstract data types. Dynamic storage allocation and memory management. Detailed study of searching and sorting methods. Analysis to determine the more efficient algorithm in a given situation.

[COM S 411 Programming Languages and Logics
Fall. 4 credits. Prerequisite: COM S 410 or permission of instructor. Not offered fall 1995; next offered fall 1996 and 1998.
The major concepts of programming languages, with emphasis on synthesis and interpretation. Language-based programming methodologies, including object-oriented, functional, and logic programming. Design and criticism of programming languages. Type theory and typed lambda-calculus. Exercises in several unusual programming languages.]

COM S 412 Introduction to Compilers and Translators
Spring. 3 credits. Prerequisites: COM S 314, 381, 410. Corequisite: COM S 413. Not offered every year; next offered spring 1996 and 1998.
Overview of the internal structure of modern compilers, with emphasis on implementation techniques. Topics covered include lexical scanning, simple parsing techniques, symbol-table manipulation, type-checking routines, code generation, and simple optimizations. The course entails a compiler implementation project.

COM S 413 Practicum in Compilers and Translators
Spring. 2 credits. Prerequisites: COM S 314, 381, 410. Corequisite: COM S 412. Not offered every year; next offered spring 1996 and 1998.
A compiler implementation project related to COMS 412.

COM S 414 Systems Programming and Operating Systems
Fall. 3 credits. Prerequisite: COM S 314 or permission of instructor.
An introduction to the logical design of systems programs, with emphasis on multiprogrammed operating systems. Topics include process synchronization, deadlock, memory management, input-output methods, information sharing, protection and security, and file systems. The impact of network and distributed computing environments on operating systems is also discussed.

COM S 415 Practicum in Operating Systems
Fall. 2 credits. Prerequisite: COM S 410. Corequisite: COM S 414.
The practical aspects of operating systems are studied through the design and implementation of an operating system kernel that supports multiprogramming, virtual memory, and various input-output devices. All the programming for the project is in a high-level language.

COM S 417 Computer Graphics and Visualization (also ARCH 374)
Spring. 3 credits. Prerequisite: COM S 211 or 212.
An introduction to the principles of interactive computer graphics and scientific visualization. Topics include surface modeling, animation, perspective transformations, hidden-line and hidden-surface algorithms, lighting models, image synthesis, and application to scientific data analysis.

COM S 418 Practicum in Computer Graphics (also ARCH 375)
Spring. 2 credits. Enrollment limited. Permission of instructor. Prerequisite: COM S 211 or 212. Recommended: COM S 314. Co-requisite: COM S 417.
Programming assignments dealing with interactive computer graphics and visualization of scientific data.

COM S 421 Numerical Analysis
Fall. 4 credits. Prerequisites: Mathematics 294 or equivalent, one additional mathematics course numbered 300 or above, and knowledge of programming.
Modern algorithms for systems of linear equations, systems of nonlinear equations, numerical optimization, and numerical solution of differential equations. Some discussion of methods suitable for parallel computation.

COM S 422 Parallel Computing for Scientific Problems
Spring. 4 credits. Enrollment limited. Permission of instructor. Prerequisites: Math 294, COM S 222 or COM S 421, knowledge of C and FORTRAN.
Parallel algorithms and programming environments for important scientific problems, such as fluid flow, systems of particles, and large-scale optimization. This course will involve algorithm development on some of the world's fastest computers, including a Connection Machine and a hypercube.

COM S 432 Introduction to Database Systems
Spring. 3 credits. Prerequisites: Either COM S 211or 212, and 410, or permission of instructor. Recommended: COM S 314.
Introduction to modern database management systems. Concepts in data modeling and query processing. Storage structures and access methods. Design and analysis of relational databases. Concurrency control. Object-oriented databases.

COM S 433 Practicum in Database Systems
Spring. 2 credits. Corequisite: COM S 432.
Issues related to the design and implementation of database-management systems will be addressed. Students will implement a simplified relational database system, including a file-access method and query-processing algorithms.

[COM S 444 Distributed Systems and Algorithms
Fall. 4 credits. Corequisite: COM S 414 or permission of instructor. Not offered fall 1995; next offered fall 1996.
The fundamentals of distributed systems and algorithms. Topics include the problems, methodologies and paradigms necessary for understanding and designing distributed applications, with an emphasis on fault-tolerant computing. Theoretical concepts will be complemented with practical examples of their application in current distributed systems.]

[COM S 462 Robotics and Machine Vision
Spring. 3 credits. Prerequisite: Permission of instructor, COM S 410, and COM S 381. Co-requisite: COM S 463. Not offered spring 1996; next offered spring 1997.
Introduction to the science of robotics and machine vision using a combination of programming techniques, applied mathematics, algorithms, and lab experiments. Topics include task-level robot planning and programming, hand-eye systems, feature detection and object recognition, motion planning, shape reconstruction, compliant motion and assembly, model-based planning and recognition, uncertainty and error, active sensing, and manipulation.]

[COM S 463 Robotics and Machine Vision Lab
Spring. 2 credits. Prerequisite: Permission of instructor, COM S 410, and COM S 381. Co-requisite: COM S 462. Not offered spring 1996; next offered spring 1997. 1 lab.
Use physical robots (vision systems, hand-eye systems, and mobile robots) in the Computer Science Robotics and Vision Teaching Laboratory. Students should be comfortable both with mathematical concepts and programming, know LISP or Scheme, have a mastery of calculus and linear algebra, a strong background in algorithms, and an ability to work independently.]

COM S 472 Foundations of Artificial Intelligence
Fall. 3 credits. Prerequisites: COM S 107 or COM S 212, COM S 280 and COM S 410. Open to juniors, seniors, and graduate students. 3 lecs.
A challenging introduction to the major subareas and current research directions in artificial intelligence. Topics include knowledge representation, search, problem solving, natural-language processing, vision, robotics, logic and deduction, planning, and machine learning.

COM S 473 Practicum in Artificial Intelligence
Fall. 2 credits. Prerequisite: COM S 107 or COM S 212, COM S 280 and COM S 410. Corequisite: COM S 472.
Project portion of COM S 472. Topics include Common LISP programming, representation systems, deductive retrieval, databases and frame languages, and truth-maintenance-system implementations.

COM S 481 Introduction to Theory of Computing
Fall. 4 credits. Prerequisite: COM S 280 or permission of instructor. Credit will not be granted for both COM S 381 and COM S 481. Corrective transfers between COM S 481 and COM S 381 (in either direction) are encouraged during the first few weeks of instruction.
A faster-moving and deeper version of COM S 381.

COM S 482 Introduction to Analysis of Algorithms
Spring. 4 credits. Prerequisites: COM S 410 and either 381 or 481, or permission of instructor.
Techniques used in the creation and analysis of algorithms. Combinatorial algorithms, computational complexity, NP-completeness, and intractable problems.

COM S 486 Applied Logic (also Mathematics 486)
Fall or spring. 4 credits. Prerequisites: Mathematics 222 or 294, COM S 100, and some additional course in mathematics or theoretical computer science.
Propositional and predicate logic, compactness and completeness by tableaux, natural deduction, and resolution. Equational logic. Herbrand Universes and unification. Rewrite rules and equational logic, Knuth-Bendix method and the congruence-closure algorithm and l-calculus reduction strategies. Topics in Prolog, LISP, ML, or Nuprl. Applications to expert systems and program verification.

COM S 490 Independent Reading and Research
Fall, spring. 1–4 credits.
Independent reading and research for undergraduates.

COM S 501 Software Engineering: Technology and Technique
Fall. 4 credits. Prerequisite: COM S 410 and knowledge of the C programming language.
An introduction to the programming languages, tools, and methods used in modern software development. Programming methodologies: modularity, data abstraction, object-oriented programming. Effective use of C++. Programming tools, software libraries, and interface definition languages. General techniques will be complemented with programming experience.

[COM S 511 Modern Programming Languages
Fall. 4 credits. Prerequisites: COM S 410 and a project course or permission of instructor. Not offered fall 1995; next offered fall 1996 and 1998.
Current trends in programming languages, with emphasis on programming methodologies supported by languages. Topics will include object-oriented programming, modularity and data abstraction, functional and declarative programming, concurrency, logic programming, and programming language design. There will be programming exercises in several new languages.]

COM S 514 Practical in Distributed Systems
Fall or spring. 4 credits. Prerequisites: COM S 414 or permission of instructor. Not offered every year; semester to be announced.
Practical issues in designing and implementing distributed software. Topics include local and wide-area network protocols, replicated data, dynamic reconfiguration, monitoring for and reacting to failures or recoveries, distributed computation, synchronization, and techniques for expressing coarse-grained parallelism at the application level.

COM S 515 Practicum in Distributed Systems
Fall or spring. 1–2 credits. Co-requisite: COM S 514. Not offered every year; semester to be announced.
The practical aspects of distributed systems are studied through the design and implementation of a significant system. Students may work alone or in teams. The project varies from year to year, at the discretion of the instructor.

COM S 516 High-performance Computer Architecture
Spring. 4 credits. Prerequisite: COM S 314 required; COM S 412 or 414 highly recommended.
Introduces techniques used in high-performance computer architecture. Covers pipelining of instruction execution to superscalar, superpipelined, and speculative architectures; memory system design, including caches, operating system support in the form of naming and protection schemes; introduction to parallel architectures.

COM S 522 Parallel Computing for Scientific Problems
For description, see COM S 422.

[COM S 562 Robotics and Machine Vision
Spring. 3 credits. Prerequisites: permission of instructor, COM S 410, and COM S 381/481. Co-requisite: COM S 563. Not offered spring 1996; next offered spring 1997.
For description, see COM S 462.]

[COM S 563 Robotics and Machine Vision Lab
Spring. 2 credits. Prerequisites: permission of instructor, COM S 410, and COM S 381/481. Co-requisite: COM S 562. Not offered spring 1996; next offered spring 1997.
For description, see COM S 463.]

COM S 572 Introduction to Automated Reasoning
Spring. 3 credits.
This course teaches the use of a modern theorem proving system such as Nuprl or PVS or HOL. It covers the underlying logic as well as system operation and style of use. Assignments and projects involve the use of these systems on typical problems in software or hardware engineering and on the issues

arising in creating a database of formalized mathematics.

COM S 600 Computer Science and Programming

Fall. 1 credit. Prerequisite: graduate standing in computer science or permission of instructor. Not offered every year; semester to be announced.

An introduction to practical, modern ideas in programming methodology. Covers style and organization of programs, basic techniques for presenting proofs of correctness of programs, and the use of a "calculus" for the derivation of programs.

COM S 611 Advanced Programming Languages

Fall. 4 credits. Prerequisites: COM S 410 and 381 or 481, or permission of instructor.

A study of programming paradigms; functional, imperative, and logic programming. The untyped lambda-calculus. The typed lambda-calculus, type systems, polymorphism, type inference. Formal semantics of programming languages. Elements of domain theory and type theory. Models of programming logic.

COM S 612 Compiler Design for High-Performance Architectures

Spring. 4 credits. Prerequisites: COM S 314 and 412 or permission of instructor.

Compiler design for pipelined and parallel architectures. Program analysis: data and control dependencies, dataflow analysis, efficient solution of dataflow equations, dependence tests, solution of Diophantine equations. Architecture and code generation for instruction-level parallel (ILP) processors: pipelined, VLIW and superscalar architectures, code reorganization and software pipelining. Architecture and code generation for multiprocessors: shared- and distributed-memory architectures, latency tolerance and avoidance, loop transformations to enhance parallelism and locality of reference.

COM S 613 Concurrent Programming

Spring. 4 credits. Prerequisite: COM S 414 or permission of instructor. Not offered every year; semester to be announced.

Advanced techniques in, and models of, concurrent systems. Synchronization of concurrent processes; parallel programming languages; deadlock; verification.

COM S 614 Advanced Systems

Spring. 4 credits. Prerequisite: COM S 414 or permission of instructor.

An advanced course in systems, emphasizing contemporary research in distributed systems. Topics may include communication mechanisms, consistency in distributed systems, fault-tolerance, knowledge and knowledge-based protocols, performance, scheduling, concurrency control, and authentication and security issues.

COM S 615 Theory of Concurrent Systems

Spring. 4 credits. Prerequisites: COM S 611 or permission of instructor. Not offered every year; semester to be announced.

Modeling, specification, and verification of concurrent systems. Topics in modeling will include interleaving vs. partial-order semantics, and linear time vs. branching time. Among the specification methods discussed are temporal logic, automata, process algebra, and Petri nets. Verification methods include proof calculi, model checking, and refinement mappings. Advanced topics will include open systems and real time.

COM S 617 Frontiers of Parallel Computer Systems

Fall. 4 credits. Prerequisites: COM S 314 or 516 required; COM S 411, 412, or 414. Not offered every year; semester to be announced.

Focus on the architecture, compiler, and operating system aspects required to support features taken for granted in sequential computing, such as portable parallel programs, powerful debuggers, multi-user machine access, virtual memory, and fast I/O.

COM S 618 Topics in the Theory of Distributed Systems

Fall. 4 credits. Prerequisites: COM S 444 or COM S 614 or permission of instructor. Not offered every year; next offered fall 1995.

This course focuses on research in distributed systems and algorithms. It covers the fundamental problems and presents some of the latest results and open questions in both message-passing and shared-memory systems. Problems will be viewed from a theoretical standpoint with an emphasis on precise specifications, proofs of correctness, upper and lower bounds on various complexity measures and impossibility results.

COM S 621 Matrix Computations

Fall. 4 credits. Prerequisites: Mathematics 411 and 431 or permission of instructor.

Stable and efficient algorithms for linear equations, least squares, and eigenvalue problems. Direct and iterative methods are considered. The Matlab system is used extensively.

COM S 622 Numerical Optimization and Nonlinear Algebraic Equations

Spring. 4 credits. Prerequisite: COM S 621.

Modern algorithms for the numerical solution of multidimensional optimization problems and simultaneous nonlinear algebraic equations. Emphasis is on efficient, stable, and reliable numerical techniques with strong global convergence properties: quasi-Newton methods, modified Newton algorithms, and trust-region procedures. Special topics may include large-scale optimization, quadratic programming, and numerical approximation.

COM S 624 Numercial Solution of Differential Equations

Spring. 4 credits. Previous exposure to numerical analysis, mathematical analysis including Fourier methods, and differential equations. Not offered every year; semester to be announced.

Finite difference and spectral methods for the solution of differential equations. A fast-moving course that begins with a three-week survey of numerical methods for ODEs, then moves on to Fourier analysis and methods for PDEs, especially parabolic and hyperbolic equations. Other topics covered include numerical stability, the treatment of boundary conditions, and multigrid methods. This course combines theory and programming (in Matlab), emphasizing fundamental principles more than applications.

COM S 631 Multimedia Systems

Fall. 4 credits. Prerequisites: COM S 414 or permission of instructor.

Hardware and software issues involved in computer manipulation of audio, video, and images. Topics include media capture, representation, compression, editing, processing, storage, and transportation. Special emphasis on the processing of digital video, including algorithms for special effects and automatic extraction of content, and applications of parallel architectures to video processing.

COM S 635 Automatic Text Processing and Information Retrieval

Spring. 4 credits. Prerequisite: COM S 410 or equivalent or permission of instructor. Letter grade only.

Modern methods for natural language text processing. Topics include text analysis, storage and retrieval, automatic spelling aids, text compression and encryption, language understanding systems, automatic abstracting, and text generation and translation.

COM S 661 Robotics

Fall. 4 credits. Prerequisites: COM S 482 and permission of instructor. Not offered every year; semester to be announced.

State-of-the-art in theoretical and experimental robotics, with an emphasis on robot-motion planning. Topics include: Task-level robot planning, collision-free path planning, grasp synthesis, modeling and propagating uncertainty, planning compliant motions for precision assembly, geometrical planning theories, motion planning with dynamics (and dynamic constraints), computational complexity of robot-motion planning, computational theories of friction, impact, and the physics of manipulation, and error detection and recovery in robotics.

COM S 662 Robotics Laboratory

Fall. 4 credits. Prerequisite: graduate standing or permission of instructor. Not offered every year; semester to be announced.

Introduction to the use of equipment and techniques in a modern robotics laboratory. Includes robot programming, force sensing, compliant motion, and mechanical assembly.

COM S 664 Machine Vision

Spring. 4 credits. Prerequisites: undergraduate-level understanding of algorithms and Math 221 or equivalent.

An introduction to computer vision. The following topics will be covered: edge detection, image segmentation, stereopsis, motion and optical flow, shape reconstruction, shape representations and extracting shapes from images, model-based recognition. Students will be required to implement several of the algorithms covered in the course and evaluate them on both synthetic and real images.

COM S 672 Advanced Artificial Intelligence

Spring. 4 credits. Prerequisite: COM S 472 or permission of instructor. Not offered every year; semester to be announced.

Advanced course in the computational study of intelligent behavior. Covers current issues in the design and implementation of agents that operate in the face of limited computational, perceptual, and effectory resources. How agents choose action (planning) and how they improve action choice using feedback from the world (learning) are the chief topics. Heuristic search with limited resources, planning in dynamic worlds, representations change, reasoning under uncertainty, active learning, knowledge assimilation, AI applications to engineering problems, and building integrated intelligent agents are covered. Exercises include building a small mobile robot and programming a player for a video game.

COM S 681 Analysis of Algorithms
Fall. 4 credits. Prerequisite: COM S 381 or 481, or permission of instructor.
Methodology for developing efficient algorithms, primarily for graph theoretic problems. Understanding of the inherent complexity of natural problems via polynomial-time algorithms, randomized algorithms, NP-completeness, randomized reducibilities. Additional topics such as parallel algorithms and efficient data structures.

COM S 682 Theory of Computing
Spring. 4 credits. Prerequisite: COM S 381 or 481, or permission of instructor.
Advanced treatment of theory of computation, computational-complexity theory, and other topics in computing theory.

COM S 683 Parallel Algorithms
Fall. 4 credits. Prerequisite: COM S 681. Not offered every year; semester to be announced.
This course is a general survey of parallel algorithms and architectures, based on *Introduction to Parallel Algorithms and Architectures: Arrays, Trees, Hypercubes,* by F. Thomson Leighton. This course is organized according to architectural paradigms and repeats the analysis of various classes of problems for each class of architectures: arrays and trees, meshes of trees, and hypercubes and related networks. The emphasis is practical. Topics include arrays of processors, systolic retiming, packet routing, randomized packet routing, sorting algorithms, computational geometry, graph and matrix algorithms, fast evaluation of straight-line code, FFT, and NC.

COM S 684 Introduction to Symbolic Computation
Spring. 4 credits. Prerequisites: COM S 381 or 481, or permission of instructor. Not offered every year; semester to be announced.
Introduction to the algorithms used for algebraic problems in symbolic computing and their mathematical and complexity theoretic foundations. Topics include simplication of, and arithmetic operations with, continued fractions, polynomials, rational functions and elements of algebraic extensions, polynomial factorization, and techniques for questions in algebraic geometry. Related topics may also be included.

COM S 685 Computational Geometry
Fall. 4 credits. Prerequisite: COM S 681 or permission of instructor. Not offered every year; semester to be announced.
The study of algorithms for geometric problems. Topics include: convex hulls, arrangements of lines, planes and hyperplanes, intersection problems, triangulations, proximity (Voronoi diagrams and Delaunay triangulations), geometric searching, randomized algorithms, parallel algorithms, and geometric optimization.

COM S 709 Computer Science Colloquium
Fall, spring. 1 credit. S-U grades only. For staff, visitors, and graduate students interested in computer science.
A weekly meeting for the discussion and study of important topics in the field.

COM S 713 Seminar in Systems and Methodology
Fall, spring. 4 credits. Prerequisites: a graduate course employing formal reasoning such as COM S 600, 611, 613, 615, 671, a logic course, or permission of instructor. Not offered every year; semester to be announced.
Discussion of contemporary issues in the design and analysis of computing systems. Emphasis on the proper use of rigor, models, and formalism.

COM S 715 Seminar in Programming Refinement Logics
Fall, spring. 4 credits. Prerequisite: permission of instructor.
Topics in programming logics, possibly including type theory, constructive logic, decision procedures, heuristic methods, extraction of code from proofs, and the design of proof-development and problem-solving systems.

COM S 717 Topics in Parallel Architectures
Fall. 4 credits. Prerequisite: COM S 612 or permission of instructor. Not offered every year; semester to be announced.
Covers topics in parallel computers. Material includes: architectures of parallel computers, parallelizing compilers, operating systems for parallel computers, and languages (functional and logic-programming languages) designed for parallel computation.

COM S 718 Topics in Computer Graphics
Fall or spring. 4 credits. Prerequisite: COM S 417 or permission of instructor. Not offered every year; semester to be announced.
Covers advanced topics in computer graphics and applications of computer graphics to scientific computation.

COM S 719 Seminar in Programming Languages
Fall, spring. 4 credits. Prerequisite: COM S 611 or permission of instructor. S-U grades only.

COM S 722 Topics in Numerical Analysis
Fall or spring. 4 credits. Prerequisite: COM S 621 or 622 or permission of instructor. Not offered every year; semester to be announced.
Topics are chosen at instructor's discretion.

COM S 729 Seminar in Numerical Analysis/ACRI
Fall, spring. 1–4 credits (to be arranged). Prerequisite: permission of instructor. S-U grades only.

COM S 739 Seminar in Text Processing and Information Retrieval
Fall, spring. 4 credits. Prerequisite: COM S 635 or permission of instructor. S-U grades only.

COM S 754 Seminar in Work-in-Progress Distributed Systems
Fall or spring. 1 credit.

COM S 761 Dynamic Manipulation and Scientific Computation
Spring. 4 credits. Prerequisites: COM S 462 or 661, a strong background in robotics and algorithms (e.g., COM S 481), and permission of the instructor. Not offered every year; semester to be announced.
Most work in dynamic manipulation, an important new area in robotics, uses computer-controlled devices, and yet has been non-computational in flavor. This course surveys the field and attempts to apply methods from numerical and symbolic computation to cast the field into a precise framework and place it on a firm algorithmic footing. Required readings include papers by a variety of researchers.

COM S 762 Robot Café
Spring. 4 credits. Prerequisite: COM S 661. Not offered every year; semester to be announced.
Advanced seminar on varying topics.

COM S 773/774 Proseminar in Cognitive Studies I & II (also Cognitive Studies, Philosophy, Linguistics, and Psychology 773/774)
Fall and spring. 2 credits.
This is a year-long lecture-and-discussion course that is intended to provide graduate students with an interdisciplinary introduction to the study of knowledge, its presentation, acquisition, and use. Topics may include the psychology of perception and cognition; the philosophy of mind, language, and knowledge; the phonology, syntax, and semantics of natural language; computational approaches to natural language processing, vision, and reasoning; parallel distributed processing; and neuropsychology.

COM S 784 Seminar in Computational Algebra
Fall, spring. 4 credits. Not offered every year; semester to be announced.
Informal weekly seminar in which current topics in computational algebra and symbolic mathematics are discussed.

COM S 789 Seminar in Theory of Algorithms and Computing
Fall, spring. 2–4 credits. Prerequisite: permission of instructor. S-U grades only.

COM S 790 Special Investigations in Computer Science
Fall, spring. Prerequisite: permission of a computer science adviser. Letter grade only.
Independent research or Master of Engineering project.

COM S 890 Special Investigations in Computer Science
Fall, spring. Prerequisite: permission of a computer science adviser. S-U grades only.
Master of Science degree research.

COM S 990 Special Investigations in Computer Science
Fall, spring. Prerequisite: permission of a computer science adviser. S-U grades only. Doctoral research.

ELECTRICAL ENGINEERING

Core Courses

ELE E 210 Introduction to Electrical Systems (also ENGRD 210)
Fall, spring. 3 credits. Corequisites: Mathematics 294 and Physics 213.
For description, see Engineering Common Courses.

ELE E 215 Electrical Engineering Laboratory I
Spring. 3 credits. Co-requisite: ENGR 210. Letter grade only.
Basic electric and electronic instrumentation. Measurements and design involving circuits with both active and passive elements; characterization of semiconductor devices. Introduction of the personal computer as a laboratory aid. Technical report writing and communication skills.

ELE E 230 Introduction to Digital Systems (also ENGRD 230)
Fall, spring. 4 credits. Prerequisite: COM S 100.
For description, see Engineering Common Courses.

ELE E 301 Electrical Signals and Systems I
Fall. 4 credits. Prerequisites: a grade of at least C+ in Engr 210 and C in Mathematics 293 and 294.
Continuous- and discrete-time signals and systems; Fourier series and transforms; bilateral Laplace and z transforms; convolution; FFTs and DFTs; applications to modulation, filtering, and sampling.

ELE E 302 Electrical Signals and Systems II
Spring. 4 credits. Prerequisite: ELE E 301.
Linear time-invariant systems as models for electrical networks; network topology; nodal analysis, loop analysis, modified nodal analysis, and state variable analysis; unilateral Laplace transforms for solving vector differential equations; elementary nonlinearities.

