Michigan**Engineering**

University of Michigan

College of Engineering

**THE UNIVERSITY OF MICHIGAN BULLETIN**

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# 2001-2002 **Bulletin**

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College of Engineering 2001-2002
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# 2001-2002 Bulletin

## The University of Michigan

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Daniel Little, *Chancellor of the University of Michigan-Dearborn*
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The University of Michigan, as an equal opportunity/affirmative action employer, complies with all applicable federal and state laws regarding nondiscrimination and affirmative action, including Title IX of the Education Amendments of 1972 and Section 504 of the Rehabilitation Act of 1973. The University of Michigan is committed to a policy of nondiscrimination and equal opportunity for all persons regardless of race, sex, color, religion, creed, national origin or ancestry, age, marital status, sexual orientation, disability, or Vietnam-era veteran status in admissions. Inquiries or complaints may be addressed to the University's Director of Affirmative Action and Title IX Section 504 Coordinator, 4005 Wolverine Tower, Ann Arbor, Michigan 48109-1281, (734) 763-0235, TTY (734) 747-1388. For other University of Michigan information call (734) 764-1817.

# ACADEMIC CALENDAR

## University of Michigan–Ann Arbor Campus
## Registrar's Office: 734-764-6280

### Fall Term 2001

| | |
|---|---|
| ***Registration (for students not pre-registered)** | **August 31, Friday** |
| Labor Day (Holiday) | September 3, Monday |
| Classes begin | September 5, Wednesday |
| Thanksgiving recess 5:00 p.m. | November 21, Wednesday |
| Classes resume 8:00 a.m. | November 26, Monday |
| Classes end | December 12, Wednesday |
| Study Days | December 13, Thursday & |
| | December 15-16, Saturday-Sunday |
| **Examinations** | **December 14, Friday &** |
| | **December 17-21, Monday-Friday** |
| Commencement | December 16, Sunday |

### Winter Term 2002

| | |
|---|---|
| ***Registration (for students not pre-registered)** | **January 4, Friday** |
| Classes begin | January 7, Monday |
| Martin Luther King, Jr. Day<br>University Symposia. No Regular Classes | January 21, Monday |
| Vacation begins 12:00 noon | February 23, Saturday |
| Classes resume | March 4, Monday |
| University Honors Convocation | March 17, Sunday |
| Classes end | April 17, Wednesday |
| Study Days | April 18, Thursday & |
| | April 20-21, Saturday-Sunday |
| **Examinations** | **April 19, Friday &** |
| | **April 22-26, Monday-Friday** |
| Commencement Activities | April 26-28, Friday-Sunday |

### Spring/Summer Term 2002

| | |
|---|---|
| ***Registration (Full and Spring Half Terms)** | **April 29, Monday** |
| Classes begin | April 30, Tuesday |
| Memorial Day (Holiday) | May 27, Monday |
| Classes end (Spring Half Term) | June 17, Monday |
| Study Days | June 18-19, Tuesday-Wednesday |
| **Examinations** | **June 20-21, Thursday-Friday** |
| Spring Half Term ends | June 21, Friday |
| Registration (Summer Half Term) | June 25, Tuesday |
| Classes begin (Summer Half Term) | June 26, Wednesday |
| Independence Day (Holiday) | July 4, Thursday |
| Classes end 5:00 p.m. | August 13, Tuesday |
| Study Day | August 14, Wednesday |
| **Examinations** | **August 15-16, Thursday-Friday** |
| Full & Summer Half Terms end | August 16, Friday |

This calendar is subject to change.

## College of Engineering Drop/Add Deadlines 2001-2002 Academic Year

### Fall Term 2001

Fall Term begins, Wednesday, September 5
Fall Term, drop/add pass/fail deadline w/o W's, Tuesday, September 25
Fall Term, drop/add deadline/pass/fail w/o petition, Friday, November 16

First Half Term (7 week course) begins, Wednesday, September 5
First Half Term (7 week course), drop/add/pass/fail deadline w/o W's, Tuesday, September 25
First Half Term (7 week course), drop/add/pass/fail deadline w/o petition, Friday, October 5
First Half Term (7 week course) ends, Friday, October 26

Second Half Term (7 week course) begins, Monday, October 29
Second Half Term (7 week course), drop/add/pass/fail deadline w/o W's, Friday, November 16
Second Half Term (7 week course), drop/add/pass/fail deadline w/o petition, Friday, November 30
Fall Term ends Wednesday, December 21

### Winter Term 2002

Winter Term begins, Monday, January 7
Winter Term, drop/add/pass/fail deadline w/o W's, Friday, January 25
Winter Term, drop/add/pass/fail deadline w/o petition, Friday, March 22

First Half Term (7 week course) begins, Monday, January 7
First Half Term (7 week course), drop/add/pass/fail deadline w/o W's, Friday, January 25
First Half Term (7 week course), drop/add/pass/fail deadline w/o petition, Friday, February 8
First Half Term (7 week course) ends, Friday, February 22

Second Half Term (7 week course) begins, Monday, March 4
Second Half Term (7 week course), drop/add/pass/fail deadline w/o W's, Friday, March 22
Second Half Term (7 week course), drop/add/pass/fail deadline w/o petition, Friday, April 5
Winter Term ends Friday, April 26

### Spring Term 2002

Spring Half begin, Tuesday, April 30
Spring Half, drop/add/pass/fail deadline w/o W's, Monday, May 20
Spring Half, drop/add/pass/fail deadline w/o petition, Friday, June 1
Spring Half Term ends Friday, June 21

### Spring-Summer Term 2002

Spring-Summer Terms begin, Tuesday, April 30
Spring-Summer, drop/add/pass/fail deadline w/o W's, Monday, May 20
Spring-Summer, drop/add/pass/fail deadline w/o petition, Friday, July 12
Spring-Summer Term ends August 16

### Summer Term 2002

Summer Term begins, Wednesday, June 26
Summer Term, drop/add/pass/fail deadline w/o W's, Tuesday, July 16
Summer Term, drop/add/pass/fail deadline w/o petition, Friday, August 2
Summer Term ends August 16

# TABLE OF CONTENTS

# TABLE OF CONTENTS

# TABLE OF CONTENTS

# TABLE OF CONTENTS

# TABLE OF CONTENTS

# LETTER FROM THE PRESIDENT

A commitment to provide a first-rate education to students from a variety of backgrounds is a hallmark of the University of Michigan's academic tradition. Diversity is critical to maintaining a vital intellectual atmosphere where learning and advancement of knowledge flourish.

As you may know, for the past several years Michigan has been at the epicenter of an intense national debate regarding the educational benefits of having a diverse student body. The eventual resolution in the judicial system and the court of public opinion is of great significance to our University, to students, and to the future of higher education in America. My own experiences as a student, a member of the faculty, and a parent, as well as the experiences of others whose views have been expanded through the prism of new ideas and different viewpoints, underpin my conviction that the University must remain a community that embraces difference and variety.

I am pleased that so many alumni/ae and students of this University share my belief that encountering differences, rather than one's mirror image, is an essential part of a high-quality education. Participating in the recent National Survey of Student Engagement, more than 90 percent of Michigan seniors said it is important for them to get along with people from diverse backgrounds and 86 percent responded it is important to understand different cultures.

Maintaining a racially diverse student body is fundamental to achieving our educational objectives: To provide an education that challenges students to become actively engaged in pursuit of understanding — an understanding of society, of the natural world, and of themselves.

Michigan benefits enormously from the wide range of perspectives and talents brought by students, faculty, and staff from a variety of backgrounds. Please join me as we continue to create a community of learning where all thrive, secure in the knowledge that their histories and cultures are valued, and where we all may learn from and develop a deeper appreciation for the viewpoints and contributions of others.

Sincerely,

Lee C. Bollinger
President
University of Michigan

# LETTER FROM THE DEAN

On behalf of the faculty, staff, and students of the College of Engineering, I welcome your interest in the University of Michigan. If you are a potential undergraduate student, you may not be sure if an engineering curriculum is for you. This is not surprising since you probably have not been exposed to engineering in high school, and many in the general public do not know what engineers do or how valuable they are to society. It is not always fully appreciated that an undergraduate engineering degree is an excellent foundation from which to pursue any one of a number of professions besides engineering.

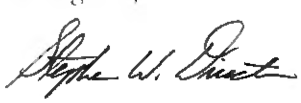
We live in an increasingly complex world, both socially and technically. This means that individuals who are comfortable with technology, and know how to use it, are well prepared for the future no matter what direction their careers take. As a result, an increasing number of students interested in pursuing a career in medicine, law, or business obtain an undergraduate degree in engineering first.

Personally, I like to think of engineering as the application of the principles of basic science in order to improve society and the world we live in. Engineers can best be thought of as creators, innovators, problem solvers, builders, fixers, and leaders. At Michigan we strive to help our students become all these. As an engineering student at Michigan, you will learn how to think logically, deal with uncertainty and change, apply technology in a socially and environmentally responsible manner, communicate effectively, and collaborate with others. You will have many opportunities to develop and use these skills both in and outside the classroom. For example, you may wish to become part of a team involved in a national competition, such as Solar Car, or become involved in one of our nationally recognized student organizations.

If you are considering Michigan for your graduate engineering degree, I am sure you are aware that Michigan is one of the nation's premier "research universities," where we are actively engaged in the creation of new knowledge. Thus, all our students, including undergraduate students, have a unique opportunity to interact with individual faculty who are at the forefront of their fields.

The U-M is a multi-dimensional university noted not only for outstanding technical education, but also for exceptional liberal and fine arts education. As a result, our students have wonderful opportunities to take advantage of this diversity to pursue interests outside of engineering. I'm confident that you will find Michigan exciting, challenging, rewarding, and enjoyable!

Best regards,



Stephen W. Director
Robert J. Vlasic Dean of Engineering

# LETTER FROM THE UMEC PRESIDENT

Dear Classmates,

Our chosen profession is demanding, much like our College and University. It demands responsibility, character, perseverance, dedication, and sometimes a sense of humor. There will be many bumps in the road, and any number of clichés describe the adversity we will face. Many times, mainly while struggling through a homework set in the early hours of morning, I have asked myself "Why did I choose a profession that will be a constant challenge?!" The best answer I can come up with is this: without challenge, anyone could do it, and that is what makes engineering special.