ELE E 303 Electromagnetic Fields and Waves
Fall. 4 credits. Prerequisites: grades of C or better in Physics 213, 214, and Mathematics 294.
Electrostatics, magnetostatics, quasistatics; electromagnetic energy and force; Maxwell's equations in integral and differential form; Poynting's theorem; wave equation; plane electromagnetic waves, phase and group velocities, dispersive media; wave reflection and transmission; dielectric and conducting interfaces; guided waves on finite-transmission lines; transient pulse propagation.

ELE E 304 Electromagnetic Fields and Applications
Spring. 4 credits. Prerequisite: ELE E 303.
Theory of electromagnetic fields and waves building on the foundations established in ELE E 303. Recommended for students interested in wireless communication, high data rate electronics, space based communications systems and fiber optics. Review of Maxwell's equations, boundary conditions, vector and scalor potentials, electromagnetic waves, and the wave equation. Theory of electromagnetic waves including transmission lines, waveguides, and fiber optic guides. Cavities, radiation from dipoles and arrays of dipoles, and other transmitting-receiving systems. If time permits, topics will be included on wave propagation in anisotropic media such as the near space regions of the earth, crystals, and ferrites.

ELE E 306 Fundamentals of Quantum and Solid-State Electronics
Spring. 4 credits. Prerequisites: Physics 214 and Mathematics 294.
Introductory quantum mechanics and solid-state physics necessary for understanding lasers and modern solid-state electronic devices. Quantum mechanics is presented in terms of wave functions, operators, and solutions of Schroedinger's equation. Topics include the formalism and methods of quantum mechanics, the hydrogen atom, the structure of simple solids, energy bands, Fermi-Dirac statistics, and the basic physics of semiconductors. Applications studied include a simple metal, thermionic emission, and the p-n junction.

ELE E 308 Fundamentals of Computer Engineering
Spring. 4 credits. Prerequisite: ELE E 230 and CS 211.
An introduction to foundations of computer engineering: structured computer organization; assembly language programming; data structures and algorithms; and computer arithmetic. Practical applications of these concepts.

ELE E 310 Introduction to Probability and Random Signals
Spring. 4 credits. Prerequisite: Mathematics 294. This course may be used in place of Engr 270 to help satisfy the engineering distribution requirement. It can then also meet a field breadth requirement if 3 additional credits of field approved or out-of-field elective are taken.
Introduction to the theory of probability as a basis for modeling random phenomena and signals, calculating the response of systems incorporating these models, and making estimates, inferences, and decisions in the presence of chance and uncertainty. Applications of these models will be given in such areas as communications, control, and device modeling. Specific topics include the basic concept of probability and its representations through densities, cumulative distribution functions, and characteristic functions; conditional probability; independence; scalar and vector random variables and nonlinear transformations of data; expectation, conditional expectation, moments, correlation; laws of large numbers and central limit theorem; linear least mean square estimation; Bayes and Neyman-Pearson decision making.

ELE E 315 Electronic Circuit Design
Fall. 4 credits. Prerequisites ELE E 210 and ELE E 215.
Design of electronic circuits for applications such as computers, signal processing, communication, microelectronics, optoelectronics, measurements/sensing, power electronics and control. Top-down approach starting from design specifications. Circuits with analog, digital, and mixed analog/digital functions. Introduction to design of electronic building blocks and extensive discussion of circuit design with existing building blocks. Design approach based on first order estimation, analytic equations, and circuit simulation. The laboratory environment includes the following computer-aided functions: design; instrumentation; data acquisition and analysis; simulation, verification, and testing; reporting and presentation.

Computer Engineering

ELE E 423 Computer Methods for Circuit Simulation
Fall. 4 credits. Prerequisite: ELE E 302. Satisfies undergraduate computer-applications requirement.
Numerical techniques presented in the context of circuit simulation. Solution of linear and nonlinear algebraic equations; integration; solution of ordinary differential equations; alternative forms of circuit-equation formulation. Starting from a program to simulate simple, linear passive, steady-state circuits, the instructor will add, and the students improve on, procedures that will finally result in a nonlinear transient integrated-circuit simulator that involves most of the techniques discussed in class.

ELE E 439 VLSI Digital System Design
Fall. 4 credits. Prerequisites: EE 230 and EE 315.
Custom VLSI design as seen by a system designer. Emphasis on structured design methodologies for VLSI systems. Topics include MOS transistors, design rules for MOS integrated circuits, implementation of common digital components, clocking disciplines for VLSI, tools for computer-aided design, system design for performance, and novel architectures for VLSI systems.

ELE E 539 Practicum in VLSI Design
Fall and spring (year-long course). 2 credits each semester. Prerequisites: EE 475 or consent of instructor. Corequisite: EE 439.
A year-long implementation project related to EE 439. Students will design a chip and have it fabricated in the fall semester and test it for functionality and performance in the spring semester. Students are required to take the course both fall and spring.

ELE E 445 Computer Networks and Telecommunications
Fall. 3 credits. Prerequisites: ELE E 308 (or COM S 314) and a course in probability.
Design, analysis, and implementation of local area networks, wide area networks, and telecommunications systems; circuit switching, packet switching; broad band switching; protocols; asynchronous transfer mode systems.

ELE E 475 Computer Structures
Fall. 4 credits. Prerequisite: ELE E 308 (or COM S 280 and 314), ENGRD 230.
Methods of designing digital computers and the hardware-software interface to the systems they function with. Topics will include types of control sequencers, memory and I/O organization and interfacing, interrupt hardware design, floating-point hardware and basic architectural alternatives. Laboratory groups will design and build a small digital computer. User-programmable logic devices will be employed for circuit implementation.

ELE E 476 Digital Systems Design Using Microcontrollers
Spring. 4 credits. Prerequisite: ELE E 308 or COM S 314 (ELE E 475 strongly recommended).
Design of real-time digital systems using microprocessor-based embedded controllers. Students working in pairs will design, debug, and construct several small systems that illustrate and employ the techniques of digital system design acquired in previous courses. The content focuses on the laboratory work, the lectures being used primarily for the introduction of examples, description of specific modules to be designed, and instruction in the hardware and high-level design tools to be employed. The laboratory environment is that of ELE E 475 enhanced with the addition of an integrated single-board computer based on the 80C196KB

microcontroller chip. Programming is in assembly language and (optionally) C.

ELE E 524 Differential Equation Numerical Methods for the Electrical Engineer
Spring. 4 credits. Prerequisites: ELE E 301 and ELE E 303. ELE E 423 is helpful. A working knowledge of a scientific programming language is required. Open to both undergraduates and graduates. Satisfies undergraduate computer applications requirement. Alternate years.
Numerical methods for ordinary and partial differential equations are presented using examples from different areas of electrical engineering. Examples include semiconductor-device simulation, plasma simulation, propagation of solitons in optical fibers, and the modeling of electrostatic fields in micromechanical devices. Numerical methods include particle-in-cell simulation techniques; spectral methods; elementary parabolic, elliptic, and hyperbolic methods; and the boundary-element method. The fundamental notions of accuracy and error, consistency, stability, and convergence are discussed.

ELE E 541 Advanced Computer Architectures
Fall. 3 credits. Prerequisite: ELE E 308 (or COMS 280 and 314).
Design and evaluation of processor architectures are examined in the light of actual implementations. Topics include parallel and pipelined architectures, interleaved memories, cache and virtual memories, I/0 processors, vector and array processors, protection mechanisms, and RISC architectures.

ELE E 542 Parallel Processing
Spring. 3 credits. Prerequisite: ELE E 541.
Parallel computer systems that are designed to provide a high computation rate for large specific problems are studied. Topics include computer architecture, interconnection networks, performance characterization, basic algorithms, and parallel programming techniques. Recent multicomputers and massively parallel processors are also discussed.

ELE E 547 Computer Vision
Fall. 4 credits. Prerequisites: ELE E 308 (or COM S 280 and 314) or consent of instructor.
Computer acquisition and analysis of image data with emphasis on techniques for robot vision. Computer vision is the construction of explicit meaningful descriptions of physical objects from images. This course will concentrate on descriptions of objects at three levels of abstraction: segmented images (images organized into subimages that are likely to correspond to interesting objects), geometric structures (quantitative models of image and world structures), and relational structures (complex symbolic descriptions of images and world structures). The programming of several computer-vision algorithms will be required.

ELE E 548 Digital Image Processing
Spring. 3 credits. Prerequisites: ELE E 310, EE 425, familiarity with linear algebra.
Introduction to image processing through four major topics: enhancement, analysis, compression, and restoration. Special attention is allocated to compression. Equal emphasis will be placed on gaining a mathematical and an intuitive understanding of algorithms through actual image manipulation and viewing.

[ELE E 320 The Audio Engineering Laboratory: An Introduction To Audio Signal Processing
Spring. 3 credits. Prerequisites: ELE E 301 and ELE E 315. Not offered 1995–96.
Hands-on laboratory experience in applying signals and systems concepts. Students are paired into teams; each team designs, constructs, and tests simple analog and digital audio circuits and programs. The course builds intuition in signal processing, valuable not only for audio, but also for general communication and control systems. In addition, students develop critical technical writing and presentation skills.]

ELE E 425 Digital Signal Processing
Fall. 4 credits. Prerequisite: ELE E 301.
Fundamentals of signal analysis, review of Fourier, Laplace, and Z transforms. Sampling theory. Multirate signal processing. Discrete Fourier transform properties and computation (FFT). Digital filter design; the approximation problem for FIR and IIR filters, the realization problem–finite word-length limitations and filter structures.

ELE E 426 Applications of Signal Processing
Spring. 3 or 4 credits. Prerequisite: ELE E 425.
Applications of signal processing, including signal analysis, filtering, and signal synthesis. The course is laboratory oriented and emphasizes individual student projects. Design is done with signal-processing hardware and by computer simulation. Topics include filter design (principally digital filtering) and spectral analysis as well as speech coding, speech processing, digital recording, adaptive noise cancellation, and digital signal synthesis.

ELE E 521 Theory of Linear Systems
Fall. 4 credits. Prerequisite: ELE E 302 or permission of instructor. Recommended: a good background in linear algebra and linear differential equations.
State-space and multi-input-multi-output linear systems in discrete and continuous time. The state transition matrix, the matrix exponential, and the Cayley-Hamilton theorem. Controllability, observability, stability, realization theory. At the level of *Linear Systems*, by T. Kailath.

ELE E 522 Nonlinear Systems: Analysis, Stability, Control, and Applications
Spring. 4 credits. Prerequisites: ELE E 521 or a solid background in linear algebra and real analysis strongly recommended but not required.
A fairly rigorous introduction to nonlinear systems, including nonlinear differential equations, flows, phase-plane analysis, fundamentals of Lyapunov theory, LaSalle's Theorem, regions of attraction, slowly varying systems, advanced stability theory, Lyapunov redesign, applied nonlinear control, describing functions, averaging and singular perturbations; bifurcation analysis and control and application to physical systems.

ELE E 525 Adaptive Filtering in Communication Systems
Fall. 4 credits. Prerequisites: ELE E 425 or 472, or 521, or permission of instructor.
Fundamentals of an adaptive filter theory intended for communication systems applications. Three traditional problems are used to motivate adaptive FIR and IIR filter design and to raise open issues of current interest: (1) channel equalization for intersymbol interference removal from distorted digital sources, (2) echo cancellation in 4 wire telephony loops, and (3) speechband signal-source compression via differential pulse code modulation.

ELE E 526 Advanced Signal Processing
Spring. 4 credits. Prerequisites: ELE E 425 and ELE E 521.
Sampling and signal reconstruction. Approximation theory. Linear inversion theory. Exponential signal modeling. Spectral estimation. Wavelets.

Communication and Information Systems

ELE E 411 Random Signals in Communications and Signal Processing
Fall. 3 credits. Prerequisite: ELE E 302 and 310 or equivalent.
Introduction to models for random signals in discrete and continuous time; Markov chains, Poisson process, queuing processes, wide-sense stationary processes and power spectral densities, Gaussian random process, including the narrowband case. Electrical engineering phenomena described by such models (e.g., communications channel noise, queues that form in multiple-access telecommunications systems). Response of linear and nonlinear systems to random signals. Elements of estimation and inference as they arise in communications and digital signal processing systems (e.g., problems of extraction of signals from noise via Wiener filtering, power spectral density estimation).

ELE E 468 Communications Systems I
Spring. 4 credits. Prerequisite: ELE E 301 or 521, and 411 or equivalent.
Analog signal representation and filtering using Fourier and Hilbert transform techniques. Varieties of amplitude modulation (AM, DSBSC, SSB, VSB, QAM), phase modulation, and phase locked loops. Frequency modulation. Demodulation of AM and FM in the presence of noise; sampling theorems and aliasing. Pulse amplitude modulation. Quantization for A/D conversion. Pulse code modulation. Elements of optimal signal parameter estimation. Application to commercial broadcasting and data transmission.

[ELE E 561 Error-Control Codes
Fall. 4 credits. Prerequisite: ELE E 301 or ELE E 521 or equivalent. A strong familiarity with linear algebra is assumed. Not offered 1995–96.
An introduction to the theory of algebraic error-control codes. Topics include: Hamming codes, group codes, the standard array, minimum-distance decoding, cyclic codes, and the dual of a linear block code. Methods of shortening and combining codes. Hamming and Singleton bounds for error-correcting codes. Algebra: groups, rings, and fields with special emphasis on Galois or finite field theory. The construction and decoding of Bose-(Ray) Chaudhuri-Hocquenghem (BCH) and Reed-Solomon (RS) codes. Two-dimensional cyclic codes and cascaded Reed-Solomon codes. Computer methods for the study of the structure and algorithms for error-control are used.]

ELE E 562 Fundamental Information Theory
Fall. 4 credits. Prerequisite: ELE E 310 or equivalent.

Fundamental results of information theory with application to storage, compression, and transmission of data. Entropy and other information measures. Block and variable-length codes. Channel capacity and rate-distortion functions. Coding theorems and converses for classical and multiterminal configurations. Gaussian sources and channels.

ELE E 563 Communication Networks
Spring. 4 credits. Prerequisite: ELE E 411 or permission of instructor.
Classical line-switched communication networks: point-process models for offered traffic; blocking and queuing analyses. Stability, throughput, and delay of distributed algorithms for packet-switched transmission of data over local-area and wide-area nets (LANS and WANS): TDMA, FDMA, ALOHA, slotted ALOHA, Ethernet, reservation, tree, and interval-searched contention resolution protocols. Flow control and capacity assignment algorithms for wideband circuit-switched and ATM networks.

[ELE E 564 Decision Making and Estimation
Fall. 4 credits. Prerequisite: Coregistration in ELE E 411. Not offered 1995–96.
An introduction to those methods of making rational decisions and inferences and of forming estimates that are central to problems of communications, detection, pattern recognition, and statistical signal processing. Topics include Bayes, minimax, and Neyman-Pearson decision theories; Bayes and maximum likelihood point estimation; Cramer-Rao bound, efficient, and consistent estimation; spectral estimation; and robust models for signal extraction.]

ELE E 567 Communication Systems II
Spring. Offered as 2 or 4 credits. Prerequisites: ELE E 562.
Fundamental topics in modern digital communication. Analytical and computational tools required to understand modern data conversion, transmission, and storage systems. Possible topics include: PCM, DPCM, PAM, PSK, FSK, matched filtering, equalization, line codes, trellis codes, Viterbi decoding, applications to audio, video, and magnetic recording. Vector quantization and universal data compression including LZ, LZW, and arithmetic coding, applied to files, speech, images, and video.

ELE E 577 Artificial Neural Networks
Fall. 4 credits. Prerequisites: ELE E 310; ELE E 411 recommended.
Artificial neural networks are brainlike in being formed out of many highly interconnected nonlinear memoryless elements. Probability theory will provide the primary analytical approach to design and analysis of neural networks. The course will cover capabilities of feed-forward nets (multilayer perceptrons) that can serve as pattern classifiers, decision-making devices, and controllers, as well as aspects of recurrent/feedback/Hopfield nets that can serve as associative memories and combinatorial optimizers. At the level of the current literature.

[ELE E 664 Foundations of Inference and Decision Making
Spring. 3 credits. Prerequisite: a course in probability and some statistics, or permission of instructor. Not offered 1995–96.
An examination of methods for characterizing uncertainty and chance phenomena and for transforming information into decisions and optimal systems. Discussion of the foundations of inference includes topics drawn from comparative probability, interval-valued probability, quantitative probability, relative frequency interpretations, computational complexity, randomness, classical probability and invariance, induction, and subjective probability.]

ELE E 668–669 Random Processes in Electrical Systems
668, fall; 669, spring. 3 credits each term.
Advanced topics in the general area of randomness and uncertainty and their relevance to the analysis and design of electrical systems.

Power and Control Systems

ELE E 451–452 Computer-Aided Analysis of Electric Power Systems I and II
451, fall; 452, spring. 4 credits each term. Prerequisite: ELE E 302.
Representation of 3-phase power systems, modeling of synchronous machines; transmission lines; transformers; loads, introduction to sparce matrix techniques, power-flow analysis, economic dispatch, optimal power flow, symmetrical components, fault studies, power-system protection, power-system stability, on-line power-flow analysis, voltage-control systems, and power-control systems.

ELE E 471 Feedback Control Systems
Fall. 4 credits. Prerequisite: ELE E 302 or M&AE 326, or permission of instructor.
Analysis techniques, performance specifications, and analog-feedback-compensation methods for single-input, single-output, linear, time-invariant systems. Laplace transforms and transfer functions are the major mathematical tools. Design techniques include PID, root-locus, frequency response, and algebraic pole placement. Computer-aided design laboratory examines modeling and control of a computer-simulated dynamic process.

ELE E 472 Digital Control Systems
Spring. 4 credits. Prerequisite: ELE E 471 or permission of instructor.
Analysis and design of feedback control systems using digital devices to implement compensation. Z-transforms and linear algebra are the major mathematical tools. Topics include: state realizations, digitizations of analog systems, least-squares system identification, state feedback control, observers, combined observer-controller, and algebraic-control design. Assignments will consist of reports on computer-aided controller design and digitally simulated evaluation.

[ELE E 555 Advanced Power Systems Analysis and Control I
Fall. 3 credits. Prerequisites: ELE E 302 and concurrent registration in 451, or permission of instructor. Not offered 1995–96.
Advanced static analysis of power systems. State estimation in power systems. Bad-data detection and identification. Static equivalent circuits of external power systems. Static contingency analysis and selection. Steady-state security assessment. Static bifurcation and voltage stability. Theoretical analysis of load flow equations.]

[ELE E 556 Advanced Power Systems Analysis and Control II
Spring. 3 credits. Prerequisite: ELE E 555 or permission of instructor. Not offered 1995–96.
Analysis of power-system components including rotating machines, excitation systems, automatic voltage regulation, boiler-turbine control, and speed regulation. Automatic Generation Control. Numerical simulations of mid-term and long-term power-system dynamics. Direct methods for power-system stability analysis. Dynamic equivalent circuits of external power systems. Dynamic contingency analysis and selection. Dynamic Security Assessment.]

[ELE E 573 Optimal Control and Estimation for Continuous Systems
Fall. 4 credits. Prerequisite: ELE E 521 or permission of instructor. Not offered 1995–96.
Control system design through parameter optimization, with and without constraints. The minimum principle; linear regulations, minimum-time and minimal-fuel problems. Computational techniques; properties of Lyapunov and Riccati equations.]

[ELE E 574 Estimation and Control in Discrete Linear Systems
Spring. 4 credits. Prerequisites: ELE E 521 and 411, or permission of instructor. Not offered 1995–96.
Optimal control, filtering, and prediction for discrete-time linear systems. Approximation on discrete point sets. The principle of optimality. Kalman filtering. Stochastic optimal control.]

ELE E 679 Advanced Topics in Systems and Control
1–3 credits. Prerequisite: permission of instructor. Not offered every year.
Topics include robotics, nonlinear feedback system stability, multivariable control, and qualitative theory on nonlinear systems.

Solid-State Electronics

ELE E 412 Applied Solid-State Physics
Spring. 4 credits. Prerequisite: ELE E 306. ELE E 407 recommended.
Review of basic solid-state concepts (lattice, primitive cell, reciprocal lattice, Brillouin zone). Lattice vibrations. The diatomic chain. Polarity of waves. Binding of crystals. Thermal properties of insulators and metals. Effective mass tensor. Magnetic flux quantization and the Fermi surface in metals. Plasmons, polaritons, and polarons. Charge-carrier scattering. Optical properties. Kramers-Kronig relations. Elements of superconductivity. Dia- and ferroelectric materials. Dia-, para-, ferro-, and antiferromagnetism.

ELE E 433 Microwave Integrated Circuits
Fall. 4 credits; may be taken for 3 credits without laboratory. Prerequisites: ELE E 303 and ELE E 306.
An introduction to the design and testing of high-speed circuits (frequencies above 1 GHz). Topics include: computer-aided design, automated microwave measurement techniques, optoelectronic applications, and GaAs monolithic microwave integrated circuits. Six two-week labs cover the basics of designing, fabricating, and testing microwave integrated circuits.

ELE E 453 Integrated Circuit Design
Fall. 4 credits. Prerequisites: ELE E 301 and ELE E 315 or equivalent. ELE E 457 recommended.
Introduction to analysis and design of digital and analog MOS and bipolar integrated circuits (IC). Device models. Computer-aided design (layout, design rules, floor planning). Common building blocks for digital and analog applications (inverters, switches, single-stage units, sources, sinks, differential pairs, active loads). Steady-state and transient analysis, frequency response and noise. Overview of common IC designs (microprocessors, memories, amplifiers).

ELE E 457 Silicon Semiconductor Electronics
Fall. 4 credits with lab. Prerequisites: ELE E 315 and ELE E 306 or equivalent.
Fundamental electronic properties of semiconductors. Energy-band diagrams, carrier transport and recombination, pn junctions, metal-semiconductor Schottky contacts, ohmic contacts, and metal-oxide-semiconductor (MOS) structures. Operation of bipolar junction transistors (BJTs) and field effect-transistors (FETs). Six two-week labs covering electrical measurements of semiconductor materials and devices.

ELE E 533 Semiconductor Lasers
Spring. 3 credits. Prerequisites: ELE E 430, ELE E 457, or permission of instructor.
Study of principles and characteristics of semiconductor lasers. Topics cover laser dynamics, noise, quantum confined structures, single-frequency lasers, traveling-wave lasers, surface-emitting lasers, reliability, and emerging research subjects. A term project and paper will be required.

ELE E 535 Semiconductor Physics
Fall. 4 credits. Prerequisites: ELE E 457 and 407, or permission of instructor.
Fundamental semiconductor physics of charge carrier transport and optical characteristics of materials and structures useful in electronic and photonic devices. Crystal structure, energy band structures, carrier effective mass, phonons, statistics, classical low-field transport, including temperature effects, high-field and ballistic charge carrier transport, electron scattering by phonons in bulk and quantum well structures, optical absorption, reflection, optical emissions, deep levels as charge carrier traps, surface and interface effects. Examples of related phenomenon in electronic and photonic devices. On the level of *Compound Semiconductor Device Physics* by S. Tiwari.

ELE E 536 VLSI Technology
Spring. 4 credits. 3 credits without laboratory with permission of instructor. Prerequisite: ELE E 457 or ELE E 453 or ELE E 539, or permission of instructor.
Processing technology for very large scale integrated circuits for CMOS, BiCMOS, ECL, and related applications. Lithography, oxidation, diffusion, ion implantation, film deposition, wet and dry etching, multilevel metal interconnect, process integration, manufacturing yield, and integrated circuit reliability. Hands-on laboratory includes full MOS device and circuit fabrication process in a clean room; process simulation on CAD tools; and process, device, and circuit characterization.

ELE E 537 Computer System Packaging
Spring. 4 credits. 3 credits without project with permission of instructor. Prerequisites: ELE E 230 and ELE E 453 or ELE E 457 or ELE E 539; or permission of instructor.
Integration of electronic systems from integrated circuits, to VLSI chips, modules, boards, and full electronic systems including handheld, notebook, desktop, workstation, mainframe, and supercomputer size classes. Packaging architectures, high-speed electrical and optical signal distribution, power distribution, and power and thermal management, functional architecture, manufacturing, wireless functions measurement and simulation methods, and fundamental limits. State of the art case studies concentrate on the following electronic systems: personal digital assistants, PC cards, wireless communicators, compact handheld/laptop/computers, workstations, mainframes, and supercomputers. Computer simulations and designs on workstations using SPICE3e and AUDIT4.4 CAD tools. Demonstrations, measurements, and projects will be performed in the Advanced Electronic Packing Facility (Kimball Hall). *Computer System Packaging*, a textbook manuscript in progress, and the textbook *Principles of Electronic Packaging* (D. P. Seraphim, R. Lasky, and C-Y Li, McGraw-Hill, 1989) will serve as the primary course texts. Lectures involve outside speakers from the electronics industry.

ELE E 554 Advanced VLSI Circuit Design
Spring. 4 credits. Prerequisite: ELE E 453 or equivalent.
Integration of building blocks on chip. Overview of recent innovations in VLSI circuits. Feedback circuits. Operational amplifiers. Switched-capacitor circuits. Digital-to-analog and analog-to-digital converters. Dynamic and static memories. Programmable logic and gate arrays. Systems on chips (microprocessors, wafer-scale integration).

ELE E 558 Compound Semiconductor Electronics
Spring. 4 credits with lab. Prerequisites: ELE E 457 or equivalent.
Electronic properties of advanced semiconductor structures using compound semiconductor materials and heterojunctions. Fundamentals of carrier transport and scattering. Properties of direct bandgap semiconductors and quantum wells. Advanced semiconductor devices including metal-semiconductor transistors (FETs), modulation-doped FETs, and heterojunction bipolar transistors (HBTs). High-frequency operation of compound semiconductor devices. Six two-week labs, which include low-temperature carrier transport, optical absorption and emission, and electrical characterization of compound semiconductor devices.

ELE E 633 Radiation Effects in Microelectronics
For description, see NS&E 621.

ELE E 636 Advanced Solid-State Devices
Spring. 4 credits. Prerequisites: ELE E 535 or ELE E 457 and ELE E 407 or equivalent. May not be offered 1995–96.
Review of quantum foundations of carriers in semiconductors. Detailed discussion of non-equilibrium transport of carriers in semiconductors including carrier dynamics, scattering, relaxation, recombination, hot carrier effects, high field effects, and quantum mechanical tunneling. Exploration of semi-classical drift-and-diffusion, hydrodynamics, and Monte Carlo–based device simulation. Project requires independent simulation study of state-of-the-art semiconductor device.

Quantum and Opto-Electronics

ELE E 306 Fundamentals of Quantum and Solid-State Electronics
Spring. 4 credits.
For description, see Core Courses.

ELE E 407 Quantum and Solid State Electronics II
Fall. Prerequisite: ELE E 306.
Continuation of review of basic quantum mechanical and solid-state concepts. Quantum topics: harmonic oscillator; annihilation and creation operators; angular momentum; selection rules; LS coupling, Pauli principle; elements of perturbation theory; atom-radiation interaction; the quantum well; solid-state topics: thermal properties of crystals; Bose-Einstein distribution; Phonons Fermi-Dirac distribution; specific heat; metallic conductivity and resistivity; thermal conduction in metals; nearly-free-electron model; k-p expansion; plasma dispersion relation; plasmons; polaritons; excitons; Schottky barrier.

ELE E 430 Lasers and Optical Electronics
Fall. 4 credits with lab. Prerequisite: ELE E 306 or equivalent.
An introduction to the operation of stimulated-emission devices such as lasers and devices based on linear and nonlinear optics. Material covered includes diffraction-limited optics, propagation of Gaussian laser beams, optical resonators, interaction of radiation with matter, physics of laser operation, laser design. Applications of coherent radiation to nonlinear optics, communication, and research will be discussed as time permits.

ELE E 530 Fiber and Integrated Optics
Spring. 4 credits with lab. Prerequisite: ELE E 303 or equivalent.
Physical principles of optical waveguides, optical sources and detectors, noise, modulators, and sensing. Wave equation solutions to the mode structure in waveguides, mode coupling, dispersion and bandwidth limitations, optical sources based on semiconductors, detectors and noise, modulation techniques, nonlinear effects in optical waveguides, and optical sensors. Laboratory includes demonstrations of optical coupling and waveguide characterization.

ELE E 531 Quantum Electronics I
Fall. 4 credits. Prerequisites: ELE E 306 and 407, or Physics 443.
A detailed treatment of the physical principles underlying lasers, related fields, and applications. Topics include the interaction of radiation and matter, including emission, absorption, scattering, and basic spectroscopic properties of key laser media; theory of the laser, including methods of achieving population inversions, dispersive effects, and laser oscillation spectrum.

ELE E 532 Quantum Electronics II
Spring. 4 credits. Prerequisite: ELE E 531 or permission of instructor.
A continuation of ELE E 531. Topics include density matrix; nonlinear optical processes; properties of nonlinear optical materials; optical parametric oscillators; spontaneous and stimulated Raman and Brillouin processes; theory of coherence; pico- and femto-second

optics; ultrafast processes in semiconductors and molecules; optical properties of semiconductor-doped glasses, quantum-well structures, and superlattices.

Plasmas, Space Engineering, and Remote Sensing

ELE E 484 Introduction to Controlled Fusion: Principles and Technology (also M&AE 559 and NS&E 484)
Spring. 3 credits. Prerequisites: ELE E 301 and 303, or permission of instructor. Intended for seniors and graduate students.
For description, see NS&E 484.

ELE E 486 Space Science and Engineering
Spring. 3 credits. Prerequisites: ELE E 301 and ELE E 303 or equivalent.
A survey of subjects relevant to spacecraft design. Astrodynamics and orbital maneuvers. Rigid-body dynamics and control. Communications. Black-body radiation and temperature control. Geospace environment. Remote sensing using electromagnetic techniques. Applications of these topics will be discussed where appropriate. At the level of *Design of Geosynchronous Spacecraft*, by Agrawal.

[ELE E 580 Applied Electrodynamics
3 credits (4 credits with project). Prerequisite: ELE E 581 or ELE E 583 or permission of instructor. Not offered 1995–96.
Contemporary electrodynamics with emphasis placed on applications. Theory, design, and use of high-power microwave devices, such as gyrotons, CARMs, free-electron lasers, and traveling-wave tubes. Electromagnetic waveguide and cavity modes, charged-particle orbit theory, particle dynamics in electromagnetic fields, field transforms, electron beam generation, equilibria, waves on beams, low- and high-power microwave devices and their applications. Project based on the numerical simulation of microwave devices.]

ELE E 581 Introduction to Plasma Physics
Fall. 4 credits. Prerequisites: ELE E 303 and ELE E 304 or equivalent. First-year graduate-level course; open to exceptional seniors with permission of instructor.
Plasma state; motion of charged particles in fields; drift-orbit theory; coulomb scattering, collisions; ambipolar diffusion; elementary transport theory; two-fluid and hydromagnetic equations; plasma oscillations and waves, CMA diagram; hydromagnetic stability; elementary applications to space physics and controlled fusion.

ELE E 582 Advanced Plasma Physics (also A&EP 607)
Spring. 4 credits. Prerequisites: ELE E 581 or A&EP 606.
Boltzmann and Vlasov Equations; dielectric tensor; waves in hot-magnetized plasma; Landau and cyclotron damping; microinstabilities; drift waves, low-frequency stability; test particles, Cerenkov emission; fluctuations; collisional effects; applications.

ELE E 585 Atmospheric and Near Earth Space Science (also Astronomy 575)
Fall. 3 credits.
Energy-balance and thermal structure of neutral planetary atmospheres. Elements of circulation theory. Waves and instabilities. Coupling of lower atmospheres to upper atmospheres. Observations of the terrestrial atmosphere and of the other planets. Physical processes in the earth's ionosphere and magnetosphere. Production, loss, and transport of charged particles. Electric and magnetic fields. Coupling of neutral-atmosphere dynamics with electric fields and charged-particle transport. Diagnostic techniques, including radar and in situ observations. The equatorial electrojet. Observations of ionospheres on the other planets.

ELE E 586 Solar Terrestrial Physics (also Astronomy 576)
Spring. 3 credits.
High-latitude ionosphere; electric fields in the polar cap and auroral zone; particle precipitation and the aurora; magnetic and ionospheric storms; plasma instabilities in the ionosphere and magnetosphere; structure and physical processes in the sun, solar corona, and solar wind; interactions between the solar wind and the earth's magnetosphere; trapping, acceleration, and drift of energetic particles in the magnetosphere.

ELE E 587 Energy Seminar (also NS&E and M&AE 545)
Fall and spring. 1 credit each semester. Master of Engineering (M.Eng) students in the Energy Option are expected to take this seminar both fall and spring for credit. 1 lec. D. Hammer.
Energy resources, their conversion to electricity of process heat, and the environmental consequences of the energy cycle will be discussed by faculty members from several departments in the College of Engineering, other units within the university, and invited experts. Examples of topics to be surveyed are energy resources, economics, and politics; coal-based electricity generation; nuclear reactors; solar power; energy conservation by users; synthetic fuels; air-pollution control; nuclear-waste disposal; electric-power transmission systems; geothermal power, wind power, and advanced oil recovery.

[ELE E 682 Nonlinear Phenomena in Plasma Physics
Fall. 3 credits. Prerequisite: ELE E 582. Offered every other year. Not offered 1995–96.
Nonlinear models and behavior of plasmas. Solitons and nonlinear wave equations, resonant mode-mode coupling, ponderomotive effects and parametric processes, development of simplified plasma dynamical models.]

[ELE E 685 Solar Plasma Physics
Fall. 3 credits. Offered upon demand. Not offered 1995–96.
This course will be coordinated with the two courses on upper atmospheric physics, ELE E 585 and 586, to provide an integrated view of solar-terrestrial physics for the graduate student intending a research career in space plasma physics. A thorough understanding of electromagnetic theory and some knowledge of fluid mechanics and plasma physics at the level of ELE E 581 and 582 are assumed.]

Fields, Waves, and Antennas

[ELE E 487 Introduction to Antennas and Radar
Fall. 3 credits. Prerequisites: ELE E 301 and ELE E 304 (or a grade of B or better in ELE E 303). Not offered fall 1995.
Fundamentals of antenna theory, including gain and effective area, near and far fields, phased arrays, aperture antennas and aperture synthesis. Fundamentals of radar, including detection, tracking, Doppler shifts, sampling, range and frequency aliasing. Pulse compression principles and the ambiguity function; synthetic aperture radars and remote sensing from aircraft and satellites; over-the-horizon (OTH) radars and ionospheric propagation effects; radar astronomy techniques, including range-Doppler mapping of planets and the problem of overspread targets.]

ELE E 488 RF Circuits and Systems
Spring. 3 credits. Prerequisites: ELE E 315 or equivalent. 2 design credits. lab credit.
Basic RF circuits and applications. Receivers, transmitters, modulators, filters, detectors, transmission lines, oscillators, frequency synthesizers, low-noise amplifiers. Applications include communication systems, radio and television broadcasting, radar, radio and radar astronomy. Computer-aided circuit analysis. Five laboratory sessions.

ELE E 583 Electrodynamics
Fall. 4 credits. Prerequisite: ELE E 301 and ELE E 304 or equivalent. 3 lecs.
Maxwell's equations, electromagnetic potentials, integral representations of the electromagnetic field, Green's functions. Special theory of relativity, Lienard-Wiechert potentials, radiation from accelerated charges, Cerenkov radiation. Electrodynamics of dispersive dielectric and magnetic media. At the level of *Classical Electrodynamics*, by Jackson.

ELE E 584 Microwave Theory
Spring. 4 credits. Prerequisites: ELE E 301 and 304 or equivalent. 3 lecs, 1 rec.
Theory of passive microwave devices. Modal analysis of inhomogeneous waveguides and cavities. Waveguide excitation, perturbation theory. Nonreciprocal waveguide devices. Scattering matrix analysis of multiport junctions, resonant cavities, directional couplers, circulators. Periodic waveguides, coupled-mode theory.

[ELE E 588 Advanced Electromagnetic Wave Propagation and Scattering
Spring. 3 credits. Prerequisite: ELE E 487 and 581 or permission of instructor. Offered alternate years. Not offered 1995–96.
WK band and full-wave solutions of the wave equations, interactions between particles and waves, scattering of radio waves from random fluctuations in refractive index, scatter propagation, incoherent scatter from the ionosphere and its use as a diagnostic tool, scattering from unstable plasma waves, pulse compression and other radar probing techniques.]

General

ELE E 250 Technology in Western Society (also ENGRG 250)
Fall. 3 credits. Approved for humanities distribution.
For description, see Engineering Common Courses.

ELE E 298 The Electrical and Electronic Revolutions (also ENGRG 292)
Spring. 3 credits. Approved for humanities distribution.
For description, see Engineering Common Courses.

ELE E 360 Ethical Issues in Engineering
Spring. 3 credits. A social science elective for engineering students. Open to juniors and seniors.
For description, see Engineering Common Courses.

ELE E 291-292 Electrical Engineering Project
291, fall; 292, spring. 1-8 credits. Limited to sophomores in Engineering.
Individual study, analysis, and, usually, experimental tests in connection with a special engineering problem chosen by the student after consultation with the faculty member directing the project. An engineering report on the project is required.

ELE E 391-392 Electrical Engineering Project
391, fall; 392, spring. 1-8 credits. Limited to juniors in Engineering.
Individual study, analysis, and, usually, experimental tests in connection with a special engineering problem chosen by the student after consultation with the faculty member directing the project. An engineering report on the project is required.

ELE E 491-492 Electrical Engineering Project
491, fall; 492, spring. 1-8 credits. Limited to seniors in Engineering.
Individual study, analysis, and, usually, experimental tests in connection with a special engineering problem chosen by the student after consultation with the faculty member directing the project. An engineering report on the project is required.

ELE E 493 MicroElectro Mechanical Systems (MEMS)
Fall. 3 credits. Letter grade. Intended for seniors in Engineering or the physical sciences.
Introductory course to the new, emerging technology of MEMS: microsensors, microactuators, and microrobots. Fundamentals of MEMS including materials, microstructures, devices and simple microelectromechanical systems. Fundamentals of scaling electronic and mechanical systems to the micrometer/nm-scale including semiconductor and thin film process constraints, material issues, micromechanical structures and the integration of micromechanical structures and actuators with simple electronics. This is an interdisciplinary course drawing content from mechanics, materials, structures, electronic systems, and the disciplines of physics and chemistry. Introductory, cross-disciplinary concepts are included in the course.

ELE E 495-496 Special Topics in Electrical Engineering
1-4 credits.
Seminar, reading course, or other special arrangement agreed on by the students and faculty members concerned.

ELE E 515-516 Applied Signal Processing Systems Design
515, fall; 516, spring. Variable credits.
Project-level design of systems in the area of signal processing and general instrumentation, including digital signal processing hardware, audio, speech, and analog interfacing. Students pursue individual projects and coordinate ideas and resources with other students with related interest.

ELE E 517-518 A Practical Electric Vehicle Motor Controller Utilizing Vector Control
517, fall; 518, spring. Variable credits (3-8 per year). Prerequisites: ELE E 471, 472, 476, or 457.
Design of a microcontroller-based vector-control system for a 3-phase induction motor. Emphasis is placed upon the coordinated design of a suitable feedback system with torque control, and a microprocessor arrangement capable of performing the coordinate rotations and implementing an overall torque feedback algorithm. Display and data acquisition software will be developed.

ELE E 591-599 Graduate Topics in Electrical Engineering
1-4 credits.
Seminar, reading course, or other special arrangement agreed on by the students and faculty members concerned.

ELE E 691-692 Electrical Engineering Colloquium
691, fall; 692, spring. 1 credit each term. For students enrolled in the graduate Field of Electrical Engineering.
Lectures by staff, graduate students, and visiting authorities. A weekly meeting for the presentation and discussion of important current topics in the field. Reports required.

ELE E 693-694 Master of Engineering Design
693, fall; 694, spring. 1-10 credits. For students enrolled in the M.Eng.(Electrical) degree program. Uses real engineering situations to present fundamentals of engineering design. Each professor is assigned a section number. To register, see roster for appropriate numbers.

ELE E 695-699 Graduate Topics in Electrical Engineering
1-6 credits.
Seminar, reading course, or other special arrangement agreed on by the students and faculty members concerned.

ELE E 791-792 Thesis Research
791, fall; 792, spring. 1-15 credits. For students enrolled in the master's or doctoral program.

GEOLOGICAL SCIENCES

Freshman and Sophomore Courses

GEOL 101 Introductory Geological Sciences
Fall, spring, or summer. 3 credits. Fall: W. Travers; spring: J. Bird; summer: W. Brice.
Designed to enhance an appreciation of the physical world. Natural environments, surface features, dynamic processes such as mountain belts, volcanoes, earthquakes, glaciers, and river systems are emphasized. Interactions of the atmosphere, hydrosphere, biosphere, and lithosphere (Earth System Science). Water, mineral, and fuel resources; environmental concerns. Field trips in the Ithaca region.

GEOL 102 Evolution of the Earth and Life (also Bio S 170)
Spring. 3 credits. GEOL 101 recommended. J. L. Cisne.
Earth systems and their evolution. Earth history's astronomical context. Plate tectonics, continental drifts, and their implications for climate and life. Coevolution of life and the atmosphere. Precedents for ongoing global change. Dinosaurs, mass extinctions, and human ancestry. Laboratories on reconstructing geological history and mapping ancient geography. Fossil collecting on field trips.

GEOL 103 Introductory Environmental Geology
Fall. 3 credits. A. L. Bloom, D. E. Karig.
The geologic factors that affect human well being and safety, taught as much as possible with examples in Tompkins County. Weekly field trips to evaluate geologic hazards such as landslides, floods, groundwater pollution, and hazardous waste disposal. Later in the term, earthquakes and volcanic hazards will be reviewed.

GEOL 104 The Sea: An Introduction to Oceanography (also BIO ES 154)
Spring. 3 credits. W. M. White, C. Green.
A survey of the physics, chemistry, geology, and biology of the oceans for both science and non-science majors. Topics include: sea-floor spreading and plate tectonics, marine sedimentation, chemistry of seawater, ocean currents and circulation, the oceans and climate, ocean ecology, coastal processes, marine pollution and waste disposal, and marine resources.

GEOL 105 Writing on Rocks (Freshman Seminar)
Fall. 3 credits. J. Chiment.
See Freshman Seminar Handbook for description.

GEOL 108 Geology and Society
Spring. 1 credit. May be taken concurrently with or after GEOL 101, 102, 103, 104, 111, 201, or 206. T. E. Jordan.
Intended for students who are curious about the impact of geological materials and processes on society, what geologists actually do, what the big questions are in current research, and what a geology career might hold in store. A different speaker each week takes a look at topics ranging from environmental law to natural resources to agriculture.

GEOL 109 Dinosaurs
Fall. 1 credit. J. L. Cisne.
An entry-level survey course for those who are interested in dinosaurs and may lack a science background. Lectures examine the fossil evidence and illustrate how various geological and biological disciplines contribute to understanding dinosaurs and their world.

GEOL 111 To Know the Earth and Build a Habitable Planet
Fall. 3 credits. J. M. Bird.
Acquaints the non-scientists with Earth. Major features and how Earth has evolved. Earth System Science and building a habitable planet. Effects of human activity on geologic environments, mitigating environment damage, living with natural hazards. Mineral resource use in 21st century and an environmentally sound fuel-minerals cycle.

GEOL 122 Earthquake! (also ENGRI 122)
Fall. 3 credits. L. Brown.
The science of natural hazards and strategic resources is explored. Techniques for locating and characterizing earthquakes, and assessing the damage they cause; methods of using sound waves to image the earth's interior to search for strategic materials; the historical importance of such resources. Seismic

experiments on campus to probe for groundwater, the new critical environmental resource.

GEOL 123–124 Science of Earth Systems Colloquium (also SES 101–102 and SCAS 101–102)

For description, see the Science of Earth Systems section in "Interdisciplinary Centers, Programs, and Studies," in the front part of the catalog.

GEOL 201 Introduction to the Physics and Chemistry of the Earth (also ENGRD 201)

Spring. 3 credits. Prerequisites: Mathematics 191 and Physics 112. L. M. Cathles.

For description, see Engineering Common Courses.

GEOL 203 Natural Hazards and the Science of Complexity

Fall. 3 credits. Prerequisites: 2 math courses, 1 physics course. D. L. Turcotte.

Studies of natural hazards; earthquakes, floods, hurricanes, severe storms, wildfires, meteor impacts. Applications of the science of complexity to natural hazards: fractals, chaos, and self-organized criticality.

GEOL 204 Hydrology and the Environment (also SCAS 371 and ABEN 371)

Spring. 3 credits. Prerequisite: 1 course in calculus. P. C. Baveye, L. M. Cathles, J.-Y. Parlange, T. S. Steenhuis, M. F. Walter.

Introduction to hydrology: the hydrologic cycle and the role of water and chemicals in the natural environment. Includes precipitation, infiltration, evapotranspiration, groundwater, surface runoff, river meandering, floods, and droughts. Case studies, short field trips, computer programs, and laboratories foster an understanding of concepts and principles of hydrologic processes.

GEOL 206 Geologic Perspectives on Climate Change

Spring. 3 credits. K. Attoh.

Principles that govern the interactions among the principal components of the climate system (atmosphere, oceans, lithosphere, and solar radiation) are used to reconstruct Earth's climates from the geologic record. Continental climate record in rocks. Geological forcing/responses to climate change.

GEOL 210 Introduction to Field Methods in Geological Sciences

Fall. 3 credits. Prerequisite: GEOL 101, 103, 201, or permission of instructor. Weekly field sessions. A weekend field trip. S. Mahlburg Kay, J. L. Cisne.

The methods by which rocks are used as a geological database. Field methods used in the construction of geologic maps and cross sections; systematic description of stratigraphic sections. Field and laboratory sessions on Saturday mornings until Thanksgiving. One additional lecture during most of these weeks. One weekend field trip to eastern New York.

GEOL 212 Special January Field Trip

Fall. 2 credits. Prerequisites: GEOL 101 or 201 or equivalent, and permission of instructor. Travel and subsistence expenses to be announced. Staff.

A trip of one week to ten days during January intersession in an area of interesting geology in the lower latitudes. Interested students should contact the instructor during the early part of the fall semester.

GEOL 213 Marine and Coastal Geology

Summer. 2 credits. Prerequisites: an introductory course in geology or permission of instructor. Staff.

A special one-week course offered at Cornell's Shoals Marine Laboratory (SML), on an island near Portsmouth, New Hampshire. For more details and an application, consult the SML office, G14 Stimson Hall. Estimated cost for 1995 (including tuition, room, board, and ferry transportation) is $895.

GEOL 214 Western Adirondack Field Course

Spring, one week at the end of the semester. 1 credit. Prerequisite: GEOL 210 or equivalent, or permission of instructor. Students should be prepared for overnight camping and share in the cost of camp meals. Independent project. W. A. Bassett.

Field mapping methods, mineral and rock identification, examination of Precambrian metamorphic rocks and lower Paleozoic sediments, talc and zinc mines.

Junior, Senior, and Graduate Courses

Of the following, the core courses GEOL 326, 355, 356, 375, and 388 may be taken by B.S. candidates who have successfully completed GEOL 201 or the equivalent and by B.A. candidates who have completed GEOL 101 or the equivalent, or who can demonstrate to the instructor that they have adequate preparation in mathematics, physics, chemistry, biology, or engineering.

GEOL 302 Evolution of the Earth System (also SES 332 and SCAS 302)

For description, see the Science of Earth Systems section in "Interdisciplinary Centers, Programs, and Studies," in the front part of the catalog.

GEOL 326 Structural Geology

Spring. 4 credits. Prerequisite: GEOL 101, 103, or 201, or permission of instructor. R. W. Allmendinger.

Nature and origin of deformed rocks at microscopic to macroscopic scales, with emphasis on structural geometry and kinematics. Topics includes stress, strain, rheology, deformation mechanisms, minor structures, faulting, folding, and structural families.

GEOL 355 Mineralogy

Fall. 4 credits. Prerequisite: GEOL 101, 103, or 201 and Chem 207 or permission of instructor. W. A. Bassett.

Examination of minerals by hand-specimen properties and optical microscopy. Geological setting, classification, crystal structures, phase relations, chemical properties, and physical properties of minerals. X-ray diffraction is introduced. Independent research project.

GEOL 356 Petrology and Geochemistry

Spring. 4 credits. Prerequisite: GEOL 355. R. W. Kay.

Principles of phase equilibrium as applied to igneous and metamorphic systems. Description, classification, chemistry, origin, regional distribution, and dating of igneous and metamorphic rocks. Geochemical distribution of trace elements and isotopes in igneous and metamorphic systems. The petrological evolution of the planets.

GEOL 375 Sedimentology and Stratigraphy

Fall. 4 credits. Prerequisite: GEOL 101, 103, or 201. J. L. Cisne, T. E. Jordan.

Formation of sedimentary rocks. Depositional processes and environments. Correlation of strata in relation to time and environment. Petrology of sandstones and limestones. Geological age determination. Reconstruction of paleogeography and interpretation of earth history from stratigraphic evidence. Organization of strata in stratigraphic sequences.

GEOL 388 Geophysics and Geotectonics

Spring. 4 credits. Prerequisites: Mathematics 192 and Physics 208, 213, or equivalent. B. L. Isacks.

Global tectonics and the deep structure of the solid earth as revealed by investigations of earthquakes, earthquake waves, the earth's gravitational and magnetic fields, and heat flow.