At the College of Engineering, we students are presented many challenging opportunities throughout our careers. Classwork, research, community service, society involvement, a social life — the ways students here take advantage of their tenure here are what make the College of Engineering such a dynamic environment. No matter your desires, I can guarantee you that the opportunity exists within the University and community. You may be asking, "How can I find these opportunities at such a large place?" I would suggest sending my successor or me an e-mail. We may not be able to help with your classwork or social life, but chances are there is a channel we can use to serve your interests.

If I could leave one piece of advice to the students of the College of Engineering from my experiences, I would urge you to seek a school/life balance, and later a work/life balance. We must remember to not be too caught up in one challenge, nor to take on too many challenges at once. The time you take from your busy lifestyle for those close to you and the things important to you will define your character. Make the most of your challenges, study hard, enjoy your career, and please, always remember to have a little fun.

Yours truly,

Bob Krentler
2001 UM Engineering Council (UMEC) President
umec.pres@umich.edu
Electrical Engineering

## The Nature of Engineering

Each scientific discovery compels us to search for something better. The relationship between discovery and application of knowledge grows increasingly intimate in the modern era; therefore, the practical art of engineering has become a little less art and a little more science. Yet, the well-being of humanity remains the professional engineer's primary concern.

Engineers solve real-life problems. They find the best solutions through the application of their combined knowledge, experience, and judgment. Every day of every year, engineers help to define our way of life by providing innovative, higher performance, safer, cleaner, or more comfortable methodologies for more and more people.

Engineers seek improvement through the processes of invention, design, manufacture, and construction. Throughout all of these steps, they continually assess the use of human power and the impact of engineering on society.

The by-products of discovery are sometimes positive, sometimes negative. Water, air, and noise pollution result from the same engineering marvels of decades ago. Even in "benign" engineering, the effects of technology can be challenging, such as the burgeoning need for larger and more efficient information storage and retrieval systems in modern communication.

The engineer's problem-solving approach grows in importance as the world's social and technological problems become more closely related. For example, the problem of air pollution cannot be solved by analyzing the physical causes alone. What social, legal, political, and ethical conflicts does it generate? How will available technological solutions affect individual and group interests and well-being? At the dawn of the 21st century, professional engineers must be attuned to these interrelated dynamics.

In many ways, the study of engineering provides students with the true "liberal education" of our technology-based future—an education which provides the technical understanding and problem-solving skills that will allow an almost unlimited range of opportunities in the complex challenges of tomorrow.

## Michigan Engineering

The University of Michigan College of Engineering is dedicated to preparing its students for the technological leadership of tomorrow. Michigan Engineers have the opportunity to elect courses and participate in research and co-curricular activities that broaden their knowledge and develop their ability to analyze problems and responsibly apply their knowledge to solutions.

The primary objective of the College of Engineering is the preparation of its students for positions of responsibility commensurate with their talents and interests. Students can prepare for a broad range of professional opportunities. According to their aptitudes and desires, students may become practicing engineers, researchers, administrators, or teachers. Moreover, the knowledge and intellectual discipline of engineering have proven to be excellent preparation for non-engineering careers, particularly in business, law, and medicine. Many graduates of the College choose to earn a master's or doctoral degree in engineering. Another opportunity for growth and professional development is available through registration as a professional engineer.

At Michigan, engineering students associate with distinguished faculty who have a solid academic base and broad professional involvement. The College believes that ongoing faculty research and industrial consultation in engineering produces an outstanding faculty. Students benefit from the high caliber of our faculty through lectures and discussions in formal and informal settings, through fundamental scientific investigations in the laboratory, and in practicum-based design projects and applications of scientific knowledge to real-world problems. Graduate and undergraduate students in the College have the opportunity to participate in such activities in the classroom, in well-equipped engineering laboratories, and at a variety of field locations.

## College of Engineering Mission

To be the place of choice for engineering education and research...A Michigan institution that challenges its students, faculty and staff to learn, to grow, to achieve, and to serve the needs of society...A place where excellence, excitement, innovation, and impact define the style and substance of its activities.

## College of Engineering Goals

1. To provide a continuously improving educational and research environment in which faculty, administrators, students and staff work together to educate our students to lead, to have impact, and to make

significant contributions to their professions, industry, government, academia, and society.

2. To attract diverse, outstanding students, and to motivate and educate them to reach their full potential as leaders in engineering professions.

## History of the College

The University of Michigan College of Engineering was founded in 1853-54, when only a half-dozen other American colleges were providing opportunities for a formal course of study in engineering.

As early as 1852, U-M President Henry P. Tappan proposed "a scientific course parallel to the classical course," containing "besides other branches, Civil Engineering, Astronomy with the use of an observatory, the application of chemistry and other sciences to agriculture, and the industrial arts generally." The early curriculum included mathematics, graphics, physics, natural science, elements of astronomy, language, philosophy, and engineering subjects including plain geodetics, railroad and mining surveying, leveling, the nature and strength of materials, theory of construction, architecture, machines (particularly the steam engine and locomotive), and motors, particularly steam and water.

The College of Engineering established itself as a significant engineering school with a number of the nation's first engineering programs: Metallurgical Engineering (1854), Naval Architecture and Marine Engineering (1881), Electrical Engineering (1890), Chemical Engineering (1898), Aeronautical Engineering (1914), Nuclear Engineering (1953), and Computer Engineering (1965).

## The College Today

Today, the College of Engineering at the University of Michigan is consistently ranked among the top engineering schools in the world. Most of its degree programs are rated in the top ten nationwide. Approximately 1,200 bachelor's degrees and 800 master's and doctoral degrees are awarded annually. The opportunities for study have expanded so that students may choose from more than 1,000 engineering courses.

There were 298 teaching faculty, 95 research faculty, 4,828 undergraduate students, and 2,143 graduate students in the College of Engineering in Fall 2000, who took advantage of the College's diverse research and teaching facilities.

The College of Engineering expends over $100 million dollars each year in research grants—almost one quarter of the total University research funds.

The College has more than 150 research laboratories, 45 of which operate with budgets of over a half-million dollars, including three National Science Foundation research centers.

## Michigan Engineering Degree Programs

The College of Engineering offers undergraduate and graduate programs through the doctoral level. The undergraduate program consists typically of a four-year schedule leading to a bachelor's degree. There are 13 courses of study that lead to the Bachelor of Science in Engineering degree (B.S.E.) and two that lead to the Bachelor of Science degree (B.S.). By careful planning, an additional bachelor's degree (B.S. or A.B.) can be earned within the College of Engineering or in combination with another college within the University of Michigan in about one year beyond the time required for a single degree. Completion of both an engineering baccalaureate and a master's degree in approximately five years is also possible. A complete list of graduate programs is found in the Graduate Studies portion of this *Bulletin*.

### Areas of undergraduate study at the College of Engineering include:

Aerospace Engineering
Atmospheric, Oceanic and Space Sciences
Biomedical Engineering
Chemical Engineering
Civil Engineering
Computer Engineering
Computer Science
Electrical Engineering
Engineering Physics
Industrial and Operations Engineering
Interdisciplinary Program
Materials Science and Engineering
Mechanical Engineering
Naval Architecture and Marine Engineering
Nuclear Engineering and Radiological Sciences

*Accreditation*

The following degree programs offered on the Ann Arbor campus have been accredited by the Accreditation Board for Engineering and Technology (ABET): Aerospace, Chemical, Civil and Environmental, Computer, Electrical, Industrial and Operations, Materials Science and Engineering, Mechanical, Naval Architecture and Marine Engineering, and Nuclear.

## Facilities

The offices and facilities used for instruction and research in engineering are located mostly in the following buildings on the North and Central campuses:

*North Campus Engineering Buildings*
Advanced Technology Laboratories (ATL)
Aerospace Wind Tunnel Laboratories
François-Xavier Bagnoud Building (FXB)
George Granger Brown Laboratories (GGB)
Chrysler Center for Continuing Engineering Education
Mortimer E. Cooley Building
Herbert H. Dow Building
Dow Connector Building
Center for Display Technology and Manufacturing Building
Electrical Engineering and Computer Science Building (EECS)
Engineering Programs Building (EPB)
Environmental and Water Resources Engineering Builing (EWRE)
Industrial and Operations Engineering Building (IOE)
Institute of Science and Technology Building (IST)
Walter E. Lay Automotive Laboratory
Robert H. Lurie Engineering Center (LEC)
Media Union
Naval Architecture and Marine Engineering Building (NAME)
Phoenix Memorial Laboratory with the Ford Nuclear Reactor
Space Research Building

*Central Campus Engineering Facility*
West Hall: Naval Architecture and Marine Engineering Hydrodynamics Laboratory

Laboratories and other facilities are described within the sections on Undergraduate Degree Programs.

### The Robert H. Lurie Engineering Center (LEC)

The Robert H. Lurie Engineering Center, the College of Engineering's "front door," is the center for College of Engineering undergraduate student support including central student services, admissions, records, scholarships, first-year and undeclared advising, and specialized academic support such as the Engineering Advising Center, Minority Engineering Program Office, the Women in Engineering Office, and the Ameritech Engineering Learning Resource Center. LEC also houses the deans' offices and provides lounge, meeting, and conference space for the College.

LEC, named in honor of the late Robert H. Lurie (BSE IOE '64, MSE '66), was made possible by a $12 million gift from the Ann and Robert H. Lurie Family Foundation. Bob Lurie and his partner, Sam Zell (AB '63, JD '66), worked together in commercial real estate and other ventures, such as the Chicago Bulls and the White Sox.

The Ann and Robert H. Lurie Tower, which stands on the North Campus Diag, is also the result of the Lurie Family Foundation's gift.

### The Media Union

The Media Union is a 225,000 square-foot integrated technology instruction center that represents a new concept for universities—a place to house collections of information resources that are normally found in a traditional library, and also a center that provides high-tech equipment to further explore the physical and simulated world. Users are invited to the Media Union to locate information, create new artifacts, and make the results of their own inquiries available to others.

Within the Media Union, users will find studios equipped with the latest technologies for visualization and virtual reality, design, digital video and audio creation, distance learning, and collaboration. The Media Union is predicated on the knowledge that information will increasingly be created and stored digitally; therefore, any new center for the storage of, and access to, information needs to accommodate this digital future. To that end, the environment has network connectivity, from casual seating to teaching facilities. Moreover, the Media Union contains the most advanced networking technologies available today, such as asynchronous transfer mode (ATM). The Media Union also houses the library collections of the College of Engineering, the College of Architecture and Urban Planning, and the School of Art & Design.

### Walter E. Wilson Student Team Project Center

One of the best ways for College of Engineering students to gain critical hands-on design experience as well as important team, organizational, and management skills is through engineering design/build competitions. Student team projects provide practical design and fabrication experience that complements classroom instruction in addition to real-life lessons in working cooperatively with others.

The Walter E. Wilson Student Team Project Center, named for University of Michigan College of Engineering alumnus Walter E. Wilson (BSE ME '33), provides students with designated space for student teams involved in national competitions.

This 10,000-square-foot center, located behind the François-Xavier Bagnoud Building and adjacent to the Wave Field, houses space and equipment for design, assembly, machining, electronics, composite lay-up, and painting and is accessible to students 24 hours a day, seven days a week. A lecture room, offices, and a student lounge round out the center.

### Use of Facilities

Laboratory, classroom and office equipment, shops, the library, and the computer labs are examples of a wide variety of facilities that serve as aids for instruction and research. Their use is limited to the purpose for which they are made available and any misuse will be subject to disciplinary action.

Student identification cards or MCards are required for entrance to many campus facilities, especially certain laboratories and libraries. These cards are issued by the Housing Office in Room 100, Student Activities Building (SAB) or the Entree Plus Office, Room 1212, on the main floor of the Pierpont Commons on North Campus. Any student may trade in the Student ID card for the MCard, which has additional features.

## Computing at the College of Engineering

The Computer Aided Engineering Network (CAEN) provides the College of Engineering with one of the world's premier computing environments for engineering-related research and education. CAEN maintains a fully integrated, multi-vendor network of advanced-function workstations and specialized high-performance computers serving the faculty, staff, and students of the College.

### The Computing Environment

Comprised of more than 3,000 engineering-class workstations, the CAEN environment has become one of the largest integrated networks in the academic world. Some of these machines are housed in faculty and graduate offices, others in laboratories for classroom instruction. The rest are spread across the campus in 18 public facilities, conveniently available to the entire Engineering community for unlimited use, 24 hours a day, seven days a week.

A tour of CAEN facilities reveals workstations from many different vendors, including Apple, Dell, Hewlett-Packard, Silicon Graphics, and Sun Microsystems. The College administers three parallel computers in the Center for Parallel Computing (CPC), including a 64 node IBM SP/2, a 32 processor HP/Convex SPP-1000, and a 16 processor Silicon Graphics Power Challenge. The CPC also has a 9710 Timberwolf that supplies up to 40 terabytes of disk space to users. The CPC provides assistance in creating, designing, and running parallel models. Access to these parallel systems is available to undergraduate and graduate students interested in parallel computing and parallel algorithm development, if sponsored by a U-M faculty member. For assistance or more detailed information, e-mail cpcinfo@umich.edu or call (734) 936-2310.

### An Integrated Network

The CAEN network allows users to sit at any workstation, from a Pentium or Apple Macintosh to an HP or Sun, and see an integrated, "single system" image of what is really a heterogeneous physical network. Several distributed file systems—Transarc's AFS, Sun Microsystems' NFS, and Novell's NetWare—are actively supported. Together they enable CAEN to provide more than a terabyte of centrally administered file storage, all of which can be reached by any computer on the CAEN network.

CAEN's single logical internet is layered over a diverse collection of physical networks. These include Ethernet, Fast Ethernet, a high-speed Fiber Distributed Data Interface (FDDI) fiber optic backbone network, and an asynchronous transfer mode (ATM) network.

CAEN's computing environment is fully integrated with other University of Michigan organizations, including the Information Technology Division (ITD), the Medical Center, and the Electrical Engineering and

Computer Science department's Departmental Computing Organization (DCO). Michigan's gateways to the Internet—MCINet and Merit—extend this connectivity across the country and around the world.

In addition to the leading workstations in the industry, CAEN provides access to the top-rated software for engineering and general productivity applications. This software is available for use both in assigned classroom projects as well as for general use by any CAEN account holder. Users are encouraged to learn and take advantage of the enormous breadth of software available on the network to enhance their learning and research efforts at the University.

## Library Resources

Engineering library collections and staff are located in the Media Union on North Campus, one of more than 25 divisional libraries in the University Library System. Its collection of over 500,000 volumes covers all fields of engineering. The Library subscribes to almost 2,000 serial titles, including popular and scholarly engineering journals, and maintains a large collection of technical reports, standards, government documents, U.S. patents, and reserve materials for course work.

The Library uses a wide variety of on-line information services, provides trained staff, course-related instruction programs, and computerized reference searching to help students, faculty, and researchers make effective use of information resources available both on the University campus and from around the world.

## Who May Apply

To be admitted at the freshman level, an applicant must be at least 16 years old and a graduate of an accredited secondary school. Graduates of unaccredited schools may be asked to take College Board Achievement Tests or the American College Test.

Home-schooled students and students attending unaccredited high schools should contact the Office of Undergraduate Admissions prior to September of their senior year to determine if additional credentials such as SAT II Subject Exams should be submitted.

For older students, the results of the General Education Development (GED) test may be presented in place of a high school diploma.

### The University of Michigan Non-discrimination Policy Notice

The University of Michigan, as an equal opportunity/affirmative action employer, complies with all applicable federal and state laws regarding non-discrimination and affirmative action, including Title IX of the Education Amendments of 1972 and Section 504 of the Rehabilitation Act of 1973. The University of Michigan is committed to a policy of non-discrimination and equal opportunity for all persons regardless of race, sex, color, religion, creed, national origin or ancestry, age, marital status, sexual orientation, disability, or Vietnam-era veteran status in employment, educational programs, activities, and admissions. Inquiries or complaints may be addressed to the University's Director of Affirmative Action and Title IX/Section 504 Coordinator, 4005 Wolverine Tower, Ann Arbor, Michigan 48109-1281, (734) 763-0235, TTY (734) 747-1388.

For other University of Michigan information call: (734) 764-1817.

## Admission as a First-Year Student

Freshman students are admitted to the College of Engineering by the University of Michigan's Office of Undergraduate Admissions. Appropriate forms and instructions are available by contacting:

Office of Undergraduate Admissions
1220 Student Activities Building
The University of Michigan
Ann Arbor, MI 48109-1316
(734) 764-7433
http://www.admissions.umich.edu/

Michigan high school students who have begun the senior year may pick up application forms from their high school advisor. An online application is also available (see URL above). Please note that freshman students are admitted to the College of Engineering and not to a degree program. Declaration of a degree program occurs after the first year in the College.

February 1 is the deadline by which you must apply and have all required credentials on file in order to receive equal consideration with other applicants. Allow sufficient time for other offices to process your request and for mail services to deliver your materials to the Undergraduate Admissions office prior to the deadline. Applications will be considered after these dates only if places are available. Consideration for admission is made on a space available basis.

Freshman applicants are encouraged to apply as early as possible in the fall of their senior year. Schools and colleges, including the College of Engineering, may close admissions before the "equal consideration" date.

Students are encouraged to submit their enrollment deposit prior to May 1. All admitted students have until May 1 to notify the University of their intention to enroll for fall term. Students submitting enrollment deposits that are received after the May 1 deadline may not be allowed to enroll due to space considerations. Admission is contingent upon completion of the student's high school program with grades consistent with those on which admission was granted.

Both the Office of Undergraduate Admissions and the College of Engineering welcome the opportunity to provide information for prospective first-year students. Contact the College of Engineering to schedule appointments and tours or the Office of Undergraduate Admissions to schedule a place in a prospective freshman group session.

### Criteria

The admission requirements are designed to assure that each student who is admitted to the College of Engineering has aptitude for the profession of engineering as well as intellectual capacity, interest, and motivation to pursue college work successfully. Students' qualifications in these respects vary widely, and from long experience it is evident that no single criterion is sufficient to judge the ability of every applicant.

The College, therefore, takes into account the following criteria for admission:

- subjects studied in high school
- scholastic performance
- standardized test scores
- high school recommendations
- student's essay

*1. Subjects Studied in High School*
A unit for admission is defined as a course covering a school year of at least 120 sixty-minute hours of classroom work. Two or three hours of laboratory, drawing, or shop work are counted as equivalent to one hour of recitation.

The following subjects and units are minimum requirements for admission:

| Units | Subject |
|---|---|
| 3 | *English* (Four units of English are strongly recommended.) |
| 3 | *Mathematics* To consist of a minimum of 1 1/2 units of algebra; 1 unit of geometry; 1/2 unit of trigonometry. (An additional 1/2 unit of algebra and 1/2 unit of analytical geometry plus calculus are recommended.) |
| 2 | *Laboratory Science* One unit of chemistry and 1 unit of physics are recommended. Other laboratory sciences are acceptable. |
| 4 | *Academic Electives* (Two units of foreign language are recommended; other acceptable subjects are social sciences, economics, and biological science.) |
| 3 | *Unrestricted Electives* May include any subjects listed above or any other subjects counted toward graduation by the high school such as art, music, business, shop, mechanical drawing, and computer programming. |
| **15** | **Total** |

*2. Scholastic Performance*
The student's grades, particularly in mathematics, laboratory sciences, and courses that indicate verbal ability, together with the standing in the class, are considered important in determining admission to study engineering. Interest and high achievement in these subjects will also help the student to decide whether or not the right choice of career is being made, as well as predicting the likelihood of success in the engineering profession.

*3. Standardized Testing*
Tests in verbal and mathematical abilities have proven helpful for predicting success in engineering courses. Applicants are required to take, during their junior or senior year in high school, the College Entrance Examination Board Scholastic Assessment Test (SAT) or American College Testing (ACT).