GEOL 411 Global Change Research: Mountains, Climate, and Erosion

Fall. 3 credits. B. L. Isacks.

Undergraduate participation in one of the interdisciplinary research projects of the Earth Observing System (EOS). Choice of topics concerning the interplay of climate, topography, and the environment of the Andes and Himalayan mountains as revealed by satellite images and other computerized data analyzed with modern image processing and Geographic Information Systems (GIS).

GEOL 423 Petroleum Geology

Fall. 3 credits. Recommended: GEOL 326. Offered alternate years. W. B. Travers.

Introduction to hydrocarbon exploration and development. Exploration techniques, including well logs, fluid pressures, seismic-reflection methods, gravity, and magnetic measurements to map subsurface structures and stratigraphy. Petroleum origin and migration. Dispersal systems and depositional patterns of petroleum reservoirs. Economics of exploration, leasing, drilling and production. Estimates of petroleum reserves, including tar sands and oil shales.

[GEOL 425 Precambrian Orogenic Cycles

Fall. 3 credits. Prerequisites: GEOL 326, GEOL 356, or permission of instructor. Offered alternate years. Not offered in 1995–96. K. Attoh.

Thermal and kinematic histories of Precambrian orogenic belts. Recent data from metamorphic, structural, and geochronological studies to infer deformation paths in selected orogens, including Dahomeyide and Eburnian orogens of West Africa, and Grenville, Penokean, and Kenoran orogens of the Canadian Shield. Current hypotheses regarding Precambrian orogenic styles and continental crust evolution.]

[GEOL 426 Geologic Evolution of South America

Spring. 3 credits. Prerequisites: GEOL 326 and GEOL 356, or permission of instructor. Not offered 1995–96. S. Mahlburg Kay.

Regional overview of Paleozoic to recent tectonic and magmatic evolution of South America in the framework of crustal and mantle evolution, with particular emphasis on the evolution of the region of the modern Andean Cordillera.]

GEOL 436 Environmental Geophysics
Spring. 3 credits. Offered alternate years. Prerequisites: PHYS 213 and MATH 192 or equivalents, or permission of instructor. L. Brown.
Theory of geophysical techniques for imaging the subsurface. Gravity, magnetic, electrical, and radar methods are covered, but emphasis is on seismic reflection and refraction. The focus is on shallow targets of environmental or archaeological interest. Field experience with these methods is offered in a companion course, GEOL 437.

GEOL 437 Geophysical Field Methods
Fall. 3 credits. Offered alternate years. Prerequisites PHYS 213 and MATH 192 or equivalents, or permission of instructor. L. Brown.
Introduction to field methods of geophysical exploration, especially as applied to environmental issues. Emphasis on seismic, gravity, and magnetic techniques. Field surveys carried out at the beginning of the semester are analyzed in a series of weekly follow-up meetings during the semester wherein the results are analyzed and interpreted. A field companion to GEOL 436, which is recommended but not required prior to this course.

[GEOL 438 Reflection Seismology II: Analysis and Interpretation
Spring. 3 credits. Offered alternate years; not offered 1995–96. L. Brown.
Methods of inferring geologic structures from seismic images. Migration, velocity, and amplitude interpretation. Seismic stratigraphy. 3D, VSP, and shear wave interpretation. Interactive seismic modeling.]

[GEOL 439 Reflection Seismology I: Acquisition and Processing
Fall. 3 credits. Offered alternate years; not offered 1995–96. L. Brown.
Design of seismic surveys, both 2D and 3D. Source characteristics, array design, recording geometries and equipment. Land and marine operations. Basis signal processing theory. Applied 2D interactive seismic processing with ProMAX:FK filtering, deconvolution, velocity analysis, stacking, migration (time and depth), display.]

GEOL 441 Geomorphology
Fall. 3 credits. Prerequisite: GEOL 101, 103, or 201, or permission of instructor. A. L. Bloom.
Systematic analysis of landforms constructed by tectonic and volcanic processes and their subsequent progressive destruction by climate-controlled erosional processes.

GEOL 442 Glacial and Quaternary Geology
Spring. 3 credits. Prerequisite: GEOL 441 or permission of instructor. A. L. Bloom.
Glacial processes and deposits and the chronology of the Quaternary Period.

GEOL 445 Geohydrology (also ABEN 471 and C&EE 431)
Fall. 3 credits. Prerequisites: Mathematics 294 and Engr 202. W. Brutsaert, L. M. Cathles, J.-Y. Parlange, T. S. Steenhuis.
Intermediate-level study of aquifer geology, groundwater flow, and related design factors. Includes description and properties of natural aquifers, groundwater hydraulics, soil water, and solute transport.

GEOL 452 X-ray Diffraction Techniques
Spring. 3 credits. Prerequisites: GEOL 355 or permission of instructor. Offered alternate years. W. A. Bassett and staff.
Automated X-ray diffractometer, Debye-Scherrer, real-time Laue, high-temperature diffraction, high-pressure diffraction, and pole-figure analysis. Applications in materials science and geological sciences. Labs will be held in the new Materials Science X-Ray Facility.

[GEOL 453 Advanced Petrology
Fall. 3 credits. Prerequisite: GEOL 356. Offered alternate years Not offered 1995–96. R. W. Kay.
Magmas and metamorphism in the context of plate tectonics. Major and trace element chemistry and phase petrology as monitors of the creation and modification of igneous rocks. Temperature and stress in the crust and mantle and their influence on reaction rates and textures of metamorphic rocks. Application of experimental studies to natural systems.]

[GEOL 454 Advanced Mineralogy
Spring. 3 credits. Prerequisite: GEOL 355 or permission of instructor. Offered alternate years. Not offered 1995–96. W. A. Bassett.
Crystallography and crystal chemistry of minerals and the methods of their study. X-ray diffraction, optical methods, computer simulation of crystal structures. Emphasis on effects of high pressures and temperatures with implications for understanding of Earth's interior.]

GEOL 455 Geochemistry
Fall. 4 credits. Prerequisites: Chemistry 207 and Mathematics 192 or equivalent. Recommended: GEOL 356. Offered alternate years. W. M. White.
The Earth from a chemical perspective. Formation of the elements; cosmochemistry; chemical evidence regarding the formation of the Earth and Solar System; trace-element geochemistry; isotope geochemistry; geochemical thermodynamics and kinetics; chemical evolution of the crust, mantle, and core; weathering and the chemistry of natural waters; chemistry of rivers and the oceans; hydrothermal systems and ore deposition.

GEOL 457 Metamorphic Petrology
Fall. 3 credits. Prerequisite: GEOL 355. Offered alternate years. K. Attoh.
Theory, field, and experimental basis for the understanding of metamorphic processes and rocks. Relations between crustal dynamics and metamorphic processes.

[GEOL 458 Volcanology
Spring. 3 credits. Corequisite: GEOL 356 or equivalent. Offered alternate years. Not offered 1995–96. W. M. White.
Causes of volcanism, melting in the Earth, and the origin of magmas. Physical volcanology, nature and types of volcanic eruptions and associated deposits, eruption mechanisms. Volcanic plumbing systems, magma chamber processes, evolution of magma. Volcanism and impact phenomena in the Solar System. Volcanic hazard assessment and volcano monitoring. Ore deposits associated with volcanism.]

GEOL 476 Sedimentary Basins: Tectonics and Mechanics
Spring. 3 credits. Prerequisite: GEOL 375 or permission of instructor. Offered alternate years. T. E. Jordan.
Subsidence of sedimentary basins from the point of view of plate tectonics and geomechanics. Interactions of subsidence, sediment supply, and environmental characteristics in development of stratigraphic sequences. Stratigraphic characteristics of active-margin, passive-margin, and cratonic basins. Geophysical and stratigraphic modeling; sequence stratigraphy. Modern and ancient examples.

[GEOL 478 Advanced Stratigraphy
Spring. 3 credits. Prerequisite: GEOL 375 or permission of instructor. Offered alternate years. Not offered 1995–96. T. E. Jordan.
Modern improvements on traditional methods of study of ages and of genetic relations among sedimentary rocks, emphasizing 3-D relationships. Techniques and applications of sequence stratigraphy at scales ranging from beds to entire basins. Physical correlation, dating techniques, and time resolution in sedimentary rocks. Physical controls on the stratigraphic record and numerical modeling.]

GEOL 479 Paleobiology (also BIO ES 479)
Fall. 3 credits. Prerequisites: BIO G 101–102 and 103–104 or equivalent, and either GEOL 375, BIO ES 274, BIO ES 373, or permission of instructor. Offered alternate years. J. L. Cisne and staff.
The major groups of organisms and their evolutionary histories. Intended to fill out the biological backgrounds of geology students and the geological backgrounds of biology students concerning the nature and significance of the fossil record.

GEOL 481 Senior Survey of Earth Systems
Fall. 3 credits. Limited to seniors majoring in geological sciences. J. M. Bird.
Survey course that integrates undergraduate course work, intended to enhance overall understanding of geological sciences. Emphasis on current models of earth's dynamic systems (e.g., global climate change; mantle evolution). Guest lecturers; synthesis and review literature; scientific literature readings; discussions; student presentations.

GEOL 490 Honors Thesis (B.A. degree candidates)
Fall, spring. 2 credits. Staff.
Thesis proposal to be discussed with director of undergraduate studies during the junior year. Participation requires acceptance of a thesis proposal by the faculty committee.

GEOL 491–492 Undergraduate Research
Fall, spring. 1 or 2 credits. Staff. (B. L. Isacks and A. L. Bloom, coordinators).
Introduction to the techniques and philosophy of research in the earth sciences and an opportunity for undergraduates to participate in current staff research projects. Topics chosen in consultation with, and guided by, a staff member. A short written report is required, and outstanding projects are prepared for publication.

GEOL 500 Design Project in Geohydrology
Fall, spring 3–12 credits. An alternative to an industrial project for M.Eng. students choosing the geohydrology option. May continue over two or more semesters. L. M. Cathles.
The project may address one of many aspects of groundwater flow and contamination, and

must involve a significant geological component and lead to concrete recommendations or conclusions of an engineering nature. Results are presented orally and in a professional report.

GEOL 502 Case Histories in Groundwater Analysis
Spring. 4 credits. L. M. Cathles.
Groundwater flow in a specific area, such as a proposed nuclear-waste disposal site, analyzed in depth. Geological and resource data on the area are presented early in the course. Then the material is analyzed by students working as an engineering analysis team. Each student makes a weekly progress report and writes part of a final report. Results are presented in a half-day seminar at end of term.

GEOL 622 Advanced Structural Geology I
Spring. 3 credits. Prerequisites: GEOL 326 and permission of instructor. Offered alternate years. R. W. Allmendinger and D. E. Karig.
Stress-strain theory and application. Advanced techniques of structural analysis. Topics include finite and incremental strain measurement; microstructure, preferred orientation, and TEM analysis; pressure solution and cleavage development; and experimental deformation. Applications to deformation of unconsolidated sediments, brittle and brittle-ductile deformation of supracrustal strata, and ductile deformation of high-grade metamorphic rocks. Kinematic analysis of shear zones and folds in these regimes.

[GEOL 624 Advanced Structural Geology II
Spring. 3 credits. Prerequisites: GEOL 326 and permission of instructor. Offered alternate years. Not offered 1995–96. R. W. Allmendinger, D. E. Karig.
Geometry, kinematics, and mechanics of structural provinces. Concentration on thrust belts, rift provinces, or strike-slip provinces. Techniques of balanced cross sections.]

GEOL 628 Geology of Orogenic Belts
Spring. 3 credits. Prerequisite: permission of instructor. J. M. Bird.
A seminar course in which students study specific geologic topics of an orogenic belt selected for study during the term. The course is intended to complement GEOL 681.

[GEOL 635 Advanced Geophysics I: Fractals and Chaos in Geology and Geophysics
Fall. 3 credits. Prerequisite: GEOL 388 or permission of instructor. Not offered 1995–96. D. L. Turcotte.
Definitions of fractal sets and statistical fractals, scale invariance, self-affine fractals, multifractals, applications to fragmentation, seismicity and tectonics, petroleum distribution and reserves, ore grade and tonnage, drainage networks and landforms, and floods and droughts. Definitions of chaos and self-organized criticality, renormalization groups, diffusion limited aggregation and percolation clusters, wavelet transforms, applications to mantle convection, the earth's dynamo, and distributed seismicity.]

GEOL 636 Advanced Geophysics II: Quantitative Geodynamics
Spring. 3 credits. Prerequisite: GEOL 388 or permission of instructor. D. L. Turcotte.
Stress and strain in the earth, elasticity and flexure, heat transfer, gravity, fluid mechanics, rock rheology, faulting, chemical geodynamics, flow in porous media.

GEOL 651 Analysis of Biogeochemical Systems
Fall. 3 credits. Prerequisite: MATH 293 or permission of instructor. L. A. Derry.
Dynamics of biogeochemical systems. Kinetic treatment of biogeochemical cycles. Box models, residence time, response time. Analytical and numerical solutions of model systems. Eigen-analysis of linear systems. Feedback and nonlinear cases, problems of uncertainties in natural systems. Modeling software such as Stella II and Matlab; applications to current research of participants or from recent literaure.

GEOL 656 Isotope Geochemistry
Spring. 3 credits. Open to undergraduates. Prerequisite: GEOL 455 or permission of instructor. Offered alternate years. W. M. White.
Nucleosynthetic processes and the isotopic abundances of the elements. Geochronology and cosmochronology using radioactive decay schemes, including U-Pb, Rb-Sr, Sm-Nd, K-Ar, U-series isotopes, and cosmogenic isotopes such as ^{14}C and ^{36}Cl. Use of radiogenic and stable isotopes in petrology and their application to study of the evolution of the crust and mantle. Isotopic evidence regarding the formation of the Earth and the Solar System. Stable isotopes and their use in geothermometry, ore petrogenesis, paleontology, and the global climate system.

GEOL 681 Geotectonics
Fall. 3 credits. Prerequisite: permission of instructor. J. M. Bird.
Theories of orogeny; ocean and continent evolution. Kinematics of lithosphere plates. Rock-time assemblages of modern oceans and continental margins, and analogs in ancient orogenic belts. Time-space reconstructions of specific regions. Problems of dynamic mechanisms—corollaries and evidence from crustal features.

GEOL 695 Computer Methods in Geological Sciences
Fall, spring. 3 credits. L. Brown, B. L. Isacks.
Independent research projects using state-of-the-art computational resources in the Department of Geological Sciences. Possibilities include: image and seismic processing, seismic and geomechanical modeling, GIS, use of interpretational workstations for 3D seismics and satellite imagery; modeling fluid flow through complex media.

GEOL 700–799 Seminars and Special Work
Fall, spring. 1–3 credits. Prerequisite: permission of instructor. Staff.
Advanced work on original investigations in geological sciences. Topics change from term to term. Contact appropriate professor for more information.

GEOL 722 Advanced Topics in Structural Geology
R. W. Allmendinger.

GEOL 725 Rock and Sediment Deformation
D. E. Karig.

GEOL 731 Plate Tectonics and Geology
J. M. Bird.

GEOL 733 Fractal Chaos—Independent Studies
D. L. Turcotte.

GEOL 741 Advanced Geomorphology Topics
A. L. Bloom.

GEOL 751 Petrology and Geochemistry
S. Mahlburg Kay, R. Kay.

GEOL 753 Advanced Topics in Mineral Physics
W. A. Bassett.

GEOL 755 Advanced Topics in Petrology and Tectonics
J. Bird, W. A. Bassett.

GEOL 757 Current Research in Petrology
S. Mahlburg Kay, R. Kay.

GEOL 762 Advanced Topics in Petroleum Exploration
W. Travers.

GEOL 771 Advanced Topics in Sedimentology and Stratigraphy
T. E. Jordan.

GEOL 773 Paleobiology
J. L. Cisne.

GEOL 780 Seismic Record Reading
M. Barazangi.

GEOL 781 Geophysics, Exploration Seismology
L. D. Brown.

GEOL 783 Advanced Topics in Geophysics
B. L. Isacks.

GEOL 789 Lithospheric Seismology (COCORP Seminar)
L. Brown.

GEOL 793 Andes-Himalaya Seminar
R. W. Allmendinger, A. L. Bloom, B. L. Isacks, T. E. Jordan, S. Mahlburg Kay.

GEOL 796 Geochemistry of the Solid Earth
W. M. White.

GEOL 797 Fluid-Rock Interactions
L. M. Cathles.

GEOL 799 Soil, Water, and Geology Seminar
L. M. Cathles, T. S. Steenhuis.

MATERIALS SCIENCE AND ENGINEERING

Undergraduate Courses

MS&E 111 Materials by Design (also ENGRI 111)
Fall. 3 credits. E. P. Giannelis.
For description, see Engineering Common Courses.

MS&E 118 Design Integration: A Portable CD Player (also ENGRI 118)
Spring. 3 credits. M. O. Thompson, W. Sachse.
For description, see Engineering Common Courses.

MS&E 261 Introduction to Mechanical Properties of Materials (also ENGRD 261)

Fall. 3 credits. S. L. Sass.

For description, see Engineering Common Courses.

MS&E 262 Introduction to Electrical Properties of Materials (also ENGRD 262)

Fall. 3 credits. Prerequisite: co-registration in Physics 213 or electricity and magnetism in high school physics. M. O. Thompson.

For description, see Engineering Common Courses.

MS&E 277 The Substance of Civilization—Materials through the Ages

Spring. 3 credits. 2 lecs, 1 lab. S. L. Sass.

Materials have enabled revolutionary advances in how we live, work, fight, travel, and play; hence the naming of eras after them—Stone, Bronze, and Iron Ages. This course explores the role of materials in the development of the modern Western industrial civilization by putting technology into a historical context and examining the advances made possible by innovations with materials, starting with the Stone Age. Interconnections between critical developments are identified and explored—for example, the relationship between materials, agriculture, and written languages in the fourth millennium B.C., and between the Exodus of the Hebrews, the general tumult in the Eastern Mediterranean, and the onset of the Iron Age, at the end of the second millennium B.C. Early technologies will be illustrated with beautiful works of art. Lectures, demonstrations, and hands-on laboratory experiments, will elucidate the origin of the unique properties of materials such as polymers, ceramics, metals and glass. This course is designed to fulfill the science requirement in the College of Arts and Sciences.

MS&E 285 Art, Archaeology, and Analysis (also ENGRI 185 and NS&E 285)

Spring. 3 credits.

For description, see Engineering Common Courses.

MS&E 331/531 Structure of Materials

Fall. 4 credits. J. M. Blakely.

Bonding in materials, crystal structures, and symmetry, defects. Crystal planes and directions, stereographic projections. Techniques for materials analysis: X-ray and electron diffraction, optical and electron microscopy. Experimental systems for structural characterization of materials.

MS&E 332/532 Electrical and Magnetic Properties of Materials

Spring. 3 credits. Prerequisite: MS&E 331 or permission of instructor. J. M. Blakely.

Introduction to electronic band structure of crystals. Electrical and magnetic properties of metals and semiconductors as affected by microstructure. Design of semiconductor properties by doping. Carrier statistics. Properties of junctions in semiconductor devices. Principles and design of ferromagnetic materials for transformers, permanent magnets, and magnetic memory devices. Ionic conductivity. Fundamentals of superconducting materials for high-field magnets and Josephson junctions. Introduction to dielectric and optical properties.

MS&E 333 Research Involvement I

Fall. 3 credits. Prerequisite: approval of course coordinator. Staff.

Supervised independent research project in association with faculty member and faculty research group of the department. Students design experiments, set up the necessary equipment, and evaluate the results. Creativity and synthesis are emphasized.

MS&E 334 Research Involvement II

Spring. 3 credits. Prerequisite: approval of department. Staff.

See MS&E 333 for description. May be a continuation of MS&E 333 or a one-term affiliation with a research group.

MS&E 335/535 Thermodynamics of Condensed Systems

Fall. 4 credits. Prerequisite: Math 293 and 294. E. J. Kramer.

The three laws of thermodynamics are introduced as a basis for understanding phase equilibria, heterogeneous reactions, solutions, electrochemical processes, surfaces, and defects. Statistical mechanics is introduced and applied to the calculation of entropy and specific heat of ideal gases and solids. Examples of design and control of processes.

MS&E 336/536 Kinetics, Diffusion, and Phase Transformations

Spring. 3 credits. Prerequisite: MS&E 335 or permission of instructor. Staff.

Introduction to absolute rate theory, atomic motion, and diffusion. Applications and design involving nucleation and growth of new phases in vapors, liquids, and solids; solidification, crystal growth, oxidation and corrosion, radiation damage, recrystallization, gas-metal reactions, and thermomechanical processing to produce desired microstructures and properties. One-third of course involves examples of design and control of processes.

MS&E 414/514 Chemical Processing of Ceramics

Spring. 3 credits. E. P. Giannelis.

Design and characterization of materials at the molecular level. Synthesis, drying, and sintering of ceramics, glasses, and composites. Sol-gel, hydrothermal, chemical-vapor deposition, and pyrolysis techniques. Surface chemistry of oxides. Analytical techniques include chromatography, mass spectrometry, infrared, uv-visible and nuclear-magnetic resonance spectroscopy. Design, synthesis, and chemical properties of inorganic/organometallic precursors. Ceramic thin films, fibers whiskers, and membranes.

MS&E 435 Senior Thesis I & II

Fall and spring. 2-semester course. 8 credits. D. T. Grubb.

Open to advanced undergraduates in lieu of the senior materials laboratory. Proposals for thesis topics should be approved by the supervising faculty member prior to beginning the senior year. Approved thesis topics will normally involve original experimental research in direct collaboration with an ongoing research program. Periodic oral and written presentations and a final written thesis are required.

MS&E 441/541 Microprocessing of Materials

Fall. 3 credits. D. G. Ast.

Materials and processing steps involved in the production of integrated circuits and other micro-devices. Science, engineering, and design of processes to produce a specific device, such as a DRAM or CMOS inverter (not detailed electrical-circuit analysis of these devices or system design). Emphasis is on silicon, with extensions to gallium arsenide. All fabrication steps are considered, from single crystal growth and wafer production, to characterization, testing and yield calculations. Major topics are thermal oxidation of silicon, chemical vapor deposition of thin films, diffusion, ion implantation, resists and the principles of lithography using UV, electrons and X-rays, and wet/dry etching.

MS&E 442/542 Macroprocessing

Spring. 3 credits.

Deformation and macro-processing of materials; sheet metals forming, superplastic forming, casting, single crystal growth, powder sintering metal/ceramic joining, surface treatments. Course based on case studies demonstrating various macro-processing techniques. Course includes comprehensive experimental project involving design, measurement, and analysis of superplastic forming process starting from basic mechanisms. Results compared with the predictions of numerical analysis.

MS&E 443–444 Senior Materials Laboratory

443, fall; 444, spring. 3 credits each term. D. T. Grubb.

Practical laboratory covering the analysis and characterization of materials and processing. Emphasis on design of experiments for evaluation of materials' properties and performance as related to processing history and microstructure. Projects available in areas such as plasticity, mechanical and chemical processing, phase transformations, electrical properties, magnetic properties, and electron microscopy.

MS&E 445 Mechanical Properties of Materials

Fall. 3 credits. Prerequisites: MS&E 331 and 336, or permission of instructor. R. Raj.

Stress, strain, and the basics of concepts in deformation and fracture for metals, polymers, and ceramics. Analysis of important mechanical properties such as plastic flow, creep, fatigue, fracture toughness, and rupture. Application of these principles to the design of improved materials and engineering structures.

MS&E 447/448 Materials Design Concepts I & II

447, fall; 448, spring. 2 credits each term. C. K. Ober.

Defines design in the field of materials science using Dieter's *Engineering Design,* Ashby's *Materials Selection in Engineering Design,* and other sources. Innovation, patent searching, and ASTMS standards. Speakers from industry and other institutions lecture on case studies of design problems. Students give short oral and written presentations. Proposal for design-study project in the fall semester. Completion of extensive design-study project in the spring semester. Study includes prior art literature, materials selection, and some modeling, as well as discussion of broader economic, regulatory, environmental, and liability concerns that may arise.

MS&E 449 Introduction to Ceramics

Fall. 3 credits. Prerequisite: MS&E 331 or permission of instructor. R. Dieckmann.

Ceramic processes and products, crystal structures, structure of glasses, point defects (point-defect chemistry and relation to nonstoichiometry), line defects, grain boundaries, diffusion in ionic materials (emphasis on the relationships between diffusion and point-defect structure), phase diagrams, phase transformations, kinetics of solid-state reactions (reactions with and between solids: heterogeneous reactions, reactions between different solids, point-defect relaxation, internal reactions), grain growth and sintering. Physico-chemical aspects are emphasized.