For information and time schedules on the Scholastic Assessment Test, the student should consult with the high school advisor or write to the College Entrance Examination Board, Box 592, Princeton, NJ 08540, or to Box 1025, Berkeley, CA 94701. For information and time schedules on the ACT test, the student should consult with a high school advisor or write to The American College Testing Program, Iowa City, IA 52240.

*4. High School Recommendations*
Statements by representatives of the applicant's high school are taken into account. This may relate to such qualities as the character and seriousness of purpose of the applicant, interests and attainments (both scholastic and extracurricular), intellectual promise, and potential for success. A counselor's recommendation is required as a part of the application for admission.

*5. Essay*
This brief essay may include your activities, interests, accomplishments, and talents. Such information provides additional background that may not be evident from the other criteria listed above. Applicants to the College of Engineering could include an explanation of their experience and interest in engineering and their education and career goals.

## Advanced Placement

Many students take Advanced Placement courses through the Advanced Placement Program in their high schools. Credit for these courses can be applied toward a degree, provided the student has performed satisfactorily on the Advanced Placement Program examination conducted nationally by the College Entrance Examination Board.

For information and time schedules on the Advanced Placement tests, write to College Entrance Examination Board, Box 592, Princeton, NJ 08540, or to Box 1025, Berkeley, CA 94701. All other questions about Advanced Placement should be referred to the Office of the Assistant Dean for Students (Engineering Advising Center), 1009 Lurie Engineering Center, College of Engineering, University of Michigan, Ann Arbor, MI 48109-2102.

### University Placement Examinations

There are a number of courses for which credit may be received by getting a satisfactory score on a Placement Examination offered by a department of the University. (See following list.)

*1. Foreign Languages*
The Foreign Language Placement Examinations are given during Orientation. Students must take both the reading and listening parts to receive credit. If a student misses the test during Orientation, it can be taken during the next Orientation period. Credit for earned-by-examination first-year-level courses cannot be used to satisfy the humanities requirement; however, such first-year-level courses can be used as unrestricted electives. Credit for second-year-level or higher, or advanced placement, or advanced credit for such courses can be used as humanities. These courses will be posted on the student's record unless the student requests otherwise. A maximum of 8 credits are granted for foriegn language credit through examination.

*2. Computer Placement*
Advanced Placement credit can be used to fulfill the computing requirement.

*3. Credit By Examination Program*
Credit for Engineering 101 can be earned by taking the UM, College of Engineering placement examination during orientation. Advanced credit can be earned through the Credit by Examination Program. Information about this is available from the Academic Outreach Program, 837 Greene, Ann Arbor, MI 48104-3213. Advanced credit for Physics 140 and Physics 240 can be earned through this program.

**Note:** The purpose of the mathematics examination given during Orientation is to determine if students are prepared to take Math 115. It is not a test for advanced placement. The same is true for the chemistry test.

## Admission as a Transfer Student

To transfer from an accredited college in the United States, including another unit in the University of Michigan, applicants should contact the College of Engineering Office of Recruitment, Transfer Admissions and Scholarships, 1108 Lurie Engineering Center, 1221 Beal Avenue, Ann Arbor, MI 48109-2102, (734) 647-7101 for application materials and guidelines. Applicants are required to submit official transcripts of both secondary school and college course work. Applicants from another UM-Ann Arbor campus are not required to submit UM transcripts.

### Application Deadlines

Applications for admission should be submitted before March 15 for the following spring half-term, summer half-term, or fall term and prior to October 15 for winter term. Applications received after the deadline date for any term will be accepted only if space is available.

### General Admission Requirements and Information

For admission consideration, an applicant must provide transcripts for all courses taken after completion of secondary education. In addition, the official college transcript(s) must list the subjects elected, the number of credit hours and grades earned in each subject, and the basis upon which grades were assigned. Results of any aptitude tests that were taken in high school or college are helpful but not required.

The academic background of an applicant must demonstrate his or her ability to meet the requirements of the College of Engineering for graduation. The grades earned in subjects related to the program elected by the applicant are of critical importance and will be taken into account in making the admission decision. An overall scholastic average that is satisfactory for good standing at the previous institution may not in itself be sufficient. Admission standards are based on departmental guidelines to specific programs that include meeting the departmental grade point average (GPA) requirements.

### Prerequisite and Basic Courses Taken at Another Institution

Most programs require the same basic pre-engineering courses for transfer admission. These include mathematics, chemistry, physics, English composition, and a computer course with "C" or "C++" as the preferred language. Generally, such courses are offered as a complete two-year program to meet the requirements for study in many engineering colleges (e.g., a mathematics sequence requiring four semesters or six quarters). Also, in many institutions students are able to satisfy the requirements of economics and some elective courses in humanities and social sciences. Students may also be able to elect engineering courses if equivalent course content is covered.

A student in another college or university who desires to transfer should examine carefully the program that he or she plans to elect at the College of Engineering and arrange the course selections accordingly. Questions pertaining to choice of field or program and course elections not answered in this *Bulletin* may be addressed to the program advisor for the program the student wishes to elect.

### Combined Programs with Other Institutions

The College of Engineering cooperates with other institutions in providing an opportunity to earn two bachelor's degrees (A.B. or B.S. and B.S.E.) in approximately five to five-and-one-half years by satisfying the requirements for both degrees. Representative institutions providing this opportunity are:

Adrian College
Albion College
Alma College
Beloit College
Hope College
Kalamazoo College
Lawrence University (Wisconsin)
Virginia Union University

An interested student would enroll at one of these institutions for the first three years and include in the elections a pre-engineering program that, under conditions of satisfactory performance, will transfer as substantially equivalent to two years of the requirements of the College of Engineering.

### Adjustment of Advanced Credit

An evaluation of the previous record of a student transferring from a college or university will be made, usually at the time of admission, to indicate tentatively the credit that will be allowed toward a bachelor's degree in the program specified by the applicant. This appraisal is subject to review by representatives of the several teaching departments involved, and by the student's intended program advisor. The adjustment may be revised if it develops that the student is unable to continue successfully because of an inadequate preparation.

Credits are granted only for transferable courses in which a grade of "C" or better is earned. A "C-" will only be accepted if earned on the U of M - Ann Arbor Campus for courses other than math, science, engineering, or other prerequisites for admission. Classification level is determined by the number of hours transferred.

Grades earned while enrolled in another college are not recorded and the student's GPA is determined solely by the grades earned while enrolled in the College of Engineering. This does not apply to students transferring from other academic units located on the Ann Arbor campus of the University. If, at any time, a transfer student has questions regarding the adjustment of credit, the Office of Recruitment, Transfer Admissions and Scholarships should be consulted.

### Admission of Graduates of Other Colleges/ Admission of Students Via Prescribed Program

Students who have completed an undergraduate degree or applicants for transfer admissions who have completed a substantial number of the requirements for the bachelor's degree in engineering can be admitted via a *prescribed program*. The prescribed program is a detailed outline of the courses that must be taken for completion of the engineering degree, and is determined by the program advisor for students who could satisfy degree requirements in 30 to 40 credit hours at Michigan (at least 30 of which must be at the 300 level or higher).

### Cross-Campus Transfer Residency Policy

Admitted cross-campus transfer students to the CoE are held accountable to the following residency policy:

1. Once admitted, students must re-register thier classes to CoE by no later than 3 weeks after the first day of classes of the admitted term:
   - Students who do not re-register their classes will be discontinued from the CoE.
   - Once a student is discontinued they will then have to reapply to the CoE, which may involve being held accountable to new admission standards.
   - A student who re-applies after being discontinued and is admitted must be re-instated to the original term of the CoE admission. This will involve having all of the student's classes re-registered to that original term of admission and the student being billed for the differences in tuition and CoE fees accordingly.

2. Students who want to be admitted to the CoE who are near graduation and receive approval from an engineering department are held to the following:
   - The engineering department will determine which past term the student should have been admitted under. The student's classes will then be re-registered back to that term for admission and the student will be billed for the differences in tuition and CoE fees accordingly.
   - A department will have the authority to go back as many past terms as they deem appropriate for the student's admission.
   - Departments must go back a minimum number of terms so that the student satisfies the CoE rule that 30 of their last 36 credits are completed in the CoE.

## International Student Admission

### International Freshman Students

International students without previous college experience whose command of the English language is equal to that of students educated in the United States should apply for admission as first-year students to the University of Michigan College of Engineering through the Office of Undergraduate Admissions (OUA), 1220 Student Activities Building, Ann Arbor, MI 49109-1316.

International applicants are urged to request the brochure titled "International Admissions Information" from the OUA.

### International Transfer Students

International students wishing to transfer from an approved accredited college are required to complete the same basic college subjects required of all transfer applicants. Application is made to the College of Engineering's Office of Recruitment, Transfer Admissions and Scholarships. See "Admission of Transfer Students: General Admission Requirements and Information" on page 24 for details.

International students are also held accountable to several other requirements for receipt of their I-20 for F-1 student visas. International students requesting this visa or other student visa classification should contact the Office of Recruitment, Transfer Admissions and Scholarships, 1108 Lurie Engineering Center, 1221 Beal Avenue, Ann Arbor, MI 48109-2102, (734) 647-7101 for additional requirements.

### English Proficiency Requirements

International applicants must also meet the prescribed standards of proficiency in English. Each student whose native language is not English is required to submit, before admission, the results of either the Michigan English Language Assessment Battery (MELAB) or Test of English as Foreign Language (TOEFL). These tests are administered abroad as well as in the United States. For MELAB registration information, write to The Testing Division, English Language Institute, Ann Arbor, Michigan, 48109-1057, USA; phone (734) 764-2416. For TOEFL registration information, write CN6154, Princeton, NJ, 08541-2416, USA; phone (609) 921-9000.

A score of 80-85, with no section scores below 80, is required on the MELAB test. A computer TOEFL score of at least 220, with no subscore below 22, is required for admission. A minimum of 560 with no subscore below 56 is required for the paper version of the TOEFL. Regardless of tests taken previously, the College of Engineering reserves the right to require testing after arrival at the University of Michigan.

### Required Documents

An applicant must submit an official copy in English of the scholastic record of secondary and college education, showing the grade (or mark) earned in each course together with an explanation of the grading system. Course descriptions/syllabi of all post-secondary classes taken outside of the United States are also required. International students must supply official score reports of all examinations such as Advanced Placement (AP), Advanced Level (A-Level), and International Baccalaureate (IB). International students must be prepared to finance their entire education while enrolled at the College of Engineering. Financial aid/scholarships are not available to undergraduate international students. A Financial Resource Statement is required documentation along with proof of financial backing, such as an official bank statement. Applicants requesting the Student F-1 Visa or the Exchange Visitor J-1 Visa are instructed in procedures for documenting financial resources.

Students on temporary visas are required to purchase the University Health Insurance Policy upon arrival from the International Center. Payment is due each semester. Additional coverage is required for students with dependents. Fees for the Health Insurance Policy are included in the costs outlined on the Financial Resource Statement.

### Student Visa

The Student F-1 Visa is used by most students. For this temporary visa, you must be enrolled full time during the academic year. In order for you to apply for the visa, the University of Michigan sends you a form I-20 with your admission letter, upon receipt of proof of full financial support. You then take the form I-20 to a United States Embassy or Consular Official to apply for the visa. We will need a copy of your current I-20 if you are currently studying in the United States.

### Finances

When an international applicant accepts an offer of admission, the applicant should clearly understand the financial obligations assumed. If assistance is needed, necessary arrangements must be made before the applicant leaves his or her country; no financial aid/scholarships are available from the University for undergraduate international students.

## Non-Candidate for a Degree (NCFD)

### Special Student Status

A qualified college student may be admitted as a "special student" to take engineering college courses for which the student has sufficient preparation. A special student is required to meet the same academic standards for enrollment as a degree candidate.

Applications for admission as a special student may be obtained from the Office of Recruitment, Transfer Admissions and Scholarships. To apply for special student admission, submit a completed application with official transcript(s) from current and former colleges or universities. Registration is subject to the approval of the instructors of the desired courses. The applicant must contact the instructor, obtain written permission to register, and forward this permission to the Office of Recruitment, Transfer Admissions and Scholarships.

Admission will be for one term and will be granted only if there is space available after all degree-seeking students have been accommodated. If admitted as a special student, registration for classes can only be done on or after the first day of classes for the term of admission. If more than one term is requested, the student may not register for the subsequent term until his or her academic record for the previous term has been reviewed by a transfer admissions officer and program advisor.

A student who has graduated from the College of Engineering may request enrollment as a special student for one term following his or her graduation. This must be done with the approval of the program advisor. The student must abide by the same rules for enrollment as all special students.

A student who is a candidate for a degree cannot transfer to special status.

### Guest Students

A student regularly enrolled in another college is permitted to elect appropriate courses as a guest student. The guest student must meet the academic qualifications of a student who is seeking admission as a special student. His or her admission must be approved by a program advisor. The applicant must apply for enrollment before the beginning of each term that he or she desires to attend.

Guest student admission is offered on a term basis only, depending on availability of space. A student must reapply each time he or she seeks to take courses as a guest student.

### Unclassified Status

When a student is no longer a candidate for a degree from the College of Engineering but is planning to transfer into another field of study, the student is advised to report to the Office of the Assistant Dean for Students at the Engineering Advising Center on effecting a transfer and, if necessary, to arrange for registration for an additional term in the College of Engineering on an "Unclassified" status.

## Readmission

A student who is not enrolled for 12 months or more must apply for readmission through the Office of Recruitment, Transfer Admissions and Scholarships, and should do so at least two months before the date of desired enrollment. Readmitted students are subject to the rules in effect at the time of readmission.

Students who have graduated from the College and wish to elect courses for an additional term, must seek readmission through the Office of Recruitment, Transfer

Admissions and Scholarships. A student whose enrollment has been withheld must first be reinstated on probation by the Committee on Scholastic Standing.

A student who withdrew for health reasons will be referred to the University Health Service for clearance.

## Residency Classification Guidelines

### Information on Residency Classification for Admission and Tuition Purposes

*Authority*

The governing board at each university in Michigan has the authority to determine residency classification guidelines for admission and tuition purposes. Therefore, residency guidelines may vary from school to school and are independent of guidelines used by other state authorities to determine residency for purposes such as income and property tax liability, driving and voting.

The following guidelines were approved by the University of Michigan's Board of Regents to take effect Spring Term 1998 and to apply to students at all campuses of the University of Michigan. The guidelines are administered by the Residency Classification Office in the Office of the Registrar at the Ann Arbor campus, 1514 LSA Building, University of Michigan, 500 S. State St., Ann Arbor, MI 48109-1382, (734) 764-1400.

*The Student's Responsibilities and the Residency Application Process*

It is the student's responsibility to read the University Residency Classification Guidelines contained in this document and to apply for admission and register under the proper residency classification. It is also the student's responsibility to file an Application for Resident Classification for an official determination of status. Students are encouraged to consult with staff in the Residency Classification Office if they have questions or need assistance.

The admissions offices at the various schools and colleges within the University perform the initial screening for residency classification. If a student indicates Michigan resident status on the admissions application and the admissions office questions that status, the student will be classified as a nonresident and notified of the need to file an Application for Resident Classification with the Residency Classification Office. The fact that a student's claim to residency for University purposes is questioned does not necessarily mean that he or she will be ineligible; it simply means that the student's circumstances must be documented and reviewed by the Residency Classification Office.

Failure on the part of admissions staff to question a student's claim to resident eligibility does not relieve the student of the responsibility to apply and register under the proper residency classification. Furthermore, the University reserves the right to audit enrolled or prospective students at any time with regard to eligibility for resident classification and to reclassify students who are registered under an improper residency classification.

Until an Application for Resident Classification is filed and approved, a student who previously attended any campus of the University of Michigan as a nonresident will continue to be classified as a nonresident at all UM campuses.

Upon application for admission to any campus of the University, an individual who claims eligibility for resident classification must file an Application for Resident Classification for an official determination of status if any of the following circumstances apply:

- the individual is living out of state at the time of application to the University
- either parent is living out of state (applies if the individual is 24 years of age or younger)
- the individual has attended or graduated from an out-of-state high school (applies if the individual is 24 years of age or younger)
- the individual has attended or graduated from an out-of-state high school and has been involved in educational pursuits for the majority of time since graduation from high school
- the individual has had out-of-state employment or domicile within the last 3 years

The above list is not exhaustive. An individual is responsible for filing an Application for Resident Classification in any situation where the individual's eligibility for residency under these Guidelines could be reasonably questioned.

*Filing Deadlines*

Students may apply for resident class-ification for any term in which they are enrolled or intend to enroll. The deadline dates for filing the Application for Resident Classification are the same for all University of Michigan schools, colleges and campuses (see next page). The following dates apply to the term for which residency is sought. If the deadline falls on a weekend, it will be extended to the next business day.

Fall Term .................... September 30
Winter Term .................... January 31
Spring, Spring/Summer,
and Summer Terms .............. July 31

(*For the On Job/On Campus program, filing deadlines are

30 calendar days after the first scheduled day of classes.)

**Note:** Applications must be received in the Residency Classification Office by the filing deadline.

*Documentation Which Must Be Included When Filing for Resident Classification*

When filing an Application for Resident Classification, the following documentation must be included with the Application form:

- for all applicants: a copy of the driver's license of the applicant and of the person or persons upon whom the applicant is basing the claim to resident eligibility
- for all applicants: copies of the front and signature pages of the most recent year's federal and state income tax returns and W2s for the applicant and the person or persons upon whom the applicant is basing the claim to resident eligibility
- for applicants born outside the U.S.: verification of U.S. citizenship or visa status
- for applicants who are dependents: (see Residency Classification Guideline B-1), copies of the front and signature pages of the parents' most recent year's federal and state income tax returns
- for applicants whose claim to eligibility for resident classification is based on permanent, full-time employment for themselves, a parent, spouse or domestic partner: a letter from the employer, written on letterhead (including phone number), stating the position, status and dates of employment. The letter should be accompanied by a copy of the most recent pay stub showing Michigan taxes being withheld.

Applicants are also responsible for providing any other documentation necessary to support their claim to resident eligibility. Additional documentation may be requested by the Residency Classification Office.

*Appeal Process*

If an Application for Resident Classification is denied by the Residency Classification Office, the student may request that his or her file be reviewed by the University's Residency Appeal Committee. The appeal request must be made in writing and must be received in the Residency Classification Office within 30 calendar days of the date on the denial letter. If the deadline falls on a weekend or University holiday, it will be extended to the next business day.

All contact with the Residency Appeal Committee must be in writing. Personal contact with a member of the Committee prior to the meeting could disqualify the member from participating in the decision. A student who wishes the Committee to consider additional information must submit the information to the Residency Classification Office, in writing, with the appeal request. The information will then be forwarded to the Residency Appeal Committee with the student's file.

The student will receive a written decision from the Committee when the review is complete. Once the Residency Appeal Committee issues its decision there are no further appeals for the term covered by the application.

*Misrepresentation and Falsification of Information*

Applicants who provide false or misleading information or who intentionally omit relevant information in an application for admission, an application for resident classification or any other document relevant to residency eligibility may be subject to legal or disciplinary measures. Students improperly classified as residents based on this type of information will have their residency classification changed and may be retroactively charged nonresident tuition for the period of time they were improperly classified.

*Residency Classification Guidelines*

For University purposes, "domicile" is defined as the place where an individual intends his/her true, fixed and permanent home and principal establishment to be, and to which the individual intends to return whenever he or she is absent. These Guidelines are designed to explain how a student may demonstrate the required intent and establishment of a domicile in Michigan. An individual whose activities and circumstances, as documented to the University, demonstrate that he or she intends to be domiciled in Michigan and has, in fact, established a domicile in Michigan will be eligible for classification as a resident. An individual whose presence in the state is based on activities or circumstances that are indeterminate or temporary, such as (but not limited to) educational pursuits, will be presumed not to be domiciled in Michigan and will be classified as a nonresident. The burden of proof is on the applicant to demonstrate with clear and convincing evidence that he or she is eligible for resident classification under these Guidelines.

These Guidelines describe situations that create presumptions of resident and nonresident status. The fact that a presumption of resident status may apply to a student does not mean that the student will automatically be classified as a resident or that the student is relieved of the responsibility for filing an Application for Resident Classification. (See The Student's Responsibilities and the Residency Application Process on page 30.)