MS&E 452 Properties of Solid Polymers
Spring. 3 credits. Prerequisite: Engr 261 or permission of instructor. E. J. Kramer.
Synthetic and natural polymers for engineering applications. Production and characterization of long-chain molecules. Gelation and networks, rubber elasticity, elastomers and thermosetting resins. Amorphous and crystalline thermoplastics and their structure. Time- and temperature-dependent elastic properties of polymers. Molecular-weight measurement. Design of high-impact-strength polymers.

MS&E 454 Processing of Glass, Ceramic, and Glass-Ceramic Materials
Spring. 3 credits. Offered alternate years. Recommended: MS&E 449.
Conventional and unconventional techniques for processing glass, glass-ceramic, and ceramic materials. Case studies illustrate the design, engineering, and scientific aspects of such processes. Vapor processes for high-purity optical fibers, hot-processing of ceramic turbine blades, photosensitive materials, and powder processing and sintering of ceramics will be discussed. This course is team taught with scientists from the research and development laboratory of Corning Glass Works.

MS&E 459 Physics of Modern Materials Analysis
Spring. 3 credits. M. O. Thompson.
The interaction of ions, electrons, and photons with solids, and the characteristics of the emergent radiation in relation to the structure and composition of materials. Aspects of atomic physics that are relevant to understanding techniques of modern materials analysis. Principles of analysis techniques such as Auger electron spectroscopy, ion scattering, and secondary ion-mass spectroscopy. Design of experiments for near-surface analysis.

MS&E 463 Principles of Electronic Packaging
Spring. 3 credits. C. Y. Li.
Design, materials, and manufacturing needs for packaging technology, from chip to board. Principles involved in key areas of materials science, and other engineering disciplines. Packaging materials to be discussed include metals, ceramics, and polymers.

Graduate-Level Professional Courses

[MS&E 516 Thin-Film Materials Science
Fall. 3 credits. Offered alternate years. Not offered 1995–96. D. G. Ast.
This course is a fundamental approach to thin-film science that will cover deposition of films, growth of epitaxial layers, formation of multilayered structures such as superlattices and quantum wells, and interdiffusion and reaction in thin films. The course will begin with the structure and thermodynamics of surfaces and ultrathin films. The conditions for epitaxial growth, such as used in semiconductor heterostructures, will be contrasted with those for amorphous or polycrystalline films. The role of thermal processing for reactive thin films involving the formation of surface oxides, metallic silicides, and aluminides will be presented.]

[MS&E 518 Introduction to Electron Microscopy
Fall. 3 credits. Prerequisite: MS&E 331 or permission of instructor. Offered alternate years. Not offered 1995–96. D. T. Grubb.
Basic optics and operation of scanning and transmission electron microscopes. Image formation, modes of contrast, and resolution in SEM and TEM. Electron diffraction. Images of perfect crystal and defects in two-beam diffraction contrast. Analytical microscopy; comparison of EDS, WDS, and EELS. Overview of specimen preparation and in-situ microscopy.]

[MS&E 520 Practical Electron Microscopy
Fall. 3 credits. Corequisite: MS&E 518. Limited to 12 students. A fee will be charged for instrument usage. Offered alternate years. Not offered 1995–96. D. T. Grubb.
Students will be instructed in the proper use of a scanning and a transmission electron microscope. All stages from initial alignment of the instrument to presentation of the results will be covered. Three or four projects will be completed, including obtaining atomic lattice fringe images and X-ray microanalysis.]

MS&E 553–554 Special Project
553, fall; 554, spring. 6 credits each term.
Master of Engineering research project.

MS&E 555 Introduction to Composite Materials
L. Phoenix.
See TAM 555 for description.

Graduate Core Courses

MS&E 601 Thermodynamics of Materials
Fall. 3 credits. Prerequisite: previous course in thermodynamics at level of MS&E 335. Staff.
Basic statistical thermodynamics. Partition function and thermodynamic state functions. Distributions. Laws of thermodynamics. Free-energy functions and conditions of equilibrium. Chemical reactions. Statistics of electrons in crystals. Heat capacity. Heterogeneous systems and phase transitions. Lattice models of 1–, 2–, 3–dimensional interacting systems. Statistical thermodynamics of alloys. Free-energy and phase diagrams. Order-disorder phenomena. Point defects in crystals. Statistical thermodynamics of interfaces.

MS&E 602 Elasticity, Plastic Flow, and Fractures
Fall. 3 credits. Staff.
Micromechanical modeling of mechanical behavior. A materials-science approach to modeling combines concepts from continuum mechanics, thermodynamics, kinetics and atomic structure. Topics include: elastic properties of crystals, deformation mechanisms from ambient temperature to very high temperatures over a wide range of strain rates, fracture in brittle materials, fracture in ductile materials, fracture at elevated temperatures, crack tip phenomena, and composite materials.

MS&E 603 Analytical Techniques for Materials Science
Spring. 4 credits. Lab. M. O. Thompson.
Survey of atomic and structural analysis techniques as applied to surface and bulk materials. Physical processes involved in the interaction of ions, electrons, and photons with solids; characteristics of the emergent radiation in relation to the structure and composition. Techniques covered include Auger electron spectroscopy, ion scattering, nuclear activation, secondary ion mass spectroscopy, UV and X-ray photoelectron spectroscopies, X-ray diffraction and related techniques, etc. Selection and design of experiments for near-surface analysis.

MS&E 604 Diffusion and Phase Transformation: Kinetics in Condensed Matter
Spring. 3 credits. Staff.
Phenomenology and microscopic aspects of diffusion in fluids, both simple and polymeric, and in solids, metallic and ionic. Phase stability and transformation; nucleation and growth, spinodal decomposition and displacive transformations. Phase coarsening processes, recrystallization and grain growth. Diffusion-controlled growth, interfacial reactions, moving-boundary problems. Grain-boundary migration controlled kinetics. At the level of *Diffusion in the Condensed State,* by Kirkaldy and Young.

MS&E 605 Structure and Chemistry of Condensed Matter
Spring. 3 credits. Staff.
This course focuses on the link between the local chemistry of the elements comprising a solid, the structure of the solid, and the bonding in the solid. Elementary aspects of group theory and representation theory; introductory quantum mechanics including Schrödinger equation for approaches to bonding in extended systems; hydrogen atom and diatomic molecules; band structures and densities of states of simple crystals. Crystal structures. Structure of and bonding in surfaces, amorphous materials, glasses, liquids, interfaces as well as case studies.

Related Course in Another Department

Introductory Solid-State Physics (Physics 454)

Further Graduate Courses

MS&E 610 Principles of Diffraction (also A&EP 711)
Spring. 4 credits. Offered alternate years. B. Batterman.
For description, see A&EP 711.

[MS&E 611 Modern Polymer Physics
Spring. 3 credits. Prerequisites: MS&E 452, ChemE 711, or equivalent. Offered alternate years. Not offered 1995–96. E. J. Kramer.
Modern engineering plastics and polymeric matrices for fiber-reinforced composite materials often demand more detailed knowledge of polymer structure and properties in the melt or solid state than is afforded by beginning courses that emphasize polymer solutions. This course is a fundamental approach to the structure and physical properties of polymers, copolymers, and polymer mixtures, including thermodynamics, phase equilibria, diffusion, kinetics of phase separation, surfaces, and interfaces. At the level of *Scaling Concepts in Polymer Physics* by de Gennes.]

MS&E 612 Solid-State Reactions
Spring. 3 credits. Offered alternate year. R. Dieckmann.
Point defects (thermal disorder, component-activity-dependent disorder, influence of dopants, different kinds of associates, Coulomb interaction between point defects), dislocations, grain boundaries transport in solids (definition and different types of diffusion coefficients, reference frames, mechanisms of electrical conduction, elementary diffusion mechanisms, atomic theory of transport, correlation effects, phenomenological theory of transport including some aspects of thermodynamics of irreversible processes, Fick's laws), point-defect relaxation (migration controlled, phase-boundary-reaction controlled), interdiffusion, solid-state reactions involving compound formation (oxidation of metals, reactions between solids), demixing of materials in potential gradients, selected solid-state processes (internal reactions, etc.).

[MS&E 614 Advanced Transmission Electron Microscopy
Fall, spring. 3 credits. Prerequisite: MS&E 518 or permission of instructor. Offered on demand. Not offered 1995–96. Staff.
Kinematic and dynamic diffraction, dispersion surfaces, and Bloch waves. Anomalous absorption, Kikuchi band theory, and energy-selected images. Contrast-transfer-function theory of phase contrast. Lattice imaging and image modeling. Calculation of multibeam defect images in theory and practice. Weak-beam images. Image processing. High-resolution SEM and STEM images. Convergent beam techniques. Plus selected current topics.]

[MS&E 615 Advanced Mechanical Properties
Fall or spring. 3 credits. Offered on demand. Not offered 1995–96. Staff.
Advanced experimental and theoretical aspects of the deformation and failure of structural materials. Although the emphasis is on metals and alloys, attention is also given to glasses, ceramics, semiconductors, and polymeric materials. Topics include theory and practice of mechanical testing, deformation behavior of polycrystal, single-crystal metals and covalently bonded semiconductors, phenomenological theories of deformation, the mechanical equation of states for metals, application to the thermal fatigue problem, micromechanical theories of plastic flow in metals, creep in metals, and the time-dependent deformation of polymers, relationship of microstructure to mechanical properties of metals and polymers, ductile fracture of metals, brittle fracture of metals and ceramics.]

[MS&E 616 Electronic and Magnetic Materials
Fall or spring. 3 credits. Offered on demand. Not offered 1995–96. Staff.
Electronic transport properties of metals and semiconductors. Semiconductor devices. Optical and dielectric properties of insulators and semiconductors. Laser materials. Structural aspects of superconducting materials, ferromagnetism, and magnetic materials. Magnetic memory devices. At the level of *Physics of Semiconductor Devices*, by Sze; *Ferromagnetism*, by Bozworth; and current review articles.]

[MS&E 617 Solid State Electrochemistry
Spring. 3 credits. Prerequisite: MS&E 612 or permission of instructor. Offered alternate years. Not offered 1995–96. R. Dieckmann.
Disorder in solids; thermodynamic quantities or quasi-free electrons and electron defects in semiconductors; mobility, diffusion and partial conductivity of ions and electrons; solid ionic conductors, solid electrolytes and solid solution electrodes; galvanic cells with solid electrolytes for thermodynamic investigations; technical applications of solid electrolytes. At the level of *Electrochemistry of Solids* by H. Rickert.]

[MS&E 618 Laser Processing of Materials
Fall or spring. 3 credits. Offered on demand. Not offered 1995–96. M. O. Thompson.
Use of high-intensity lasers in the processing of materials to achieve unique microstructures and metastable phases. Topics: fundamentals of the interaction of E&M fields with metals, semiconductors and ceramics, transfer of energy between electronic and phonon systems, kinetics of rapid solidification, metastable phase transformations, microstructure of rapidly solidified materials, and current industrial applications.]

MS&E 619 Superhard Materials
Fall. 3 credits. Prerequisite: permission of instructor. A. L. Ruoff.
The superhard materials include diamond, cubic boron nitride (possibly the new C_4N_3) and borderline, B_4C. The origin of their extreme hardness is examined. The thermodynamics of their stability and the kinetics of their crystal growth will be described. Commercial methods of synthesis of large crystals, powders, thin films and polycrystalline aggregates (by sintering at pressure) will be examined. Their chemical, optical and mechanical properties will be studied. Moreover, there is substantial potential for radiation-hard semi-conducting devices and the status of this area will be covered. At the level of Field, *The Properties of Natural and Synthetic Daimonds*, plus recent papers.

MS&E 524/624 Synthesis of Polymeric Materials
Spring. 3 credits. Alternate years. Prerequisite: MS&E 452 or permission of instructor. C. K. Ober.
Preparation of synthetic polymers by step- and chain-growth polymerization: condensation; free radical, anionic, and cationic mechanisms; ring opening and coordination routes. Statistical and kinetic aspects of homopolymer and copolymer formation. Stereochemistry of polymers and spectroscopic methods for polymer analysis. Molecular aspects of polymer design for properties such as conductivity, elasticity, thermal stability, and engineering properties. Special topics will include liquid crystalline polymers, photoresists, and supermolecular chemistry. At the level of *Principles of Polymerization*, by Odian.

Specialty Courses

[MS&E 707 Solar Energy Materials
3 credits. Offered on demand. Not offered 1995–96. D. G. Ast.
Photovoltaic energy conversion: (1) theory (on the level of Hovel); (2) the role of crystal defects and grain boundaries on the conversion efficiency, and schemes to passivate these defects; (3) current investigations in the DOE program to produce large quantities of solar-grade semiconducting Si; (4) theory and materials for amorphous silicon solar cells.]

MS&E 716 Transition Metal Oxides (also Chem 716)
Fall. 3 credits. Offered on demand.
For description see Chem 716.

MS&E 779 Special Studies in Materials Sciences
Fall, spring. Variable credit. Offered on demand. Staff.
Supervised studies of special topics in materials science.

MS&E 798 Materials Science and Engineering Colloquium
Fall, spring. 1 credit each term. Credit limited to graduate students. Staff.
Lectures by visiting scientists, Cornell staff members, and graduate students on subjects of interest in materials sciences, especially in connection with new research.

MS&E 799 Materials Science Research Seminars
Fall, spring. 2 credits each term. For graduate students involved in research projects. Staff.
Short presentations on research in progress by students and staff.

MS&E 800/801 Research in Materials Science
800, fall; 801, spring. Credit to be arranged. Staff.
Independent research in materials science under the guidance of a member of the staff.

MECHANICAL AND AEROSPACE ENGINEERING

General and Required Courses

M&AE 101 Naval Ship Systems
For description, see NAV S 202.

M&AE 102 Drawing and Engineering Design (also ENGRG 102)
Fall, spring. 1 credit. Half-term course offered twice each semester. Enrollment limited to thirty students each half term. Recommended for students without previous mechanical drawing experience. S-U grades optional.
For description, see Engineering Common Courses.

M&AE 117 Introduction to Mechanical Engineering (also ENGRI 117)
Spring. 3 credits.
For description, see Engineering Common Courses.

M&AE 212 Mechanical Properties and Processing of Engineering Materials
Spring. 4 credits. Prerequisite: ENGRD 202.
Introduction to the broad range of mechanical behavior of materials and their processing. The mechanical properties of metals, ceramics, and composite materials are covered together with their microstructural features and processing. Ideal work methods are introduced for the analysis of bulk deformation processes. Heat treatment of metals and alloys, phase diagrams, casting and quenching processes.

M&AE 221 Thermodynamics (also ENGRD 221)
Fall, spring, may be offered summer. 3 credits. Prerequisites: Mathematics 192 and Physics 112.
For description, see Engineering Common Courses.

M&AE 225 Mechanical Design and Synthesis
Spring. 3 credits. Prerequisite: ENGRD 202. Lab fee.
A hands-on laboratory, the use of machine tools, mechanical dissection, and a number of design projects provide direct experience of creative design synthesis.

M&AE 323 Introductory Fluid Mechanics
Fall; usually offered in Engineering Cooperative Program. 4 credits. Prerequisites: Engr 202 and 203 and coregistration in 221, or permission of instructor.
Statics, kinematics, potential flow, dynamics, momentum, and energy relations. Thermodynamics of compressible flow; dimensional analysis; real fluid phenomena, laminar and turbulent motion, boundary layer; lift and drag; supersonic flow and shock waves.

M&AE 324 Heat Transfer
Spring; may be offered in Engineering Cooperative Program. 3 credits. Prerequisite: M&AE 323 or permission of instructor.
Conduction of heat in steady and unsteady situations. Surfaces with fins and systems with heat sources. Forced and natural convection of heat arising from flow around bodies and through ducts. Heat exchangers. Emission and absorption of radiation; radiative transfer between surfaces. Introduction to boiling and phase change.

M&AE 325 Mechanical Design and Analysis
Fall; usually offered in Engineering Cooperative Program. 4 credits. Prerequisites: Engr 202 and 203. Lab fee.
Application of the principles of mechanics and materials to problems of analysis and design of mechanical components and systems.

M&AE 326 System Dynamics
Spring; may be offered in Engineering Cooperative Program. 4 credits. Prerequisite: Mathematics 294, Engr 203. Junior standing required.
Dynamic behavior of mechanical systems: modeling, analysis techniques, and applications; vibrations of single- and multi-degree-of-freedom systems; feedback control systems, stability analysis. Computer simulation and experimental studies of vibration and control systems.

M&AE 427 Fluids/Heat Transfer Laboratory
Fall. 3 credits. Prerequisites: M&AE 323, 324. Fulfills the writing requirement.
Laboratory exercises in methods, techniques, and instrumentation used in fluid mechanics and heat transfer. Measurements of temperature, heat transfer, viscosity, drag, fluid-flow rate, effects of turbulence, air foil stall, two-phase flows and engine performance. Biweekly written assignments.

M&AE 428 Engineering Design
Fall. 2 credits. Prerequisite: completion of six semesters in mechanical engineering or equivalent.
A comprehensive look at principles of design with a focus on case studies. Examples taken from fluid, thermal, and energy areas, as well as mechanical systems and the manufacturing area of mechanical engineering. Special emphasis on the design sources of engineering failures in products, machines, and mechanical systems, as well as how design should relate to a successful manufactured product.

Mechanical Systems, Design, Materials Processing, and Precision Engineering

M&AE 386 Automotive Engineering
Spring. 3 credits. Prerequisite: M&AE 325 or permission of instructor.
Selected topics in the analysis and design of vehicle components and vehicle systems. Emphasis on automobiles, trucks, and related vehicles. Power plant, drive line, brakes, aerodynamics, suspension, and structure. Other types of vehicles may be considered.

M&AE 389 Computer-Aided Design
Fall. 3 credits. Limited to juniors and seniors. May be offered in Engineering Cooperative Program. Prerequisite: A course in programming. May be taken either before or in conjunction with a numerical-methods course. Fulfills computer applications requirement.
A first course in CAD, introducing the use of software and computer methods in mechanical engineering. Topics include simulation, optimization, solution of field equations (finite elements, finite differences), least-square function approximation, geometry (space curves, splines, patches), computer graphics, and data visualization.

M&AE 412 Metal Forming, Machining and Solidification Processes
Fall. 4 credits. Prerequisite: M&AE 212 or M&AE 261.
Analysis and design of extrusion, drawing, forging and rolling processes using slab analysis techniques. Sheet forming and anisotropy. Machining processes. The mechanics of chip formation. Cutting forces and stresses, shear angle theories, velocity diagrams, heat generation and optimum selection of cutting process parameters. Basic solidification processes. Solution of heat conduction/solute diffusion driven solidification problems for metals and alloys.

M&AE 414 Introduction to Precision Engineering
Fall. 3 credits or 4 with laboratory. Prerequisites: ENGRG 102 and M&AE 212, or 412, or permission of instructor.
Variability in mechanical products arises primarily from the processes used to make and assemble parts; it must be accommodated in design and controlled in manufacturing. This course addresses *form* variability through studies of ideal-form modeling, form tolerancing, form measurement, and manufacturing process modeling (sources of form error). Central principles, practices, and limitations are summarized.

[M&AE 417 Introduction to Robotics
Spring. 3 credits. Enrollment limited. Not offered 1995–96.
Coordinate transformations for manipulator kinematics. Newton-Euler and Lagrangian developments of manipulator dynamics. Robot control schemes. Trajectory generation. Motion planning. Robot programming.]

[M&AE 425 Design: Beyond the Imaginary
Fall. 4 credits. Prerequisite: M&AE 325 or permission of instructor. Lab fee $50. Fulfills senior design requirement. Not offered 1995–96.
Serves as a mechanical engineering field elective. Requires a comprehensive technical report on the design project and fulfills the field design requirement. Students will form teams to design, analyze, and create a prototype of a new mechanism. The experience of creative synthesis is of primary importance; analytic skills will play a critical role in both concept evaluation and final design specification. This course aims to develop an appreciation for the balanced interplay between the synthetic analytic, and "just build it and see" processes. Student teams will present their work and analysis of techniques of special relevance to their design; e.g., dynamic simulation and kinematic analysis of CAD packags. Eclectic design topics include human-powered vehicles, robot submarines, technology appropriate for non-industrialized nations and projects for local industry.]

M&AE 461 Engineering for Entrepreneurs
Spring. 3 credits.
Intent is to provide students with the tools and skills necessary to identify, evaluate, and undertake new business ventures. A major course project will be the development of a business plan for an innovative new venture and will require the detailing of manufacturing, support, and information systems as well as staffing and cost data. Intended for juniors and seniors in the College of Engineering, this course is open to all undergraduates.

M&AE 464 Design for Manufacture
Fall. 3 credits. Prerequisites: M&AE 212 and 428 and senior standing. Enrollment limited. Fulfills field design requirement.
Principles and methodologies for conceptual design; elimination procedures for selecting design alternatives; emphasis on design for manufacturability, quality, and cost considerations; team design projects from concept, analysis, and computer-aided drafting to manufacturing methods.

M&AE 465 Biomechanical Systems—Analysis and Design
Spring. 3 credits. Prerequisites: Engr 202 and 203. Enrollment limited.
Selected topics from the study of the human body as a mechanical system. Emphasis on the modeling, analysis, and design of biomechanical systems frequently encountered in orthopaedic engineering and rehabilitation engineering.

M&AE 469 Stress Analysis for Mechanical and Aerospace Design
Fall. 3 credits. Prerequisite: T&AM 202 and M&AE 325 or permission of instructor.
Study of advanced topics in the analysis of stress and deformation of elastic bodies, with applications to the analysis and design of mechanical and aerospace systems and components. Review of fundamentals and application to classical problems. Introduction to modern computational methods (e.g., finite element) for analysis of stress and deformation.

M&AE 478 Feedback Control Systems
For description, see ELE E 471.

M&AE 486 Automotive Engineering Design
Spring. 4 credits. Prerequisite: M&AE 428 and senior standing. Fulfills field design requirement.
For description, see M&AE 386.

M&AE 489 Computer-Aided Design Project
Fall. 4 credits. Limited to seniors in mechanical engineering. Fulfills both field design and computer applications requirements.
Requires extensive project in addition to course assignments. For description, see M&AE 389.

M&AE 511 Survey of Manufacturing Processes
Spring; may be offered in summer program. 3 credits. Prerequisites: graduate standing or permission of instructor. Not for M&AE majors.
Yield criteria and plastic flow. Manufacturing processes for engineering materials, including metals, polymers, ceramics and composites. Casting, forming, material removal and joining processes. Intended for non-mechanical engineers.

M&AE 555 Introduction to Composite Materials (also T&AM 555)
For course description, see T&AM 555.

M&AE 570 Intermediate Dynamics
Fall. 3 credits. Prerequisites: graduate standing or permission of instructor. 2 lecs.
Introduction to analytical mechanics, virtual work, Lagrangian mechanics. Small vibration and stability theory. Newtonian-Eulerian mechanics of rigid bodies.

M&AE 577 Mechanical Vibrations
For description, see T&AM 574.

[M&AE 578 Feedback Control Systems Design and Implementation
Spring. 3 credits. Prerequisite: M&AE 478 or ELE E 471, graduate standing, or permission of instructor. Fulfills the computer application requirement. Not offered 1995–96.
Further development of the theory, design, and implementation of feedback control systems with particular emphasis on applications, modeling and system identification, and hardware implementation. Digital control is introduced. Labs include real-time microprocessor-based control of a D.C.-motor positioning system, a two-link robot arm, and a two-tank level-control system.]

[M&AE 590 Mechanical Engineering Design
Spring. 4 credits. Lab fee $25. Prerequisites: graduate standing or permission of instructor. Intended for students in M.Eng.(Mechanical) program. Fulfills M.Eng. (M.E.) design requirement. Not offered 1995–96.]

M&AE 612 Materials Processing: Theory and Applications
Fall. 4 credits. Prerequisite: graduate standing, or permission of instructor.
Basic principles governing the inelastic behavior of solids. Slab-analysis models and bound theorems for problems of forging, extrusion, and rolling. Analysis of sheet-metal forming including limit diagrams and springback. Defect initiation during forming processes. Basic solidification processes. Morphological instability of a solid/liquid interface, solidification microstructures, solute redistribution, microsegregation and macrosegregation. Thermomechanical defects in casting processes. Rapid solidification microstructures. Behavior and forming of metal alloys in the semisolid state.

M&AE 613 Computational Methods in Materials Processing
Spring. 4 credits. Prerequisite: M&AE 612 or permission of instructor.
Thermodynamic framework for inelastic constitutive models, temperature and rate dependence, phenomenology of plastic deformation. The finite-element method for rigid plastic flow analysis of extrusion, drawing, forging, rolling and plate bending. Integration of viscoplastic models, geometry updating, boundary conditions, friction at tool/workpiece interface, modeling of incompressibility, iterative process, and applications to process design. Comparison of the flow formulation with an elasto-plastic analysis. Analysis of hot forming processes. Procedures for heat-transfer analysis. Preform design. Modeling of plastic anisotropy with applications to sheet forming. Modeling of heat flow and deformation on casting processes.