To overcome a presumption of nonresident status, a student must file a residency application and document with clear and convincing evidence that a Michigan domicile has been established.

### A. General Guidelines

1. *Circumstances which may demonstrate permanent domicile*

   The following circumstances and activities, though not conclusive or exhaustive, may lend support to a claim to eligibility for resident classification:

   - both parents (in the case of divorce, one parent) permanently domiciled in Michigan as demonstrated by permanent employment, establishment of a household and severance of out-of-state ties
   - applicant employed in the state in a full-time, permanent position provided that the applicant's employment is the primary purpose for the applicant's presence in Michigan
   - spouse or domestic partner employed in the state in a full-time, permanent position provided that the spouse's or partner's employment is the primary purpose for the student's presence in Michigan

2. *Circumstances which do not demonstrate permanent domicile*

   The circumstances and activities listed below are temporary or indeterminate and, in and of themselves, do not demonstrate permanent domicile:

   - enrollment in high school, community college or university
   - participation in a medical residency program, fellowship or internship
   - employment that is temporary or short-term
   - military assignment
   - employment in a position normally held by a student
   - ownership of property
   - presence of relatives (other than parents)
   - possession of a Michigan driver's license or voter's registration
   - payment of Michigan income or property taxes
   - the applicant's statement of intent to be domiciled in Michigan

3. *One-year continuous presence*

   In cases where it is determined that an applicant has not demonstrated establishment of a domicile in Michigan as defined by these Guidelines, the University will require the applicant to document one year of continuous physical presence in the state as one of the criteria for determining eligibility for resident classification in any subsequent Application for Resident Classification. The year to be documented will be the one year immediately preceding the first day of classes of the term in question. The year of continuous presence is never the only criterion used for determining resident eligibility, and, in itself, will not qualify a student for resident status.

   If substantial and new information arises which changes the circumstances of a student's presence in Michigan and which clearly demonstrates the establishment of a Michigan domicile, the student may be immediately eligible for resident classification prior to the passage of one year.

   In documenting the year of continuous physical presence in Michigan, the applicant will be expected to show actual physical presence by means of enrollment, employment, in-person financial transactions, health care appointments, etc. Having a lease or a permanent address in the state does not, in itself, qualify as physical presence. Short-term absences (summer vacation of 21 days or less, spring break and break between fall and winter term), in and of themselves, will not jeopardize compliance with the one-year requirement.

   In determining the effect of a short- term absence, the nature of the absence will be assessed to determine whether it is contrary to an intent to be domiciled in Michigan. Absences from the state in excess of the time mentioned above or failure to document physical presence at the beginning and end of the year will be considered as noncompliance with the one-year continuous presence requirement.

### B. Residency Presumptions in Particular Circumstances

The fact that a presumption of resident status may apply to a student does not mean that the student will automatically be classified as a resident or that the student is relieved of the responsibility for filing an Application for Resident Classification. (See The Student's Responsibilities and the Residency Application Process on page 23.)

1. *Dependent Students*

   For University residency classification purposes, a student is presumed to be a dependent of his or her parents if the student is 24 years of age or younger and (1) has been primarily involved in educational pursuits, or (2) has not been entirely financially self-supporting through employment.

   a. Residents

      i. Dependent Student—Parents in Michigan

      A dependent student whose parents are, according to University Residency Classification Guidelines, domiciled in Michigan is presumed to be eligible for resident classification for University purposes as long as the student has not taken steps to establish a domicile outside of Michigan or any other action inconsistent with maintaining a domicile in Michigan.

ii. Dependent Student of Divorced Parents—One Parent in Michigan
A dependent student whose parents are divorced is presumed to be eligible for resident classification for University purposes if one parent is, according to University Residency Classification Guidelines, domiciled in Michigan. The student must not have taken steps to establish an independent domicile outside of Michigan or any other action inconsistent with maintaining a domicile in Michigan.

iii. Dependent Resident Student Whose Parents Leave Michigan
A student who is living in Michigan and who is, by University Residency Classification Guidelines, permanently domiciled in Michigan does not lose resident status if the parents leave Michigan, provided: (1) that the student has completed at least the junior year of high school prior to the parents' departure, (2) that the student remains in Michigan, enrolled as a full-time student in high school or an institution of higher education, and (3) that the student has not taken steps to establish a domicile outside Michigan or any other action inconsistent with maintaining a domicile in Michigan.

b. Nonresidents
Dependent Student—Parents not in Michigan
A dependent student whose parents are domiciled outside the state of Michigan is presumed to be a nonresident for University purposes.

2. *Michigan Residents and Absences From the State*
Individuals who have been domiciled in Michigan according to University Residency Classification Guidelines immediately preceding certain types of absences from the state may retain their eligibility for resident classification under the conditions listed below:

a. One-Year Absence
An individual who has been domiciled in Michigan immediately preceding an absence from the state of less than one year may return to the University as a resident for admission and tuition purposes provided: (1) that the individual has maintained significant ties to the state during his or her absence, and (2) that the individual severs out-of-state ties upon returning to Michigan.

b. Absence for Active Duty Military Service (Army, Navy, Air Force, Marines, Coast Guard), Missionary Work, Peace Corps or Similar Philanthropic Work
An individual who is domiciled in Michigan at the time of entry into active military duty, missionary work, Peace Corps or similar philanthropic work does not lose eligibility for resident classification as long as he or she is on continuous active duty and continuously claims Michigan as the state of legal residence for income tax purposes. Dependent children of such an individual are also eligible for resident classification, provided: (1) that they are coming to the University directly from high school or they have been continuously enrolled in college since graduating from high school, and (2) that they have not claimed residency for tuition purposes elsewhere.

c. Absence for Education or Training
An individual who is domiciled in Michigan immediately preceding an absence from the state for full-time enrollment in school or for a medical residency program, internship or fellowship does not lose eligibility for resident classification provided: (1) that the individual has maintained significant ties to the state during his or her absence (e.g., parents still in the state, payment of state taxes, active business accounts), and (2) that the individual has not claimed residency for tuition purposes elsewhere.

3. *Residence Status of Immigrants and Aliens*
Only persons who are entitled to reside permanently in the United States may be eligible for resident classification at the University. These individuals, like U.S. citizens, must still prove that they have established a Michigan domicile as defined in these Guidelines. Having the privilege of remaining permanently in the United States, in itself, does not entitle a person to resident classification for University purposes. The Residency Classification Office will review the circumstances of the following classes of immigrants:

- Permanent Resident Aliens (must be fully processed and possess Permanent Resident Alien card or stamp in passport verifying final approval by filing deadline for applicable term)
- Refugees (I-94 card must designate "Refugee")
- A, E (primary), G and I visa holders*
(*Based upon current law, these nonimmigrant visa classifications are the only ones that permit the visa holder to establish a domicile in the United States. The University Registrar shall update this list as changes occur in applicable law.)

## Financial Aid

To determine your eligibility for need-based financial aid, contact the University of Michigan's Office of Financial Aid at the number or address below. Excellent information is also available on the Office's Web site.

*University of Michigan Office of Financial Aid*
*2011 Student Activities Building*
*or*
*1212 Pierpont Commons*
*(734) 763-6600*
*www.finaid.umich.edu*

## Scholarships

In keeping with the University's practice and policy, financial assistance is available to qualified students irrespective of sex, race, color, or creed.

Scholarships are established by gifts to the College and by allocations from the University's general fund. The loyal alumni and many friends of the University and the College of Engineering—along with other interested individuals, industry, and many public and private organizations—contribute support through annual gifts and endowment funds that earn income to be used for scholarship awards.

There is no direct obligation to repay a scholarship, but as recipients recognize their moral obligation to return gifts to the College scholarship fund, according to their abilities, other worthy students will benefit.

The broad range of undergraduate scholarships available to Engineering students is described below.

### Entering Students

Although families (students, parents, spouses) are primarily responsible for meeting college costs, and are expected to contribute according to their ability, Academic or Merit Scholarships are granted by the University of Michigan's Admissions Office, the Office of Financial Aid, and the College of Engineering to incoming students (first-year students and transfer students). Once a student has completed a full term (12 credit hours) in the College of Engineering, it is possible to apply for a Scholarship (see details on the next page).

*University Admissions Office and Office of Financial Aid Academic Scholarships*

The University of Michigan has established a variety of programs to recognize superior academic achievement. Participation in these programs is restricted to citizens of the United States and persons on Permanent Resident Visas. Nominees are selected or identified from admissions applications or the roster of admitted students and are formally notified of their eligibility. Financial need is not a factor in the criteria for most merit awards. The stipends may change from year to year.

*College of Engineering Merit Scholarships*

Each year, a number of incoming first-year students are selected for honorary scholarships. Selection is made from a review of all first-year students admitted to the College of Engineering and is based on SAT and/or ACT scores, class rank, and grade point average (GPA). An application is not required for consideration. Candidates will receive notification of their status, need for additional information, or selection before mid-April. Most honorary awards are renewable.

These scholarships are restricted to citizens of the United States and persons on Permanent Resident Visas. For information pertaining to First-Year Merit Awards, entering students should contact the Director of Recruitment, Transfer Admissions and Scholarships in Room 1108 Lurie Engineering Center (LEC) or call (734) 647-7101. Merit Scholarships for transfer students are awarded to the top students of the admitted class. The Transfer Student Award is renewable. For further information on scholarships, contact the Office of Recruitment, Transfer Admissions and Scholarships in Room 1108, Lurie Engineering Center (LEC) or call (734) 647-7101.

### Continuing Students

*Need-based Scholarships*

To qualify for a need-based scholarship, students should also apply for financial aid through the University of Michigan Office of Financial Aid. Other criteria that must be met exist within the various scholarship funds.

The Office of Recruitment, Transfer Admissions and Scholarships matches qualified students with the appropriate funding resources. Need-based scholarships are not renewable. Students must reapply for these scholarships each academic year.

Scholarships are restricted to full-time (12 credit hours) students who have completed one full term in the College of Engineering, have established a grade point average (GPA) of 2.7 or higher, and can demonstrate financial need. Need-based scholarships are also restricted to students who are citizens of the United States or have a Permanent Resident Visa.