[M&AE 614 Precision Engineering
Fall. 4 credits. Prerequisite: graduate standing or permission of instructor. Not offered 1995–96.
This is a graduate version of M&AE 414. The themes are ideal-form modeling, form tolerancing, form measurement, and manufacturing process modeling (sources of form error). Relevant theory is developed, current practices are summarized, and current research issues are examined. Research in the area is expanding rapidly, because form-variation control is a central tool in continuous quality improvement.]

M&AE 615 Experiments in Materials Processing
Fall. 4 credits. Prerequisite: graduate standing or permission of instructor.
This course will focus on experiments related to the mechanical properties of materials and experiments using various materials processing apparati and will include a general introduction to sensors and instrumentation for engineering measurements. Testing for mechanical properties/model parameter characterization: inelastic deformation, fatigue, and fracture, including rate and temperature effects. Process simulation experiments including forging, extrusion, rolling, and ironing. Formability experiments. Determination of heat transfer coefficients associated with quenching and solidification process. Fluidity measurements. Specimen design and fabrication. Although the focus is on metals and alloys attention is also given to polymers and ceramic materials.

M&AE 625 Product Development
Fall or spring. 4 credits. Prerequisite: graduate standing.
Covers a wide range of methods and techniques used in the product development process. Cognitive methods of design, team organization, conceptual design, parametric design, concurrent engineering, quality function deployment, and Taguchi method.

M&AE 655 Advanced Composite Materials and Structures (also T&AM 655)
For course description, see T&AM 655.

[M&AE 665 Advanced Topics in Orthopaedic Biomechanics
On demand. 4 credits. Prerequisites: graduate standing, prior or concurrent registration in advanced courses in strength of materials or elasticity, and intermediate dynamics. Not offered 1995–96.
Advanced treatment of topics in the biomechanics of the musculoskeletal system. Force analysis of the musculoskeletal system under static and dynamic conditions, compact and trabecular bone as structural materials, structural analysis of bone-implant systems, remodeling of bone.]

M&AE 670 Finite Element Analysis for Mechanical and Aerospace Design
Spring. 4 credits. Prerequisite: graduate standing, or permission of instructor.
Introduction to the finite-element method for static and dynamic analysis of mechanical and aerospace structures (and related nonstructural applications such as heat conduction). Primary emphasis on underlying mechanics and numerical methods. Secondary consideration of inherent capabilities and limitations of large-scale, general-purpose structural mechanics programs. Introduction to computational aspects through development of small, special-purpose programs and application of available general-purpose programs. Term project.

[M&AE 678 Optimal Control and Estimation
Fall, on demand. 3 credits. Prerequisite: M&AE 478, ELE E 471, graduate standing, or permission of instructor; programming ability in FORTRAN, Pascal, or C. Corequisite: ELE E 521. Not offered 1995–96.
Develops the theory of the design of modern multi-input–multi-output feedback control systems using optimal control techniques. Topics covered include trajectory optimization and the minimum principle, bang-bang optimal control solutions, Kalman filtering, LQR/LQE compensator design, suboptimal control and estimation, and applications to regulator and tracking problems. Both linear and nonlinear systems, and continuous-time and discrete-time control, and considered.]

M&AE 679 Modeling and Simulation of Dynamic Systems
Spring. 4 credits. Prerequisite: graduate standing or permission of instructor.
Practice tools with selected applications from diverse fields. Representation of continuous dynamic systems by state-variable models. Simulation by numerical integration using procedural languages (such as FORTRAN and Pascal) and digital simulation packages (such as CSMP and STELLA). Special topics in linear and nonlinear dynamics. Term project.

[M&AE 682 Hydrodynamic Lubrication: Fluid-Film Bearings
4 credits. Prerequisite: graduate standing or permission of instructor. Not offered 1995–96. Course offering depends upon faculty availability.
Theory of hydrodynamic lubrication and its application to the analysis and design of fluid-film bearings and other devices. General topics include viscous flow in thin films, self-acting and externally pressurized bearings

with liquid and gas lubricant films, bearing-system dynamics, and computational methods. Selected special topics such as elastohydrodynamic lubrication and artificial joints. Term project.]

[M&AE 685 Optimum Design of Mechanical Systems
On demand. 4 credits. Prerequisite: graduate standing or permission of instructor. Not offered 1995–96. Course offering depends upon faculty availability.
The formulation of design problems frequently encountered in mechanical systems as optimization problems. Theory and application of methods of mathematical programming for the solution of optimum design problems.]

[M&AE 715 Finite-Deformation Plasticity and Rheology and Their Applications in Materials Processing
Fall. 4 credits. Prerequisites: advanced graduate students, Introduction to Continuum Mechanics and Plasticity. Offered alternate years. Not offered 1995–96.
Hyperelasticity and hypoelasticity. Phenomenology of rate-dependent plastic deformation. Kinematic framework for inelastic constitutive modeling. Lagrangian and Eulerian FEM formulations for large deformation elastoviscoplastic problems. Viscoplasticity coupled with damage. Slip systems and lattice rotation. Texture development and strain hardening in rate-dependent polycrystals. Modeling of the evolution of deformation-induced crystallographic texture in forming processes. Rheological models for polymers.]

Energy, Fluids, and Aerospace Engineering

M&AE 305 Introduction to Aeronautics
Fall. 3 credits. Limited to upperclass engineers; others with permission of instructor.
Introduction to the concept of aircraft design. Principles of incompressible and compressible aerodynamics, boundary layers, and wing theory. Description and performance of propeller-driven and jet propulsion engines. Design studies focus on transonic passenger airplanes and small supersonic jets.

[M&AE 400 Components and Systems: Engineering in a Social Context (also Physics 481 and Science, Technology, and Society 400)
Spring. 3 credits. Prerequisites: upperclass standing, two years of college physics. Serves as an approved elective but not as a field elective in mechanical engineering. Offered alternate years. Not offered 1995–96.
This course addresses, at a technical level, broader questions than are normally posed in the traditional engineering or physics curriculum. Through the study of individual cases such as the Strategic Defense Initiative (SDI), the National Aerospace Plane, and nuclear power and its alternatives, we investigate interactions between the scientific, technical, political, economic, and social forces that are involved in the development of engineering systems.]

[M&AE 401 Components and Systems: Engineering in a Social Context
Spring. 4 credits. Prerequisites: senior standing, two years of college physics. Fulfills field design requirement. Offered alternate years. Not offered 1995–96.
For description, see M&AE 400.]

M&AE 423 Intermediate Fluid Dynamics
Spring. 3 credits. Prerequisite: M&AE 323.
This course builds on the foundation of M&AE 323. Emphasis will be both on the calculation of real flows (both engineering and environmental) and fundamental principles. Topics covered will include some exact solutions to the Navier-Stokes equations, boundary layers, wakes and jets, separation, convection, stratified and rotating flows, fluid instabilities, turbulence and chaos.

[M&AE 436 Turbomachinery and Applications
Spring. 3 credits. Prerequisite: M&AE 323 or 324 or permission of instructor. Not offered 1995–96.
Aerothermodynamic design of turbomachines in general, energy transfer between fluid and rotor in specific types, axial and radial devices, compressible flow. Three-dimensional effects, surging.]

[M&AE 439 Acoustics and Noise
Fall. 3 credits. Prerequisites: some knowledge of fluid mechanics or permission of instructor. Not offered 1995–96.
Sound propagation, transmission, and absorption. Sound radiation by surfaces and flow. Room acoustics and noise-control techniques. Hearing, music, noise, and noise control.]

[M&AE 441 Advanced Thermodynamics with Energy Applications
Spring. 3 credits. Prerequisites: M&AE 221 and 323, or permission of instructor. Not offered 1995–96.
Brief review of classical thermodynamics. Applications to power cycles and refrigeration cycles of particular interest to energy systems. Other topics include the thermodynamic properties of pure systems, phase and chemical equilibria. Brief introduction to statistical thermodynamics.]

M&AE 449 Combustion Engines
Spring. 3 credits. Prerequisites: Engr 221 and M&AE 323.
Introduction to combustion engines, with emphasis on the application of thermodynamic and fluid-dynamic principles affecting their performance. Air-standard analyses, chemical equilibrium, ideal-cycle analyses, deviations from ideal processes, combustion knock. Formation and control of undesirable exhaust emissions.

[M&AE 454 Solar Engineering Design
Spring. 3 credits. Prerequisites: M&AE 428 or senior standing in M&AE. Fulfills field design requirement. Enrollment limited to 30 students. Not offered 1995–96.
A broad coverage of solar-energy utilization by humankind. Fundamentals of solar radiation. Direct radiation as a source of heat and work. Indirect radiation utilization or natural collection; water power, wind power, and biomass. The production of liquid and gaseous fuels. Solar architecture and environmental control by both active and passive means. Each student will execute a design project in solar engineering. Course grade will be based on design project; presentation of a design proposal, an oral presentation on the progress of the project, and submission of a final design report.]

[M&AE 456 Power Systems
Fall. 3 credits. Corequisites: M&AE 428 and senior standing. Fulfills field design requirement. Not offered 1995–96.
A broad survey of methods of large-scale power generation, emphasizing energy sources, thermodynamic cycle considerations, and component description. Power-industry, economic, and environmental factors, trends, and projections.]

M&AE 459 Introduction to Controlled Fusion: Principles and Technology (also ELE E 484)
For description, see NS&E 484.

M&AE 506 Aerospace Propulsion Systems
Spring. 3 credits. Prerequisite: M&AE 323 or permission of instructor. Offered alternate years.
Application of thermodynamic and fluid-mechanic principles to the design and performance of aerospace systems. Jet propulsion principles, including rockets. Pollution characteristics. Future possibilities for improved performance.

[M&AE 507 Dynamics of Flight Vehicles
Spring. 3 credits. Prerequisites: M&AE 405 and Engr 203, or permission of instructor. Offered alternate years. Not offered 1995–96.
Introduction to stability and control of atmospheric-flight vehicles. Review of aerodynamic forces and methods for analysis of linear systems. Static stability and control. Small disturbance equations of unsteady motion. Dynamic stability of longitudinal and lateral-directional motions; transient control response. At the level of *Dynamics of Flight: Stability and Control*, by Etkin.]

[M&AE 524 Thermal Management of Electronic Packages
Spring. 3 credits. Prerequisites: M&AE 221 and MATH 294 or permission of instructor. Not offered 1995–96.
This course presents the basic elements of heat transfer in the context of thermal control of a microelectronic package: conduction, convection, radiation, and boiling. The application is to semiconductor chips, transistors, resistors, and optoelectronic devices. Topics include component reliability and temperature; conduction of heat in steady and unsteady states; multilayered structures; thermal contact resistance; extended surfaces (fins); analyses of forced and natural convection flows over surfaces and within enclosures; functional solutions, Reynolds analogy, and integral analyses; calculation of the heat-transfer coefficient; the basics of radiative transfer; jet impingement cooling; immersion cooling; and compact heat exchangers.]

M&AE 543 Combustion Processes
Fall. 3 credits. Prerequisite: graduate standing or permission of instructor.
An introduction to combustion and flame processes, with emphasis on fundamental fluid dynamics, heat and mass transport, and reaction-kinetic processes that govern combustion rates. Thermochemistry, kinetics, vessel explosions, laminar and turbulent premixed and diffusion flames, droplet combustion, and combustion of solids.

M&AE 601 Foundations of Fluid Dynamics and Aerodynamics
Fall. 4 credits. Prerequisite: graduate standing or permission of instructor.
Foundations of fluid mechanics from an advanced viewpoint. Aspects of kinetic theory as it applies to the formulation of continuum fluid dynamics. Surface phenomena and boundary conditions at interfaces. Fundamental kinematic descriptions of fluid flow, tensor analysis, derivation of the Navier-Stokes equations and energy equation for compressible fluids. Viscous flows, boundary layers, potential flows, vorticity dynamics.

M&AE 602 Fluid Dynamics at High Reynolds Numbers
Spring. 4 credits. Prerequisite: M&AE 601.
Navier-Stokes and Euler equations, integral formulas for fluid forces and moments on immersed bodies in compressible and incompressible viscous flows. Vorticity dynamics in compressible flows, Kelvin's theorem. Fjortoft's theorem, Helmholtz decomposition of vector fields. Singularities, vortex filaments, vortex sheets, Biot-Savart relations. Irrotational motion: representations in terms of velocity or vector potentials. Topology of flows; general results in potential theory.

M&AE 608 Physics of Fluids
Spring. 4 credits. Prerequisite: graduate standing or permission of instructor.
Behavior of a gas is considered at the microscopic level. Introduction to kinetic theory: velocity distribution, collisions, Boltzmann equation. Quantum theory: internal structure, rigid rotator, harmonic oscillator, one-electron atom. Statistical mechanics: partition functions, relation to thermodynamics. These ideas are combined through application to modeling finite rate changes in the vibrational energy and chemical composition of high-temperature air.

M&AE 651 Advanced Heat Transfer
Spring. 4 credits. Prerequisite: graduate standing or permission of instructor.
Advanced treatment of conductive and convective heat transfer. Basic equations reasoned in detail. Integral and differential formulations. Exact and approximate solutions. Forced convection. Natural convection. Laminar and turbulent flows. Effects of viscous dissipation and mass transfer.

M&AE 654 Radiation Heat Transfer
2–4 credits. Prerequisite: graduate standing or permission of instructor.
An independent readings course. Coverage of surface- and gas-radiation properties, including reflection, emission, absorption, and scattering. Deductions from the first and second laws of thermodynamics. The radiative-transfer equation; surface-surface, surface-volume, and volume-volume exchange. Simplifying approximations. Modern methods for exchange calculations and transport analysis including integral, computer-graphics-assisted, and Monte Carlo approaches. Assigned readings from *Radiative Heat Transfer*, by Modest. Discussion sessions. Assigned problems and papers.

M&AE 732 Analysis of Turbulent Flows
Spring. 4 credits. Prerequisite: M&AE 601 or permission of instructor. Offered alternate years.
Study of methods for calculating the properties of turbulent flows. Characteristics of turbulent flows. Direct numerical simulations, large-eddy simulations, and the closure problem. Reynolds-stress equation: effects of dissipation, anisotropy, deformation. Transported scalars. Probability density functions (pdf's): definitions and properties, transport equations, relationship to second-order closures, stochastic modeling, Langevin equation, and Monte Carlo solutions. The course emphasizes comparison of theory with experiment.

M&AE 733 Stability of Fluid Flow
Fall, on demand. 4 credits. S-U grades only. Prerequisite: graduate standing or permission of instructor. May be offered 1995–96.
Basic stability and bifurcation theory in fluid systems. Thermal, double-diffusive, and related instabilities. Post-bifurcation behavior: the Ginzburg-Landau (Stewartson-Stuart) and Chapman-Proctor-Sivashinsky amplitude equations. Phase dynamics and pattern formation. Stability of periodic motion: Floquet theory. Secondary instabilities; Eckhaus instability, Busse "balloons." Energy stability theory. Effects of symmetry. Taylor-Couette instability. "Open" flow systems: inviscid Kelvin-Helmholtz, Rayleigh-Taylor instability, and capillary instability of liquid jets. Stability of parallel shear flows and of concentrated vortex flows. Spatial development of linearly unstable motion: "absolute" and "convective" instability.

M&AE 734 Turbulence and Turbulent Flow
Fall. 4 credits. Prerequisite: M&AE 601, graduate standing, or permission of instructor.
Topics include the dynamics of buoyancy and shear-driven turbulence, boundary-free and bounded shear flows, second-order modeling, the statistical description of turbulence, turbulent transport, and spectral dynamics.

M&AE 736 Computational Aerodynamics
Spring. 4 credits. Prerequisites: graduate standing, an advanced course in continuum mechanics or fluid mechanics, and some FORTRAN programming experience.
Numerical methods to solve inviscid and high-Reynolds-number fluid-dynamics problems, including finite-difference, finite-volume, and surface-singularity methods. Accuracy, convergence, and stability; treatment of boundary conditions and grid generation. Focus on hyperbolic (unsteady flow with shock waves) and mixed hyperbolic-elliptic (steady transonic flow) problems. Assignments require programming digital computer.

M&AE 737 Computational Fluid Mechanics and Heat Transfer
Fall. 4 credits. Prerequisites: graduate standing; an advanced course in continuum mechanics, heat transfer, or fluid mechanics; and some FORTRAN or C programming experience. May be offered 1995–96.
Numerical methods for elliptic and parabolic partial differential equations arising in fluid flow and heat-transfer problems involving convection and diffusion. Finite-difference, finite-volume, and spectral methods. Accuracy, stability, convergence, and conservation. Review of current methods. Emphasis on steady and unsteady incompressible flows. Assigned problems are solved on a digital computer and at the College Workstation Facility.

Special Offerings

M&AE 490 Special Investigations in Mechanical and Aerospace Engineering
Fall, spring. Credit to be arranged. Limited to undergraduate students. Prerequisite: permission of instructor.
Intended for an individual student or a small group of students who want to pursue a particular analytical or experimental investigation outside of regular courses or for informal instruction supplementing that given in regular courses.

M&AE 491 Design Projects in Mechanical and Aerospace Engineering
Fall, spring. Credits to be arranged. Prerequisite or corequisite: M&AE 428. Fulfills field design requirement.
Intended for individual students or small groups of students who want to pursue particular design projects outside of regular courses.

M&AE 545 Energy Seminar
For description, see NS&E 545.

M&AE 592 Seminar and Design Project in Aerospace Engineering
Fall, spring. 2 credits each term. Prerequisite: graduate standing or permission of instructor. Intended for students in M.Eng.(Aerospace) program.
Introduction to topics of current research interest in aerospace engineering by Aerospace faculty and invited speakers. Individual design projects supervised by separate faculty members after introductory sessions.

M&AE 594 Manufacturing Seminar
For description, see OR&IE 893.

M&AE 690 Special Investigations in Mechanical and Aerospace Engineering
Fall, spring. Credit to be arranged. Limited to graduate students.

M&AE 695 Special Topics in Mechanical and Aerospace Engineering
Fall, spring. Credit to be arranged. Graduate standing and permission of instructor.
Special lectures by faculty members on topics of current research.

M&AE 791 Mechanical and Aerospace Research Conference
Fall, spring. 1 credit each term. S-U grades only. For graduate students involved in research projects.
Presentations on research in progress by faculty and students.

M&AE 799 Mechanical and Aerospace Engineering Colloquium
Fall, spring. 1 credit each term. Credit limited to graduate students. All students and staff invited to attend.
Lectures by visiting scientists and Cornell faculty and staff members on research topics of current interest in mechanical and aerospace science, especially in connection with new research.

M&AE 890 Research in Mechanical and Aerospace Engineering
Credit to be arranged. Prerequisite: candidacy for M.S. degree in mechanical or aerospace engineering or approval of director.
Independent research in an area of mechanical and aerospace engineering under the guidance of a member of the faculty.

M&AE 990 Research in Mechanical and Aerospace Engineering
Credit to be arranged. Prerequisite: candidacy for Ph.D. degree in mechanical or aerospace engineering or approval of director.
Independent research in an area of mechanical and aerospace engineering under the guidance of a member of the faculty.

NUCLEAR SCIENCE AND ENGINEERING

A number of courses in nuclear science and engineering are offered through the School of Applied and Engineering Physics (see A&EP 609, 612, 633, 634, 636, 638, and 651).

NS&E 121 Fission, Fusion, and Radiation (also ENGRI 121)
Spring. 3 credits.
This is a course in the Introduction to Engineering series. For description, see Engineering Common Courses.

NS&E 285 Art, Archaeology, and Analysis
For description, see ENGRI 185.

NS&E 303 Introduction to Nuclear Science and Engineering I (also A&EP 303)
Fall. 3 credits. Prerequisite: Physics 214 or Mathematics 294. This course is designed for juniors or seniors from any engineering field who want to prepare for graduate-level nuclear science and engineering courses at Cornell or elsewhere. It can also serve as a basic course for those who do not intend to continue in the field.
Introduction to the fundamentals of nuclear reactors. Topics include an overview of the field of nuclear engineering; nuclear structure, radioactivity, and reactions; interaction of radiation and matter; and neutron moderation, neutron diffusion, the steady-state chain reaction, and reactor kinetics. At the level of *Introduction to Nuclear Engineering*, by Lamarsh.

NS&E 484 Introduction to Controlled Fusion: Principles and Technology (also ELE E 484, M&AE 459, and A&EP 484)
Spring. 3 credits. Prerequisites: PHYS 112, 213, and 214, or equivalent background in electricity and magnetism and mechanics; and permission of instructor. Intended for seniors and graduate students.
Introduction to the physical principles and various engineering aspects underlying power generation by controlled fusion. Topics include: (i) fuels and conditions required for fusion power, and basic fusion-reactor concepts; (ii) fundamental aspects of plasma physics relevant to the confinement of thermonuclear plasmas, and basic engineering problems for a fusion reactor; and (iii) an engineering analysis of the present engineering design for the large, international, next-step tokamak experiment, ITER (International Toroidal Experimental Reactor), which is to be a fusion-power test reactor, and/or analysis of inertial confinement fusion-reactor designs. Parts (i) and (ii) will be treated in lectures; part (iii) will include talks by course participants.

NS&E 509 Nuclear Physics for Applications
Fall. 3 credits. Prerequisites: sophomore physics and math, or permission of instructor; some upper-division physics is desirable. Primarily for graduate students, especially those with a major or minor in Nuclear Science and Engineering; also open to qualified undergraduates.
A first course in nuclear physics. Systematic presentation of nuclear phenomena and processes that underlie applications ranging from nuclear power (fission and fusion), to nuclear astrophysics, to nuclear analytical methods for research in nonnuclear fields. Radioactivity, nuclear reactions, and interaction of radiation with matter. At the level of *Radiochemistry and Nuclear Methods of Analysis,* by Ehmann and Vance or *Nuclear and Radiochemistry,* by Friedlander, et al.

NS&E 545 Energy Seminar (also M&AE 545 and ELE E 587)
Fall and spring. 1 credit each semester. May be taken both fall and spring for credit. Master of Engineering (M.Eng.) students in the Energy Option are expected to take this seminar both fall and spring for credit.
Energy resources, their conversion to electricity or process heat, and the environmental consequences of the energy cycle will be discussed by faculty members from several departments in the College of Engineering, other units within the university, and invited experts. Examples of topics to be surveyed are energy resources, economics, and politics; coal-based electricity generation; nuclear reactors; solar power; energy conservation by users; synthetic fuels; air-pollution control; nuclear-waste disposal; electric-power transmission systems; geothermal power; wind power; and advanced oil recovery.

NS&E 551 Nuclear Methods in Non-Nuclear Research Fields
Spring. 3 credits. Prerequisite: Physics 214 or 218, or permission of instructor; some upper-division physics desirable. Primarily for graduate students in archaeology, geology, chemistry, biology, materials science, and other non-nuclear fields in which nuclear methods are used. Open to qualified undergraduates. A more intensive related course, A&EP 651, is intended for nuclear specialists.
Lectures on interaction of radiation with matter, radiation protection, and nuclear instruments and methods including data reduction. About ten experiments are available on radiation detection, attenuation, and measurement; electronic instrumentation, including computerized systems; activation analysis; and emerging applications such as prompt gamma analysis and neutron radiography. The TRIGA reactor is used. Emphasis is on those nuclear methods, particularly instrumental ones using neutrons, that are used in, or are being adapted for, non-nuclear fields, but tracer and other chemical techniques are not included. Students each select seven or eight experiments to meet their interests and needs. At the level of *Radiochemistry and Nuclear Methods of Analysis*, by Ehmann and Vance or *Nuclear and Radiochemistry,* by Friedlander, et al.

NS&E 590 Independent Study
Fall, spring. 1–4 credits. Grade option letter or S-U.
Independent study or project under guidance of a faculty member.

NS&E 591 Project
Fall, spring. 1–6 credits.
Master of Engineering or other project under guidance of a faculty member.

NS&E 621 Radiation Effects in Microelectronics (also ELE E 633)
Fall. 3 credits. Prerequisite: Permission of instructor. A seminar intended for seniors and graduate students in engineering or applied physics.
An introduction to the physical processes that underlie the malfunction of microelectronic circuitry resulting from exposure to ionizing radiation. Basic device-failure mechanisms, including total-dose effects, single-event upsets, and latchup, as well as the roles that circuit testing and modeling methods play in improving circuit design. Impact of surface radiation typical of low-energy electron and photon sources on device fabrication. Reference materials from the current literature.

OPERATIONS RESEARCH AND INDUSTRIAL ENGINEERING

OR&IE 115 Engineering Application of Operations Research (also ENGRI 115)
Fall, spring. 3 credits. Enrollment not open to OR&E upperclass majors.
For description see Engineering Common Courses.

OR&IE 270 Basic Engineering Probability and Statistics (also ENGRD 270)
Fall, spring, summer. 3 credits. Prerequisite: first-year calculus.
For description see Engineering Common Courses.

OR&IE 310 Industrial Systems Analysis
Spring. 4 credits. Prerequisite or corequisite: ENGR 270. 3 lecs. 1 computing session.
Design of production facilities, including engineering economy, taxation effects, materials handling process design, and facility layout. Operations analysis, including process scheduling, process evaluation, procedural analysis, project management, methods analysis and design, work measurement, inventory control, job evaluation, and quality engineering and control. Formerly listed as OR&IE 410.

OR&IE 320 Optimization I
Fall. 4 credits. Prerequisite: Mathematics 221 or 294.
Formulation of linear programming problems and solution by the simplex method. Related topics such as sensitivity analysis, duality, and network programming. Applications include such models as resource allocation and production planning.

OR&IE 321 Optimization II
Spring. 4 credits. Prerequisite: OR&IE 320 or equivalent.
A variety of optimization methods stressing extensions of linear programming and its applications but also including topics drawn from integer, dynamic, and nonlinear programming. Formulation and modeling are stressed as well as numerous applications.

OR&IE 350 Financial and Managerial Accounting
Fall. 4 credits.
Principles of accounting, financial reports, financial-transactions analysis; financial-statement analysis, budgeting, job-order and process-cost systems, standard costing and variance analysis, economic analysis of short-term decisions.

OR&IE 360 Engineering Probability and Statistics II
Fall. 4 credits. Prerequisite: ENGRD 270 or equivalent. Not open to students who have taken OR&IE 260.
This second course in probability and statistics provides a rigorous foundation in theory combined with the methods for modeling, analyzing, and controlling randomness in engineering problems. Probabilistic ideas are used to construct models for engineering problems, and statistical methods are used to test and estimate parameters for these models. Specific topics include random variables, probability distributions, density functions, expectation and variance, multidimensional random variables, and important distributions including normal, Poisson, exponential, hypothesis testing, confidence intervals, and point estimation using maximum likelihood and the method of moments.

OR&IE 361 Introductory Engineering Stochastic Processes I
Spring. 4 credits. Prerequisite: OR&IE 260 or OR&IE 360 or equivalent.
Basic concepts and techniques of random processes are used to construct models for a variety of problems of practical interest. Topics include the Poisson process, Markov chains, renewal theory, models for queuing and reliability.

OR&IE 416 Design of Manufacturing Systems
Fall. 4 credits. Senior OR&E students only. Others by permission of instructor only.
Project course in which students, working in teams, design a manufacturing logistics system and conduct capacity, material flow, and cost analysis of their design. Meetings between project teams and faculty advisers are substituted for some lectures. Analytical methods for controlling inventories, planning production, and evaluating system performance will be presented in lectures. Lab fee $15.

OR&IE 417 Material Handling Systems
Fall. 4 credits.
Design of the layout of processes and storage areas and the material-handling system for movement of items. Typical equipment used. Material flow analysis. The functions of identification control, storage, movement, batching, merging, and dispersion.

OR&IE 431 Discrete Models
Spring. 4 credits. Prerequisites: OR&IE 320 and COM S 211, or permission of instructor.
Basic concepts of graphs, networks, and discrete optimization. Fundamental models and applications, and algorithmic techniques for their analysis. Specific optimization models studied include flows in networks, the traveling salesman problem, and network design.

OR&IE 432 Nonlinear Optimization
Spring. 4 credits. Prerequisite: OR&IE 320.
Introduction to the practical and theoretical aspects of nonlinear optimization. Attention given to the computational efficiency of algorithms and the application of nonlinear techniques to linear programming; e.g., interior-point methods. Methods of numerical linear algebra introduced as needed.

OR&IE 435 Introduction to Game Theory
Fall. 3 credits.
A broad survey of the mathematical theory of games, including such topics as two-person matrix and bimatrix games; cooperative and noncooperative n-person games; games in extensive, normal, and characteristic function form. Economic market games. Applications to weighted voting and cost allocation.

OR&IE 451 Economic Analysis of Engineering Systems
Spring. 4 credits. Prerequisites: OR&IE 320 and OR&IE 350.
Financial planning, including cash-flow analysis and inventory flow models. Engineering economic analysis, including discounted cash flows and taxation effects. Application of optimization techniques, as in equipment replacement or capacity expansion models. Issues in designing manufacturing systems. Student group project.

OR&IE 462 Introductory Engineering Stochastic Processes II
Spring. 4 credits. Prerequisite: OR&IE 361 or equivalent. 3 lecs, 1 rec.
Stationary processes, martingales, random walks, and gambler's ruin problems, processes with stationary independent increments, Brownian motion and other cases, branching processes, renewal and Markov-renewal processes, reliability theory, Markov decision processes, optimal stopping, statistical inference from stochastic models, and stochastic comparison methods for probability models. Applications to population growth, spread of epidemics, and other models.

OR&IE 475 Regression
Fall. Second half of term. 2 credits. Prerequisite: ENGRD 270.
Linear models; estimation and testing; confidence sets; diagnostics and residual analysis; variable selection and modeling.

OR&IE 476 Experimental Design I
Fall. First half of term. 2 credits. Prerequisite: ENGRD 270.
Experimental design to improve industrial products and manufacturing processes. Randomization. Blocking. Fractional factorials. Orthogonal arrays. Nested designs.

OR&IE 480 Information Technology
Spring. 4 credits. 3 lecs, 1 rec.
The objective of this course is to introduce students to information technologies. Topics include Communications Systems, Computer Architectures, Database Management Systems, and Development Methodologies found in Manufacturing Engineering, Product Document Management, Forecasting and Marketing, Order Entry, Production Planning and Control, Distribution, Finance, Trading, and Transportation. Lectures, cases, and laboratory experiences will be used.

OR&IE 499 OR&IE Project
Fall, spring. Credit to be arranged. Prerequisite: permission of instructor.
Project-type work, under faculty supervision, on a real problem existing in some firm or institution, usually a regional organization. Opportunities in the course may be discussed with the associate director.

OR&IE 515 Design of Manufacturing Systems
Fall. 4 credits. Prerequisite: permission of instructor. Limited to M.Eng. students in OR&IE.
For description, see OR&IE 416. Lab fee $15.

OR&IE 516 Case Studies
Fall. 1 credit. Limited to M.Eng. students in OR&IE.
Students are presented with unstructured problems that resemble real-world situations. They work in project groups to formulate mathematical models, perform computer analyses of the data and models, and present oral and written reports.

OR&IE 520 Operations Research I: Optimization I
For description, see OR&IE 320.

OR&IE 521 Optimization II
For description, see OR&IE 321.

OR&IE 523 Operations Research II: Introduction to Stochastic Modeling
For description, see OR&IE 361.

OR&IE 525 Production Planning and Scheduling Theory and Practice
Spring. 3 credits. Prerequisite: OR&IE 320.
Production planning, including MRP, linear programming, and related concepts. Scheduling and sequencing work in manufacturing systems. Job release strategies and control of work in process inventories. Focus on setup time as a determinant of plans and schedules.

OR&IE 528–529 Selected Topics in Applied Operations Research
Fall, spring. Credit to be arranged. Prerequisite: permission of instructor.
Current topics dealing with applications of operations research.

OR&IE 551 Economic Analysis of Engineering Systems
Spring. 4 credits. Prerequisites: OR&IE 320 and OR&IE 350.
Lectures concurrent with OR&IE 451. For description see OR&IE 451.

OR&IE 560 Engineering Probability and Statistics II
For description, see OR&IE 360.

OR&IE 561 Queuing Theory and Its Applications
Spring. 3 credits. Prerequisite: OR&IE 361 or permission of instructor.
Basic queuing models. Little's Law, PASTA property, Markovian and non-Markovian queues. Optimization of queues. Polling queues: exhaustive and gated service. Jackson queuing networks. Open networks and closed networks. Product-form queuing networks.

OR&IE 562 Inventory Theory
Spring. 4 credits. Prerequisite: OR&IE 321, 361 or permission of instructor.
Discussion of the nature of inventory systems and their design and control. Periodic and continuous review policies for single-item and single-location problems. Multi-item and

multi-echelon extensions. Dynamic and static models are discussed. Distribution problems are analyzed. Applications are stressed.

[OR&IE 563 Applied Time-Series Analysis
Spring. 3 credits. Prerequisites: OR&IE 361 and OR&IE 270, or permission of instructor. Not offered 1995–96. Next offered 1996–97.
The first part of this course treats regression methods to model seasonal and non-seasonal data. After that, Box-Jenkins models, which are versatile, widely used, and applicable to nonstationary and seasonal time series, are covered in detail. The various stages of model identification, estimation, diagnostic checking, and forecasting are treated. Analysis of real data is carried out. Assignments require computer work with a time-series package.]

OR&IE 564 Introductory Engineering Stochastic Processes II
Spring. 4 credits. Prerequisite: OR&IE 361 or equivalent. Lectures concurrent with OR&IE 462. 3 lecs, 1 recs.
For description, see OR&IE 462.

OR&IE 565 Applied Financial Engineering
Spring. 4 credits. 3 lecs.
This course has two components: a sequence of lectures and a project. The course will be co-listed with the Johnson School and will be co-taught by one faculty member from each school. The lectures will be given by the faculty for the course and by invited speakers from the financial industry. The project will satisfy the M.Eng. project requirement.

[OR&IE 575 Experimental Design II
Spring. Last half of term. 2 credits. Prerequisite: OR&IE 476. Not offered 1995–96. To be offered 1996–97.
Continuation of OR&IE 476. Design of industrial experiments. Response surfaces. Robust product designs. Taguchi's methods.]

OR&IE 577 Quality Control
Fall. 3 credits. Prerequisites: ENGRD 270. 3 lecs.
Concepts and methods for process and acceptance control. Control charts for variables and attributes. Process capability analysis. Acceptance sampling. Continuous sampling plans. Life tests. Use of experimental design and Taguchi methods for off-line control.

OR&IE 580 Design and Analysis of Simulated Systems
Fall. 4 credits. Prerequisites: programming experience and OR&IE 360/560, or permission of instructor. Note: OR&IE 360/560 may be taken concurrently.
Digital computer programs to simulate the operation of complex discrete systems in time. Modeling, program organization, pseudo–random-variable generation, simulation languages, statistical considerations; applications to a variety of problem areas.

OR&IE 599 Project
Fall, spring. 5 credits. For M.Eng. students.
Identification, analysis, design, and evaluation of feasible solutions to some applied problem in the OR&IE field. A formal report and oral defense of the approach and solution are required.

[OR&IE 625 Scheduling Theory
Spring. 3 credits. Not offered 1995–96. To be offered 1996–97.
Scheduling and sequencing problems, including single-machine problems, parallel-machine scheduling, and shop scheduling. The emphasis is on the design and analysis of polynomial time optimization and approximation algorithms and on related complexity issues.]

OR&IE 626 Advanced Production and Inventory Planning
Spring. 3 credits.
Introduction to a variety of production and inventory control planning problems; the development of mathematical models corresponding to these problems; a study of approaches for finding solutions.

OR&IE 630 Mathematical Programming I
Fall. 4 credits. Prerequisites: advanced calculus and elementary linear algebra.
A rigorous treatment of the theory and computational techniques of linear programming and its extensions. Formulation, duality theory, simplex, and dual simplex methods. Sensitivity analysis. Network flow problems and algorithms. Theory of polyhedral convex sets, systems of linear equations and inequalities, Farkas' Lemma. Exploiting special structure in the simplex method, computational implementation. Decomposition Principle.

OR&IE 631 Mathematical Programming II
Spring. 4 credits. Prerequisite: OR&IE 630.
A continuation of OR&IE 630. Introduction to nonlinear programming, interior-point methods for linear programming, complexity theory, and integer programming. Some discussion of dynamic programming, and elementary polyhedral theory.

[OR&IE 632 Nonlinear Programming
Fall. 3 credits. Prerequisite: OR&IE 630. Not offered 1995–96. To be offered 1996–97.
Necessary and sufficient conditions for unconstrained and constrained optima. Duality theory. Computational methods for unconstrained (e.g., quasi-Newton) problems, linearly constrained (e.g., active set) problems, and nonlinearly constrained (e.g., successive quadratic programming) problems.]

[OR&IE 633 Graph Theory and Network Flows
Fall. 3 credits. Prerequisite: permission of instructor. Not offered 1995–96. To be offered 1996–97.
Directed and undirected graphs. Bipartite graphs. Hamilton cycles and Euler tours. Connectedness, matching, and coloring. Flows in capacity-constrained networks. Maximum flow and minimum cost flow problems.]

OR&IE 634 Combinatorial Optimization
Fall. 3 credits. Prerequisite: permission of instructor.
Topics in combinatorics, graphs, and networks, including matching, matroids, polyhedral combinatorics, and optimization algorithms. Topics change each semester. This course may be taken more than once for credit.

OR&IE 635 Interior-Point Methods for Mathematical Programming
Fall. 3 credits. Prerequisites: Math 411 and OR&IE 630, or permission of instructor.
Interior-point methods arising from Karmarkar's Algorithm. Application to linear and quadratic programming and the linear complementarity problem. Projective-scaling, affine-scaling, path-following, and potential-reduction methods.

[OR&IE 636 Integer Programming
Fall. 3 credits. Prerequisite: OR&IE 630. Not offered 1995–96. To be offered 1996–97.
Discrete optimization. Linear programming in which the variables must assume integral values. Theory, algorithms, and applications. Cutting-plane and enumerative methods, with additional topics drawn from recent research in this area.]

OR&IE 639 Polyhedral Convexity
Spring. 3 credits. Prerequisite: basic knowledge of linear algebra.
A comprehensive introduction to the geometry and combinatorics of polyhedral convex sets. Linear inequalities, supporting and separating hyperplanes. Polarity. Convex hulls, facets, and vertices. Face lattices. Convex cones and polytopes. Minkowski sums. Gale transforms. Simplicial and polyhedral subdivision. Applications to linear programming, combinatorial optimization, and computational geometry.

OR&IE 650 Applied Stochastic Processes
Fall. 4 credits. Prerequisite: a one-semester calculus-based probability course.
An introduction to stochastic processes that presents the basic theory together with a variety of applications. Topics include Markov processes, renewal theory, random walks, branching processes, Brownian motion, stationary processes, martingales, and point processes.

OR&IE 651 Probability
Spring. 4 credits. Prerequisite: Real analysis at the level of Math 413 and a previous one-semester course in calculus-based probability.
Sample spaces, events, sigma fields, probability measures, set induction, independence, random variables, expectation, review of important distributions and transformation techniques, convergence concepts, laws of large numbers and asymptotic normality, conditioning.

[OR&IE 662 Advanced Stochastic Processes
Fall. 3 credits. Prerequisite: OR&IE 651 or equivalent. Not offered 1995–96. To be offered 1996–97.
Brownian motion, martingales, Markov processes, and topics selected from: diffusions, stationary processes, point processes, weak convergence for stochastic processes and applications to diffusion approximations, Lévy processes, regenerative phenomena, random walks, and stochastic integrals.]

OR&IE 663 Time-Series Analysis
Fall. 3 credits. Prerequisite: OR&IE 650 or equivalent.
Representations of stationary time series. The ARIMA models. Spectral analysis. Long-range dependence. Problems of estimation. Multivariate time series.

OR&IE 670 Statistical Principles
Fall. 4 credits. Co-requisite: OR&IE 650 or equivalent.
Review of distribution theory of special interest in statistics: normal, chi-square, binomial, Poisson, t, and F; introduction to statistical decision theory; sufficient statistics; theory of minimum variance unbiased point estimation; maximum likelihood and Bayes estimation; basic principles of hypothesis testing, including Neyman-Pearson Lemma and likelihood ratio principle; confidence interval construction; introduction to linear models.

OR&IE 671 Intermediate Applied Statistics
Spring. 3 credits. Prerequisite: OR&IE 670 or equivalent.
Statistical inference based on the general linear model; least-squares estimators and their optimality properties; likelihood ratio tests and corresponding confidence regions; simultaneous inference. Applications in regression analysis and ANOVA models. Variance components and mixed models. Use of the computer as a tool for statistics is stressed.

OR&IE 672 Selected Topics in Environmental Statistics (also BTRY 672)
Fall, spring. 2 credits. Prerequisite: ENGR 270 or equivalent.
For description, see Biometry 672.

OR&IE 676 Statistical Analysis of Life Data
Fall. 3 credits. Prerequisite: OR&IE 671 or equivalent.
Analysis of data from reliability, fatigue, and life-testing studies in engineering; biomedical applications. Survival distributions, hazard rate, censoring. Life tables. Estimation and hypothesis testing. Standards. Goodness of fit, hazard plotting. Covariance analysis, accelerated life testing. Multiple decrement models, competing risks. Sample-size determination. Adaptive sampling.

OR&IE 678 Asymptotic Methods in Statistics
Fall. 3 credits. Prerequisite: OR&IE 670 or Mathematics 574.
Topics chosen from: large-sample behavior of MLEs and other estimates; chi-square, likelihood ration, and related tests; Pitman and Bahadur efficiency; LAN families and LAM estimates; statistical applications of Edgeworth expansions; adaptive estimation and semiparametric inference, rank statistics, EDF and sample quantiles, nonparametric estimation, and smoothing.

[OR&IE 680 Simulation
Spring. 4 credits. Prerequisite: permission of instructor. Not offered 1995–96. To be offered 1996–97.
An advanced version of OR&IE 580, intended for Ph.D.-level students.]

OR&IE 728–729 Selected Topics in Applied Operations Research
Fall, spring. Credit to be arranged.
Current research topics dealing with applications of operations research.

OR&IE 738–739 Selected Topics in Mathematical Programming
Fall, spring. Credit to be arranged.
Current research topics in mathematical programming.

OR&IE 768–769 Selected Topics in Applied Probability
Fall, spring. Credit to be arranged.
Topics are chosen from current literature and research areas of the staff.

OR&IE 778–779 Selected Topics in Applied Statistics
Fall, spring. Credits to be arranged.
Topics chosen from current literature and research of the staff.

OR&IE 790 Special Investigations
Fall, spring. Credit to be arranged.
For individuals or small groups. Study of special topics or problems.

OR&IE 799 Thesis Research
Fall, spring. Credit to be arranged.
For individuals doing thesis research for master's or doctoral degrees.

OR&IE 891 Operations Research Graduate Colloquium
Fall, spring. 1 credit.
A weekly 1-1/2 hour meeting devoted to presentations by distinguished visitors, by faculty members, and by advanced graduate students on topics of current research in the field of operations research.

OR&IE 893–894 Applied OR&IE Colloquium (also M&AE 594)
893, fall; 894, spring. 1 credit each term.
A weekly meeting for Master of Engineering students. Discussion of various topics on manufacturing with faculty members and outside speakers.

THEORETICAL AND APPLIED MECHANICS

Basics in Engineering Mathematics and Mechanics

[T&AM 123 Sensors and Actuators (also Engr 123)
Fall. 3 credits. Not offered 1995–96.
For description, see Engineering Common Courses.]

T&AM 181 Structures and Machines in Urban Society (also Engr 181)
Fall. 3 credits.
For description, see Engineering Common Courses.

T&AM 202 Mechanics of Solids (also ENGRD 202)
Fall, spring. 3 credits.
For description, see Engineering Common Courses.

T&AM 203 Dynamics (also ENGRD 203)
Fall, spring. 3 credits. Prerequisite: T&AM 202, coregistration in Mathematics 294, or permission of instructor.
For description, see Engineering Common Courses.

Engineering Mathematics

T&AM 191 Calculus for Engineers (also Mathematics 191)
Fall. 4 credits. Limited to 25 students per section. Prerequisite: 3 years of high school mathematics, including trigonometry.
Plane analytic geometry, differential and integral calculus, and applications.

[T&AM 192 Calculus for Engineers (also Mathematics 192)
Fall, spring, or summer. 4 credits. Prerequisite: Mathematics/T&AM 191. Not offered 1995–96.
Methods of integration, hyperbolic functions, polar coordinates, infinite series, complex numbers, introduction to partial derivatives, introduction to surface and volume integrals.]

T&AM 293 Engineering Mathematics (also MATH 293)
Fall, spring. 4 credits. Prerequisites: Mathematics/T&AM 192 plus a knowledge of computer programming equivalent to that taught in Engineering Common Courses 100. In exceptional circumstances, Mathematics 192 and 293 may be taken concurrently.
Introduction to physical vectors, linear algebra and matrix theory, inner product spaces. May include computer use in solving problems.

T&AM 294 Engineering Mathematics (also MATH 294)
Fall, spring. 4 credits. Prerequisite: Mathematics/T&AM 293.
Systems of linear ordinary differential equations, introduction to orindary differential equations. Vector fields and vector calculus. Introduction to boundary-value problems and Fourier series. May include computer use in solving problems.

T&AM 310 Advanced Engineering Analysis I
Fall, spring. 3 credits. Prerequisite: Mathematics/T&AM 294 or equivalent.
Special functions, initial value, boundary value, and eigenvalue problems in linear partial differential equations; introduction to nonlinear ordinary differential equations. Use of computer algebra to solve problems. Introduction to probability and statistics.

T&AM 311 Advanced Engineering Analysis II
Spring. 3 credits. Prerequisite: Mathematics/T&AM 293 or equivalent (T&AM 311 can be taken without T&AM 310).
Introduction to complex variable theory. Cauchy's Integral theorem, Laurent series, Classification of singularities, Method of Residues. Applications include conformal mapping (Laplace equation), Laplace transform, Fourier transform, Fourier series, Transfer function, Solution and stability of Linear Systems, Fast Fourier Transform. Examples are drawn from fluid mechanics, heat transfer, electromagnetics, and elasticity.

T&AM 610 Methods of Applied Mathematics I
Fall. 3 credits. Intended for beginning graduate students in engineering and science. An intensive course, requiring more time than is normally available to undergraduates (see T&AM 310–311) but open to exceptional undergraduates with permission of instructor.
Emphasis is on applications. Linear algebra, calculus of several variables, vector analysis, series, ordinary differential equations, complex variables.

T&AM 611 Methods of Applied Mathematics II
Spring. 3 credits. Prerequisite: T&AM 610 or equivalent.
Emphasis on applications. Partial differential equations, transform techniques, tensor analysis, calculus of variations.

T&AM 612 Methods of Applied Mathematics III

Fall. 3 credits. Prerequisite: T&AM 610 or 611 or equivalent. Offered alternate years. First of a 6-credit sequence (T&AM 612 and 613) that develops advanced mathematical techniques for engineers and applied physicists.

Review of complex variable theory, conformal mapping, special functions, integral transform, Wiener-Hopf technique, and singular integral equations. Problems drawn from electromagnetics, elasticity, fluid mechanics, heat transfer, and acoustics.

T&AM 613 Methods of Applied Mathematics IV

Spring. 3 credits. Prerequisite: T&AM 612 or equivalent. Offered alternate years.

Topics include asymptotic behavior of solutions of linear and nonlinear ODE (e.g., the WKB and multiple-scale methods), asymptotic expansion of integrals (method of steepest descent, stationary phase and Laplace methods). Regular and singular perturbation methods for PDE (e.g., method of composite expansions). Other topics (depending on instructor) may include normal forms, center manifolds, Liapunov-Schmidt reductors, Stokes phenomenon. The course may also include computer algebra (MACSYMA) exercises at the option of the instructor.

[T&AM 614 Topics in Applied Mathematics V

Fall. 3 credits. Prerequisites: T&AM 610–613 or equivalent. Offered alternate years. Not offered 1995–96.

Topics such as nonlinear wave motion, bifurcation theory, or computer algebra will be covered, depending on the instructor and student interest.]

[T&AM 615 Topics in Applied Mathematics VI

Spring. 3 credits. Prerequisites: T&AM 610–613 or equivalent. Offered alternate years. Not offered 1995–96.

See T&AM 613 for description.]

Continuum Mechanics

T&AM 501 Topics in Composites I

Fall. 1 to 3 credits (1 credit each topical minicourse)

Analysis of Composite Structures (T. J. Healey)

Linear analysis of thin structural members possessing anisotropic material properties relevant to a composite. Focus on analysis, rather than on modeling or design. Topics include: (1) analysis of rodes, beams, and sandwich beams; (2) analysis of thin, orthotropic plates; and (3) analysis of thin orthotropic cylindrical shells. Grading may be based on homework and a short final examination.

Biological Composites I (J. T. Jenkins)

Overview of the microstructural features and the origin of mechanical properties of bone and soft tissues, such as tendon, ligament, muscle, and skin, and outline of their use as structural components. Survey of design principles for composite materials that mimic those found in biological systems. Final grade determined by the student's in-class presentation on a relevant topic.

Design Principles for Composite Structures (R. H. Lance)

A review of thermo-mechanical behavior of anisotropic, orthotropic, and transversely isotropic materials. Includes development of pertinent equations for laminated materials and sandwich structures. Application is made to the design and analysis of rods, beams, tubs, and plates. Examples drawn from space structures.