*Industry-Sponsored Scholarships*
Several industries offer scholarships to students. Sometimes a summer internship accompanies the monetary award given by industry and often the industry awards are renewable. Recipients are selected based on the criteria established by the donor.

Scholarships are restricted to full-time (12 credit hours) students who have completed one full term in the College of Engineering, have established a grade point average (GPA) of 3.0 or higher, and are citizens of the United States or on Permanent Res-ident Visas.

*Where to Apply*
Application forms for Merit, Need-Based or Industry-Sponsored Scholarships can be obtained in Room 1432, Lurie Engineering Center (LEC). Completed applications should be returned to this office as well.

*When to Apply*
Applications for scholarships should be submitted one term prior to the term for which the scholarship is requested. Scholarship applications from first-term students are held until completion of the term and verification of credit hours and grades.

*Limitations*
It is the policy of the College of Engineering to not "over award" a student, which means, if the sum of awards and expected family contribution equals more than the student budget, as established by the University, you will not qualify for an Engineering award. Scholarships are given for the term designated only.

*Deadline*
Applications for awards are accepted from January 1-March 31. Applications submitted after the deadline will be reviewed based on the availability of funds.

Industry-Sponsored Scholarships have application deadlines that may vary. An updated merit application should be completed each September. See the Office of Financial Aid for their current deadlines.

### International Students
International students must be prepared to finance their entire undergraduate education while enrolled in the College of Engineering. A guarantee of total financial backing must be provided when making application for admission. Scholarship applications are not accepted from international students.

### College of Engineering Tuition Waiver Program
As a signatory in numerous exchange agreements, the College of Engineering welcomes students from its partner institutions, and encourages its own students to consider study abroad to fulfill the terms of the exchange. But the College underscores the value it places on international exchange by implementing a tuition waiver plan that exceeds merely maintaining a balance of exchange students. For those incoming international exchange students who exceed the balance established by the agreements, the College assumes 12 consecutive months' worth of tuition payments for 15 students per semester. The tuition waiver program is open to both undergraduate and graduate students from our overseas partner institutions. The College believes that despite the challenge in maintaining exchange balances, the support of incoming international exchange students in this manner is not only beneficial to the tuition waiver recipient, but also to those domestic College students who interact with him her.

Our exchange partner organizations include: Shanghai Jiao Tong University, École Polytechnique, École Nationale Supérieure de Techniques Avancées, École Nationale Supérieure de l'Aerospace, Technical University of Berlin, Technical University of Munich (under development), Rheinische Westfaelische Technische Hochschule Aachen, Global Engineering Education Exchange ($GE^3$), Hong Kong University of Science and Technology, Nagoya University, Delft University of Technology, Eindhoven University of Technology, Warsaw University of Technology, Nanyang Technological University.

### Veterans and Social Security Benefits
Educational benefits are available to students who qualify under the Public Laws providing benefits for veterans (or their children) and to orphans or children of a disabled parent who qualify under the Social Security Law. Questions may be referred to the Office of Student Certification, LS&A Building.

## Fee Regulations, Expenses, Indebtedness
A non-refundable application fee of $40 will be required of each applicant for admission to the University.

The Estimated Tuition and Registration Fees for one full term for the 2001–2002 academic year:

**Fall 2001**

| | |
|---|---|
| Resident Lower Division | $ 3,343 |
| Resident Upper Division | $ 4,345 |
| Non-Resident Lower Division | $ 10,130 |
| Non-Resident Upper Division | $ 11,379 |

Students enrolled as special students or guest students in the College of Engineering will be assessed the upper-division fees. Fees are subject to change at any time by the Regents of the University. Detailed information relating to fees, deposits, payments, and refunds may be obtained in the Engineering Academic Services Office and/or may be found in the first few pages of the current *Time Schedule.*

## Class Standing

The number of credit hours accumulated toward graduation at the close of a given term are used to determine a student's class standing for statistical purposes. Questions concerning class-level designations should be referred to the Engineering Academic Services Office.

| | Class | Hours |
|---|---|---|
| **Lower Division** | Freshman | 0 to 24 |
| | Sophomore | 25 to 54 |
| **Upper Division** | Junior | 55 to 84 |
| | Senior | 85 or more |

A student admitted to a prescribed program will be a senior when there are 35 hours or fewer to complete.

## Withdrawal

A student who withdraws after registration shall pay a disenrollment fee according to the rules in effect at the time of withdrawal as published in the Time Schedule each term.

## Indebtedness to the University

Students shall pay all accounts due the University in accordance with regulations set forth for such payments by the Executive Vice President and Chief Financial Officer.

When a student's account shows indebtedness, no transcript of academic record or diploma will be issued, nor will future registration be permitted.

## Academic and Personal Support Services

Students have many places on campus to seek help with personal and academic problems. This section briefly describes the offices in the College of Engineering and in the University that have staff who are dedicated to providing the support that is needed to help students resolve their problems.

For **academic problems**, students are encouraged to discuss the matter with their course instructor or GSI as soon as problems arise. If the problem cannot be resolved at that time, the student can speak with their department's program advisor and/or the department chair, or for the case of first year and undeclared students, with the advisors in the Engineering Advising Center. If further assistance is needed, one of the academic deans in the College should be consulted. On some occasions, formal processes for resolving academic problems may be needed, and these are described in the section on Academic Rules and Policies.

For **personal problems**, there are a number of offices on campus where staff are available to help students get the support that is needed. In the College, students may contact staff in the Engineering Program Office, (especially for First Year and Undeclared Students), the Minority Engineering Program Office, the Women in Engineering Office, or the Student Leadership and Academic Services Office. The offices of the Assistant Dean for Students and the Associate Dean for Undergraduate Education are also available resources. Students may also wish to consult directly with the University offices, especially Counseling and Psychological Services, University Health Services, the University Ombuds Office and the Office of Public Safety.

### Engineering Advising Center

*1009 Lurie Engineering Center (LEC)*
*Phone: (734) 647-7106*
*Fax: (734) 647-7126*

First year students in the College of Engineering begin a partnership with the Engineering Advising Center (EAC) and its many resources, which are designed to help with the transition from high school to college, plan course schedules, and choose a major. Student's first encounter with the EAC is through Orientation, a three-day program welcoming incoming first-year students to campus during the summer before their first semester.

*Orientation*

The Engineering Orientation is coordinated through the EAC. First-year students are divided into small groups and guided through the program including testing, obtaining an identification card, consultation with academic advisors, course selection, basic computer training, registration, and attendance at the necessary Orientation group meetings.

First-year students entering in the Fall term are encouraged to come to campus for Orientation. At the same time, parents are invited to attend a program specifically arranged for them.

Transfer students for fall admission are also offered an opportunity to come to campus during the summer for a one-day orientation.

*Academic Advising for First-year Students*

First-year students' advisors, consisting of a group of well-qualified faculty from the engineering departments, professional EAC advisors, and peer advisors, are available for consultation throughout the fall and winter terms.

Each entering freshman meets with an advisor to determine a schedule of courses for the first term. This is covered in detail in the section "Planning the Student's Program".

Developing self-reliance and the ability to make choices, as well as the ability to appraise one's own performance and intellectual growth is an important part of a student's education. Nevertheless, each freshman is encouraged to consult with first-year students' program advisors any time for questions relating to career plans, choice of academic program, or to discuss any matter of interest or concern. Midterm is a particularly appropriate time to examine progress.

*Other services the EAC offers include:*

- A comprehensive first-year student handbook
- A monthly newsletter full of helpful information
- E-mail contact with advisors
- Workshops throughout the year on topics such as time management, test-taking skills, and degree programs.

*Academic Advising for Continuing and Transfer Students*

Continuing and transfer students receive advising from Program Advisors on the faculty.

At the beginning of each undergraduate degree program description (beginning on page 85) is the name(s) of the faculty member(s) designated as Program Advisor(s). Upon selecting a degree program, the student is referred to the respective Program Advisor, who is responsible for the necessary academic advising through graduation.

### Minority Engineering Program Office (MEPO)

*1463 Lurie Engineering Center (LEC)*
*Phone: (734) 647-7120*
*Fax: (734) 647-7126*

The UM College of Engineering's Minority Engineering Program Office (MEPO) was established to increase the number of under-represented minority engineering students who graduate with engineering degrees, from the baccalaureate to the doctorate. To accomplish this, MEPO works with students from a diversity of backgrounds, from 7th grade through completion of graduate studies; maintains collaborative relationships with UM faculty and staff; and networks with industry to secure resources and employment opportunities for engineering students.

At the pre-college level, MEPO offers students in grades 7 through 12 opportunities to actively explore and prepare for engineering and other technical career fields. MEPO hosts the Summer Engineering Academy each year to address participants' pre-college academic and personal development needs. MEPO also maintains a formal relationship with the Detroit Area Pre-College Engineering Program (DAPCEP), which sponsors tutorial services, hands-on projects, academic enrichment, and engineering exposure sessions for Detroit Public School students.

At the college level, MEPO provides orientation and professional development activities, scholarship assistance, career and academic advising services, and support to the Society of Minority Engineering Students (SMES). MEPO manages the Ameritech Engineering Learning Resource Center (AELRC), at G264 Lurie Engineering Center, where reference books and other study materials, tutorial and study group assistance, and computers are available for student use.

At the undergraduate level, MEPO works closely with corporations to facilitate summer, co-op, and permanent employment opportunities. MEPO also is actively engaged in the local, regional, and national initiatives of GEM (National Consortium for Graduate Degrees for Minorities in Engineering and Science, Inc.), which encourages promising minority students to pursue graduate degrees in engineering.

MEPO's Industrial Cluster provides advice and support for outreach and retention efforts. The Cluster also sponsors interview sessions and operates a Corporate Scholarship Program to facilitate greater industry involvement.

Additionally, MEPO hosts CoE faculty and staff activities that promote an environment conducive to ethnic and cultural diversity.