Mechanical Testing of Composite Constituents (P. Petrina)

Focuses on the theoretical and experimental characterization of strength and life of advanced composite constituents and materials. Reviews test methods, specimen preparation, testing, data reduction, and analysis. Perform laboratory experiments to determine short-term strength distribution of fiber material, and the evaluation of interface and life strength.

Reliability Models for Composites (S. L. Phoenix)

Surveys statistical models for the strength of fibers, fiber bundles, and composites with emphasis on reliability assessment. Features include the roles of the Weibull distribution, size effects, and the micromechanics of stress transfer around fiber breaks. Time-dependent failure in fatigue is considered as an extension involving matrix creep and interface debonding. Grades are based on several homework tasks.

T&AM 502 Topics in Composites II

Spring. 1 to 3 credits (1 credit each topical minicourse)

Design and Manufacturing of Laminated Composites (P. Petrina)

Students learn to manufacture and to perform analysis and design of laminated composite structures. Practical applications will include manufacturing and analysis of bars, tubes, sandwich beams, and plates. Each student will have a chance to make several types of composite structures and have access to software for the analysis.

Nondestructive Testing of Composites (W. Sachse)

Overview of nondestructive testing techniques that are used to monitor composite material-fabrication procedures to determine the mechanical properties of composite specimens and to assess the integrity of composite structural components. A survey of current NDT research. Topics include (1) goals and problems of NDT/NDE measurements in composites, (2) survey of NDT technologies applicable to measurements in composites, (3) active (UT) and passive (AE) ultrasonic NDT measurements in composite materials, and (4) developments and directions of NDT research applicable to composite materials evaluation. Grade based on laboratory work and a written response to a specific composite NDT problem.

T&AM 555 Introduction to Composite Materials (also M&AE 555 & MS&E 555)

Fall. 4 credits.

Introduction to composite materials: varieties of reinforcements, matrix materials, and their properties. Mechanics and failure analysis of lamina, laminates, and wound structures. Introduction to micromechanics theories of composites, manufacturing methods, fabrication and assembly techniques, composite applications, environmental effects.

[T&AM 569 Sensors

Fall. 3 credits. Not offered 1995–96.

This course deals with the general properties of sensors and actuators used in measurement and process-control applications involving thermal and mechanical quantities. Considered are sensors and actuators based on a broad range of physical transduction phenomena. Attention is given to the development of sensor models and criteria for evaluating the general performance characteristics of a sensor, including its transduction characteristics and its measurement field. Also studied are algorithms for processing sensor signals to recover the characteristics of the sensor or to remove its effect in a specific measurement application. An integral part of the course is the Sensors Laboratory, which provides students with hands-on opportunities for measuring the characteristics and operational parameters of a broad range of thermo-mechanical sensors.]

T&AM 591 Master of Engineering Design Project I

Fall. 3–6 credits.

M. Eng. (Mechanics) project related to the mechanics of advanced composites and structures.

T&AM 592 Master of Engineering Design Project II

Spring. 5–15 credits.

M. Eng. (Mechanics) project related to the mechanics of advanced composites and structures.

[T&AM 655 Advanced Composite Materials and Structures (also M&AE 655)

Spring. 4 credits. Not offered 1995–96.

Advanced mechanics of composite materials. Strength theory of continuous- and discontinuous-reinforced composites. Micromechanics, interface mechanics, modes of failure, creep rupture. Mechanics of strcutural components. Design and analysis of composite structures: pressure vessels, aerospace structures, thick composites, and plates. Adhesive bonding and mechanical fastening. Dynamic effects and hygrothermal effects.]

T&AM 663 Solid Mechanics I

Fall. 4 credits.

Rigorous introduction to small-strain solid mechanics with emphasis on linear elasticity; stress, strain, tensors, balance laws, energy principles, general theory of linear elasticity, and solutions of elementary boundary-value problems.

T&AM 664 Solid Mechanics II

Spring. 4 credits. Prerequisites: Mathematics 610 and T&AM 663, or equivalent.

Preparation for advanced courses in solid mechanics. Singular solutions in linear elasticity, large deformations, nonlinear elasticity, linear visco-elasticity, mechanics of defects (cracks and dislocations), classical plasticity, and constitutive relations.

T&AM 751 Continuum Mechanics and Thermodynamics

Fall. 3 credits. Prerequisites: T&AM 610 and 611; and 663 and 664 or equivalents. Offered alternate years.

Kinematics, conservation laws, the entropy inequality, constitutive equations, frame indifference, material symmetry. Rate-dependent materials and materials with internal variables.

[T&AM 752 Nonlinear Elasticity
Fall. 3 credits. Prerequisites: T&AM 610 and 611; and 663 and 664 or equivalents. Offered alternate years. Not offered 1995–96.
Review of kinematics and constitutive theory appropriate for large deformations of nonlinearly elastic bodies. The basic field equations of nonlinear elastostatics and elastodynamics. Exact solutions of special problems. Linearization and stability. Nonlinear theories of thin structural members and their relationship to the three-dimensional theory. Introduction to static bifurcation theory with applications to strings, rods, plates, and shells.]

T&AM 753 Fracture
Fall. 3 credits. Prerequisites: T&AM 610 or 611; and 663 and 664 or equivalents. Offered alternate years.
Topics will be selected from (1) elastic fracture mechanics: K, small-scale yielding, solutions of elastic crack problems; (2) nonlinear rate-independent, small-deformation fracture mechanics: plastic fracture, J-integral, small-scale yielding; (3) rate-dependent fracture mechanics: dynamic fracture, creep fracture; (4) mechanics of failure in polymers, ceramics, composites, and metals: void growth, load transfer between fibers, crazing.

T&AM 757 Inelasticity
Spring. 3 credits. Prerequisites: T&AM 610 and 611; and 663 and 664 or equivalents. Offered alternate years.
Inelasticity; plasticity, visco-elasticity, and modern nonlinear theories. Plasticity: general principles, limit analysis, and boundary value problems. Visco-elasticity: general principles and solution of boundary value problems. Modern state variable theories: their relation to classical theories, their phenomenology, and use in solving boundary value problems.

[T&AM 759 Computational Methods
Fall. 4 credits. Prerequisites: T&AM 610 and 611; and 663 and 664 or equivalents. Offered alternate years. Not offered 1995–96.
The aim of this course is to survey a wide range of applications of the boundary element method (BEM) and finite element method (FEM) in solid mechanics. The boundary element method will be introduced and then be used in problems in linear elasticity, diffusion, wave propagation, and problems with material and/or geometric nonlinearities. Finite-element applications will emphasize nonlinear problems in solid mechanics.]

T&AM 768 Elastic Waves
Fall. 3 credits. Prerequisites: T&AM 610 or 611; and 663 and 574 or equivalents. Offered alternate years.
An advanced course on dynamic stress analysis and wave propagation in elastic solids. Theory of elastodynamics. Waves in isotropic and anisotropic media. Reflection and refraction. Surface waves and waves in layered media. Transient waves and methods of Lamb-Cagniard-Pakeris. Thick-plate theories. Vibration of spheres. Scattering of waves and dynamic stress concentration.

Dynamics and Space Mechanics

T&AM 570 Intermediate Dynamics
Fall. 3 credits. 2 lecs.
Newtonian mechanics; motion in rotating coordinate systems. Introduction to analytical mechanics; virtual work, Lagrangian mechanics. Hamilton's principle. Small vibration and stability theory. Newtonian-Eulerian mechanics of rigid bodies. Gyroscopes.

[T&AM 574 Vibrations and Waves in Elastic Systems (also M&AE 577)
Spring. 4 credits. Prerequisites: T&AM 570 and 610. Not offered 1995–96.
Oscillations and one- and two-degree-of-freedom vibrating systems. General properties of vibrating systems. Modal analysis. Vibration of continuous systems. Elementary nonlinear systems and chaos. Characterization of vibrating systems. Measurements and applications. Two vibrations laboratory experiments.]

T&AM 578 Nonlinear Dynamics and Chaos
Spring. 3 credits. Prerequisite: Mathematics/T&AM 293 or equivalent.
Introduction to nonlinear dynamics, with applications to physics, engineering, biology and chemistry. Emphasizes analytical methods, concrete examples, and geometric thinking. Topics: One-dimensional systems. Bifurcations. Phase plane. Nonlinear oscillators. Lorenz equations, chaos, strange attractors, fractals, iterated mappings, period doubling, renormalization.

[T&AM 671 Advanced Dynamics
Spring. 3 credits. Prerequisite: T&AM 570 or equivalent. Offered alternate years. Not offered 1995–96.
Review of Lagrangian mechanics; Hamilton's principle, the principle of least action, and related topics from the calculus of variations; Hamilton's canonical equations; approximate methods for two-degrees-of-freedom systems (Lie transforms); canonical transformations and Hamilton-Jacobi theory; KAM theory.]

[T&AM 672 Celestial Mechanics (also Astronomy 579)
Spring. 3 credits. Offered alternate years. Not offered 1995–96.
Description of orbits; 2-body, 3-body, and n-body problems; Hill curves, libration points and their stability; capture problems; virial theorem. Osculating elements, perturbation equations; effects of gravitational potentials, atmospheric drag, and solar radiation forces on satellite orbits; secular perturbations, resonances, mechanics of planetary rings.]

T&AM 673 Mechanics of the Solar System (also Astronomy 571)
Spring. 3 credits. Prerequisite: an undergraduate course in dynamics. Offered alternate years.
Gravitational potentials, planetary gravity fields. Free and forced rotations. Chandler wobble, polar wander, damping of nutation. Equilibrium tidal theory, tidal heating. Orbital evolution of natural satellites, resonances, spin-orbit coupling, Cassini states. Long-term variations in planetary orbits. Dust dynamics. Dynamics of ring systems. Physics of interiors, seismic waves, free oscillations. Illustrative examples are drawn from contemporary research.

T&AM 675 Nonlinear Vibrations
Fall. 3 credits. Prerequisite: T&AM 578 or equivalent. Offered alternate years.
Quantitative analysis of weakly nonlinear systems in free and forced vibrations, perturbation methods, averaging method. Applications to problems in mechanics, physics, and biology. Additional topics may include Hopf bifurcation, Invariant manifolds, coupled oscillators, vibrations in continuous media, normal forms, and exploitation of symmetry.

[T&AM 776 Applied Dynamical Systems
Not offered 1995–96.
For description, see MATH 617.]

Special Courses, Projects, and Thesis Research

T&AM 491–492 Project in Engineering Science
491, fall; 492, spring. 1–4 credits, as arranged.
Projects for undergraduates under the guidance of a faculty member.

T&AM 796–800 Topics in Theoretical and Applied Mechanics
Fall, spring. 1–3 credits, as arranged.
Special lectures or seminars on subjects of current interest. Topics are announced when the course is offered.

T&AM 890 Master's Degree Research in Theoretical and Applied Mechanics
Fall, spring. 1–15 credits, as arranged. S-U grades optional.
Thesis or independent research at the M.S. level on a subject of theoretical and applied mechanics. Research is under the guidance of a faculty member.

T&AM 990 Doctoral Research in Theoretical and Applied Mechanics
Fall, spring. 1–15 credits, as arranged. S-U grades optional.
Thesis or independent research at the Ph.D. level on a subject of theoretical and applied mechanics. Research is under the guidance of a faculty member.

FACULTY ROSTER

Abel, John F., Ph.D., U. of California at Berkeley. Prof., Civil and Environmental Engineering
Albright, Louis D., Ph.D., Cornell U. Prof., Agricultural and Biological Engineering
Allmendinger, Richard, Ph.D., Stanford U. Assoc. Prof., Geological Sciences
Aneshansley, Daniel J., Ph.D., Cornell U. Assoc. Prof., Agricultural and Biological Engineering
Anton, A. Brad, Ph.D., California Inst. of Technology. Assoc. Prof., Chemical Engineering
Ast, Dieter G., Ph.D., Cornell U. Prof., Materials Science and Engineering
Attoh, K., Ph.D., Northwestern U., Assoc. Prof., Geological Sciences
Auer, Peter L., Ph.D., California Inst. of Technology. Prof., Mechanical and Aerospace Engineering
Avedisian, C. Thomas, Ph.D., Princeton U. Prof., Mechanical and Aerospace Engineering
Ballantyne, Joseph M., Ph.D., Massachusetts Inst. of Technology. Prof., Electrical Engineering
Barazangi, Muawia, Ph.D., Columbia U. Senior Scientist, Geological Sciences
Bartel, Donald L., Ph.D., U. of Iowa. Prof., Mechanical and Aerospace Engineering
Bartsch, James A., Ph.D., Purdue U. Assoc. Prof., Agricultural and Biological Engineering
Bassett, William A., Ph.D., Columbia U. Prof., Geological Sciences

Batterman, Boris W., Ph.D., Massachusetts Inst. of Technology. Walter S. Carpenter, Jr. Professorship in Engineering, Applied and Engineering Physics
Berger, Toby, Ph.D., Harvard U. J. Preston Levis Professor of Engineering, Electrical Engineering
Billera, Louis J., Ph.D., City U. of New York. Prof., Operations Research and Industrial Engineering
Bird, John M., Ph.D., Rensselaer Polytechnic Inst. Prof., Geological Sciences
Birman, Kenneth P., Ph.D., U. of California at Berkeley. Prof., Computer Science
Bisogni, James J., Ph.D., Cornell U. Assoc. Prof., Civil and Environmental Engineering
Blakely, John M., Ph.D., Glasgow U. (Scotland). Prof., Materials Science and Engineering
Bland, Robert G., Ph.D., Cornell U. Prof., Operations Research and Industrial Engineering
Bloom, Arthur L., Ph.D., Yale U. Prof., Geological Sciences
Bloom, Bard, Ph.D., Massachusetts Inst. of Technology. Asst. Prof., Computer Science
Bojanczyk, Adam W., Ph.D., U. of Warsaw (Poland). Assoc. Prof., Electrical Engineering.
Booker, John F., Ph.D., Cornell U. Prof., Mechanical and Aerospace Engineering
Boyd, Iain, Ph.D., U. of Southampton (England). Asst. Prof., Mechanical and Aerospace Engineering
Brock, Joel D. Ph.D., Massachusetts Inst. of Technology. Asst. Prof., Applied and Engineering Physics
Brown, Geoffrey M., Ph.D., U. of Texas. Assoc. Prof., Electrical Engineering
Brown, Larry D., Ph.D., Cornell U. Prof., Geological Sciences
Brutsaert, Wilfried H., Ph.D., U. of California at Davis. Prof., Civil and Environmental Engineering
Buhrman, Robert A., Ph.D., Johns Hopkins U. John Edson Sweet Professor of Engineering, Applied and Engineering Physics
Burns, Joseph A., Ph.D., Cornell U. Irving Porter Church Professor in Engineering, Theoretical and Applied Mechanics
Cady, K. Bingham, Ph.D., Massachusetts Inst. of Technology. Prof., Theoretical and Applied Mechanics
Capps, Susan G., Ph.D., North Carolina State U. Asst. Prof., Agricultural and Biological Engineering
Cardie, Claire T., Ph.D. U. of Massachusetts at Amherst. Asst. Prof., Computer Sciences
Cathles, Lawrence M. III, Ph.D., Princeton U. Prof., Geological Sciences
Caughey, David A., Ph.D., Princeton U. Prof., Mechanical and Aerospace Engineering
Chiang, Hsiao-Dong, Ph.D., U. of California at Berkeley. Assoc. Prof., Electrical Engineering
Cisne, John L., Ph.D., U. of Chicago. Prof., Geological Sciences
Clancy, Paulette, Ph.D., Oxford U. (England). Assoc. Prof., Chemical Engineering
Clark, David D., Ph.D., U. of California at Berkeley. Prof., Engineering
Cohen, Claude, Ph.D., Princeton U. Prof., Chemical Engineering
Coleman, Thomas F., Ph.D., U. of Waterloo. Prof., Computer Science
Compton, Richard C., Ph.D., California Inst. of Technology. Assoc. Prof., Electrical Engineering
Constable, Robert L., Ph.D., U. of Wisconsin. Prof., Computer Science
Cooke, J. Robert, Ph.D., North Carolina State U. Prof., Agricultural and Biological Engineering
Cool, Terrill A., Ph.D., California Inst. of Technology. Prof., Applied and Engineering Physics
Craighead, Harold G., Ph.D., Cornell U. Prof., Applied and Engineering Physics, and Electrical Engineering
Datta, Ashim K., Ph.D., U. of Florida. Assoc. Prof., Agricultural and Biological Engineering
Dawson, Paul R., Ph.D., Colorado State U. Prof., Mechanical and Aerospace Engineering
deBoer, P. Tobias, Ph.D., U. of Maryland. Prof., Mechanical and Aerospace Engineering
Deierlein, Gregory G., Ph.D., U. of Texas at Austin. Assoc. Prof., Civil and Environmental Engineering
Delchamps, David F., Ph.D., Harvard U. Assoc. Prof., Electrical Engineering
Derksen, Richard C., Ph.D., U. of Illinois. Asst. Prof., Agricultural and Biological Engineering
Dick, Richard I., Ph.D., U. of Illinois. Joseph P. Ripley Professor of Engineering, Civil and Environmental Engineering
Dieckmann, Rudiger, Ph.D., Technical U. of Clausthal. Prof., Materials Science and Engineering
Donald, Bruce, Ph.D., Massachusetts Inst. of Technology. Assoc. Prof., Computer Science
Duncan, Michael, Ph.D., California Inst. of Technology. Assoc. Prof., Chemical Engineering
Eastman, Lester F., Ph.D., Cornell U. Given Foundation Professor of Engineering, Electrical Engineering
Engstrom, James R., Ph.D., California Inst. of Technology. Asst. Prof., Chemical Engineering
Farley, Donald T., Ph.D., Cornell U. Prof., Electrical Engineering
Fine, Terrence L., Ph.D., Harvard U. Prof., Electrical Engineering
Fisher, Elizabeth M., Ph.D., U. of California at Berkeley. Asst. Prof., Mechanical and Aerospace Engineering
Fleischmann, Hans H., Ph.D., Technische Hoch., München (Germany). Prof., Applied and Engineering Physics
Furry, Ronald B., Ph.D., Iowa State U. Prof., Agricultural and Biological Engineering
Gaeta, Alexander L., Ph.D., U. of Rochester. Asst. Prof., Applied and Engineering Physics
Gebremedhin, Kifle G., Ph.D., U. of Wisconsin. Assoc. Prof., Agricultural and Biological Engineering
George, Albert R., Ph.D., Princeton U. John F. Carr Prof. of Mechanical Engineering, Mechanical and Aerospace Engineering
Gergely, Peter, Ph.D., U. of Illinois. Prof., Civil and Environmental Engineering
Giannelis, Emmanuel, Ph.D., Michigan State U. Assoc. Prof., Materials Science and Engineering
Gossett, James M., Ph.D., Stanford U. Prof., Civil and Environmental Engineering
Gouldin, Frederick C., Ph.D., Princeton U. Prof., Mechanical and Aerospace Engineering
Gries, David J., Ph.D., Technische Hoch., München (Germany). William L. Lewis Prof. of Engineering, Computer Science
Grigoriu, Mircea D., Ph.D., Massachusetts Inst. of Technology. Prof., Civil and Environmental Engineering
Grubb, David T., Ph.D., Oxford U. (England). Assoc. Prof., Materials Science and Engineering
Gubbins, Keith E., Ph.D., U. of London (England). Thomas R. Briggs Professor of Engineering, Chemical Engineering
Guckenheimer, John, Ph.D., U. of California at Berkeley. Prof., Mathematics and Theoretical and Applied Mechanics
Haith, Douglas A., Ph.D., Cornell U. Prof., Agricultural and Biological Engineering
Hammer, Daniel A., Ph.D., U. of Pennsylvania. Assoc. Prof., Chemical Engineering
Hammer, David A., Ph.D., Cornell U. J. Carlton Ward Sr. Prof. of Electrical Engineering
Harriott, Peter, Sc.D., Massachusetts Inst. of Technology. Fred H. Rhodes Professor of Chemical Engineering
Hartmanis, Juris, Ph.D., California Inst. of Technology. Walter R. Read Professor of Computer Science
Healey, Timothy J., Ph.D., U. of Maryland. Assoc. Prof., Theoretical and Applied Mechanics
Heath, David C., Ph.D., U. of Illinois. Prof., Operations Research and Industrial Engineering
Heegard, Chris, Ph.D., Stanford U. Assoc. Prof., Electrical Engineering
Hemami, Sheila, Ph.D., Stanford U. Asst. Prof., Electrical Engineering
Henzinger, Thomas A., Stanford U. Asst. Prof., Computer Science
Henzinger, Monika R., Ph.D., Princeton U. Asst. Prof., Computer Science
Hopcroft, John E., Ph.D., Stanford U. Joseph Silbert Dean of Engineering, Prof., Computer Science
Hover, Kenneth C., Ph.D., Cornell U. Prof., Civil and Environmental Engineering
Hui, Chung Y., Ph.D., Harvard U. Prof., Theoretical and Applied Mechanics
Hunter, Jean B., Ph.D., Columbia U. Assoc. Prof., Agricultural and Biological Engineering
Huttenlocher, Daniel, Ph.D., Massachusetts Inst. of Technology. Assoc. Prof., Computer Science
Ingraffea, Anthony R., Ph.D., U. of Colorado. Dwight C. Baum Prof. of Engineering, Civil and Environmental Engineering
Irwin, Lynne H., Ph.D., Texas A & M U. Assoc. Prof., Agricultural and Biological Engineering
Isaacson, Michael S., Ph.D., U. of Chicago. Prof., Applied and Engineering Physics
Isacks, Bryan L., Ph.D., Columbia U. William and Katherine Snee Prof. of Geological Sciences
Jackson, Peter L., Ph.D., Stanford U. Assoc. Prof., Operations Research and Industrial Engineering
Jelinski, Lynn W., Ph.D., U. of Hawaii. Prof., Engineering
Jenkins, James T., Ph.D., Johns Hopkins U. Prof., Theoretical and Applied Mechanics
Jewell, William J., Ph.D., Stanford U. Prof., Agricultural and Biological Engineering
Jirka, Gerhard H., Ph.D., Massachusetts Inst. of Technology. Prof., Civil and Environmental Engineering
Johnson, C. Richard, Jr., Ph.D., Stanford U. Prof., Electrical Engineering
Jordan, Teresa, Ph.D., Stanford U. Assoc. Prof., Geological Sciences

Karig, Daniel E., Ph.D., U. of California at San Diego. Prof., Geological Sciences
Kay, Robert W., Ph.D., Columbia U. Prof., Geological Sciences
Kay, Suzanne M., Ph.D., Brown U. Assoc. Prof., Geological Sciences
Kelley, Michael C., Ph.D., U. of California at Berkeley. Prof., Electrical Engineering
Kintner, Paul M., Ph.D., U. of Minnesota. Prof., Electrical Engineering
Kline, Ronald R., Ph.D., U. of Wisconsin. Assoc. Prof., Electrical Engineering (History of Technology)
Koch, Donald L., Ph.D., Massachusetts Inst. of Technology. Assoc. Prof., Chemical Engineering
Kostroun, Vaclav O., Ph.D., U. of Oregon. Assoc. Prof., Applied and Engineering Physics
Kozen, Dexter, Ph.D., Cornell U. Joseph Newton Pew, Jr. Professor in Engineering, Computer Science
Kramer, Edward J., Ph.D., Carnegie Inst. of Technology. Samuel B. Eckert Prof. of Materials Science and Engineering
Krusius, J. Peter, Ph.D., Helsinki U. of Technology (Finland). Prof., Electrical Engineering
Kulhawy, Fred H., Ph.D., U. of California at Berkeley. Prof., Civil and Environmental Engineering
Kusse, Bruce R., Ph.D., Massachusetts Inst. of Technology. Prof., Applied and Engineering Physics
Lance, Richard H., Ph.D., Brown U. Prof., Theoretical and Applied Mechanics
Leeser, Miriam E., Ph.D., U. of Cambridge, England. Asst. Prof., Electrical Engineering
Leibovich, Sidney, Ph.D., Cornell U. Samuel B. Eckert. Prof. of Mechanical and Aerospace Engineering
Li, Che-Yu, Ph.D., Cornell U. Francis Norwood Bard Professor, Materials Science and Engineering
Liboff, Richard L., Ph.D., New York U. Prof., Electrical Engineering
Liggett, James A., Ph.D., Stanford U. Prof., Civil and Environmental Engineering
Lion, Leonard W., Ph.D., Stanford U. Assoc. Prof., Civil and Environmental Engineering
Liu, Philip L.-F., Sc.D., Massachusetts Inst. of Technology. Prof., Civil and Environmental Engineering
Lo, Yu-hwa, Ph.D., U. of California at Berkeley. Asst. Prof., Electrical Engineering
Loucks, Daniel P., Ph.D., Cornell U. Prof., Civil and Environmental Engineering
Louge, Michel Y., Ph.D., Stanford U. Assoc. Prof., Mechanical and Aerospace Engineering
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