### Student Leadership and Academic Services

*1408 Lurie Engineering Center (LEC)*
*Phone: (734) 647-7155*
*Fax: (734) 647-7126*

The College of Engineering's Student Leadership and Academic Services (SLAS) office serves students through facilitating opportunities that enrich, support and broaden the educational experience. SLAS focuses on the distinct areas of student leadership and academic support, yet its philosophy bridges the two by stressing the need for students to take responsibility in all areas of their lives.

*Student Leadership*
The SLAS office is the College of Engineering's primary contact with student groups, providing programmatic and leadership support to its many teams, societies and professional organizations. Student organizations may seek funding form SLAS for approved events and activities. SLAS coordinates student outreach and service learning opportunities for students and groups. It also plays an instrumental role in Michigan LeaderShape, a week-long program designed to develop student leaders.

*Academic Services*
SLAS mentors and advises students in the areas of academic and personal development. It acts as a liaison between students and the Office of the Registrar. In addition, SLAS helps students understand the academic standards and procedures of the College of Engineering, especially in relation to their academic record. SLAS also guides students to University resources to address academic and personal issues, including but not limited to learning disabilities, tutoring, study skills, test-taking techniques, time management and psychological counseling.

SLAS staffs the Scholastic Standing Committee (SSC), processes all petitions and provides academic support for students. SSC decisions are implemented and audited by SLAS. Students in academic difficulty often solicit advice and mentorship from SLAS.

### The Women in Engineering Office

The Women in Engineering Office (WIE) division of the Women in Science and Engineering Program (WISE) works with students, faculty and staff to provide an inviting and supportive environment for women at all levels throughout the College of Engineering. The WIE Office provides services and resources to assist women in various stages of academic and professional development and provides leadership in the College concerning women's issues. The goals of the WIE Office include increasing the pool of qualified women who enter engineering, assisting in their retention, assisting women in pursuing undergraduate and graduate degrees and careers, supporting student, staff and faculty groups that focus on women's issues and facilitating a cooperative environment within engineering. To meet these goals, WIE:

- generates and disseminates data on women in engineering disciplines
- administers several scholarships
- offers research opportunities for juniors through the Marian Sarah Parker Program, a graduate school awareness program
- sponsors weekend and summer outreach programs for middle and high school students
- provides advising and counseling
- oversees the WISE Residence Program, a living-learning program for first-year students
- maintains a small library of print and video resources
- sponsors an Alumnae Speaker Series
- publishes a biannual newsletter
- maintains a website with scholarship, career and academic information
- provides graduate peer advisors for new graduate students
- provides administrative support to student organizations such as the Society of Women Engineers
- offers professional development workshops
- publishes the "Survival Guide" for graduate students

The WIE Office also advocates for women students by educating the University community about gender equity—an important contribution to supporting the success of women and providing a more comfortable campus climate for all students. WIE is committed to responding to the needs of our constituents and enhancing the educational experience of all College of Engineering students.

### International Programs and Services

The University of Michigan and the College of Engineering offer support for the highly diverse international student population on campus. In addition, units on campus also support and encourage those domestic students who would like to enhance their academic experience with an international component.

### For International Students

The international student body at the College of Engineering brings a richness and diversity to the College community by providing students with the opportunity to interact with students of other cultures, and be exposed to different perspectives and behaviors. This interaction will help students operate effectively as future engineers in global corporations.

The transition from a home culture to a new learning environment can be a major adjustment for many international students. The University recognizes the needs of the international student body and offers support services to them. For information on admissions requirements for international students, please refer to Admissions sections. For international students researching the possibility of an exchange semester at the University, please read the section on the Tuition Waiver Program.

### English Language Institute

*3003 North University Building*
*University of Michigan*
*Ann Arbor, MI 48109*
*Tel. 734-764-2413*

The English Language Institute (ELI) offers advanced instruction in the English language to non-native speakers enrolled in the University. Since the main purpose of this instruction is to help non-native speakers become effective and fully participating members of the academic community, the majority of ELI courses are concerned with English for Academic Purposes. Most courses address specific areas such as pronunciation, lecture comprehension, or academic writing and usually involve no more than 20 contact hours per semester. Before enrolling in ELI courses, most international students will take the Academic English Evaluation (AEE) as a condition of their admission to the University. Results of the AEE are then used to help the students choose the most suitable ELI courses. In major areas such as speaking and writing, a sequence of courses of increasing difficulty and specialization is available, including some that carry graduate credit. ELI operates a Writing Clinic and a Speaking Clinic as one-on-one facilities for those who have taken or are taking ELI courses in the relevant areas. ELI also offers a Summer Half-Term Intensive Program for non-native speakers who have already received admission to the University but who wish to improve their language and study skills before beginning their academic program. There are three programs: a) English for Academic Purposes, b) English for Business Studies, and c) English for Legal Studies.

### International Center

*Main Office: 603 E. Madison, Ann Arbor, MI 48109-1370, Tel. 734-764-9310*
*North Campus: Pierpont Commons, 2101 Bonisteel Blvd., Ann Arbor, MI 48109-2092, Tel. 734-936-4180*

International Center services are available to international students and to all students considering work, travel, or study abroad.

The International Center is adjacent to the Michigan Union building, with an entrance on East Madison Street. A second office is located in the Pierpont Commons on North Campus. Admitted international students may use the International Center as an advance mailing address.

The International Center will help international students deal with the United States Immigration and Naturalization regulations, with their sponsors and governments, and with other individuals and organizations. International student advisors are available to discuss and advise on visa and immigration issues, employment regulations, cross-cultural issues, health insurance, personal and family concerns, housing, adjustment, finances, and other matters.

The International Center offers a customized orientation to incoming international students in addition to informational workshops addressing topics such as income tax filing, making friends in the US, communicating with academic advisors, and financial resources and job possibilities for international students.

International students may also take advantage of a varied program of cultural and social events provided by nationality clubs, student associations, and other organizations throughout the year.

American and international students may obtain information regarding options for overseas study, scholarships, internships, work, volunteering, travel and international careers through individual consulting and informational programs. The Center's Overseas Opportunities Office library has one of the largest collections of its kind in the United States.

### Study and Work Abroad Programs

*245 Chrysler Center*
*2121 Bonisteel Blvd.*
*Ann Arbor, MI 48109-2092*
*Tel. 734-647-7129*
*coe-international@umich.edu*

The College of Engineering offers study and work abroad opportunities that allow students the chance to experience the educational, social, political, and professional climate of a foreign country. Study and work abroad participants gain global skills and a new level of personal self-reliance that attracts the attention of future employers who seek self-confident, imaginative people having global experience.

With careful planning, students can take advantage of these opportunities and still graduate on time. In addition to English-speaking programs in Australia, Europe, and Asia, immersion programs are available for study in Europe and Asia for those who have the requisite language skills (at least 2 years of college-level language courses).

Both graduate and undergraduate students can participate in College of Engineering study abroad programs. The International Programs in Engineering office staff advises students to find the study abroad option that best meets their needs. The International Programs in Engineering office also assists in the process of having study abroad credits transferred onto the student's transcript upon return. Grades from study abroad will not be calculated into a student's GPA, however.

Applicants for these programs should have a good academic record (GPA 3.0). Most CoE programs involve direct enrollment in regular classes at the host institution, which normally require junior or senior standing by the time the program begins. Students who qualify for financial aid may apply most aid to any CoE- or UM-sponsored study abroad program. In addition, some scholarships are available through the International Programs in Engineering Office and the office has information on other financial aid resources available for study abroad.

For those students who prefer to have a work abroad experience, the International Programs in Engineering office also has resources to help students find an internship overseas. IAESTE and AISEC are two internship organizations that help arrange placement of students in valuable internships overseas with either a technical or business focus.

Please see Engineering course descriptions section, Division 290 for brief descriptions of current programs abroad.

### International Institute

*1080 South University Ave., Suite 2660*
*Ann Arbor, Michigan 48109-1106*
*Phone: 734.763.9200 Fax: 734.763.9154*
*iimichigan@umich.edu*

The International Institute establishes priorities and provides resources to support the production and dissemination of knowledge to enable the University community of faculty, students, and staff to understand and engage a diverse and increasingly interconnected world. To this end, the Institute promotes linkages with partner institutions in the United States and abroad, and cooperates with schools, departments, and programs at the University of Michigan to enhance collaboration across units. The Institute and its constituent units offer programs, services and funding opportunities that contribute to internationalizing undergraduate and graduate-level education at the University of Michigan, and is a particularly valuable resource for graduate students and faculty seeking interdisciplinary relationships with area studies and language faculty.

## University of Michigan Student Support Services

The College of Engineering partners with the University of Michigan to provide the tools and services necessary to foster success and promote good health. Engineering students are encouraged to learn about the numerous campus offices, organizations, and services available to them. Refer to the University's Web site at http://www.umich.edu for detailed information. Of particular importance is the University's Counseling and Psychological Services.

### Counseling and Psychological Services

*3100 Michigan Union*
*Central Campus*
*(734) 764-8312*

*Pierpont Commons, Ground Floor*
*North Campus*
*(734) 763-9658*

Counseling and Psychological Services offers a variety of personal counseling, workshop, and consultation services to University of Michigan students and other members of the University community. Services to students include crisis intervention; brief personal counseling and short-term psychotherapy for individuals, couples, and groups; and workshops on various informational and skill-building topics. The staff consists of social workers, psychologists, psychiatrists, and graduate students in psychology and social work.

### Services for Students with Disabilities

The University of Michigan Office of Services for Students with Disabilities (SSD) provides services to students with visual impairments, learning disabilities, mobility impairments, or hearing impairments. SSD also works with students who have chronic health problems or psychological disabilities, and it offers services that are not provided by other University offices or outside organizations. SSD provides accessible campus transportation, adaptive technology, sign language and oral interpreting, readers and other volunteers, guidance for course accommodations, and requests to modify degree requirements. Services are free of charge.

Before and after a student enrolls at the University, SSD staff are available to answer questions and provide referrals concerning admission, registration, services available, financial aid, etc. In addition, SSD can help assess the need for modified housing, attendants, interpreters, transportation, classroom accommodations, notetakers, and adaptive equipment.

To request additional information contact SSD at G-625 Haven Hall 1045, call them at (734) 763-3000 (Voice/TTY), or visit their website at http://www.umich.edu/~sswd/ssd/.

### University Health Service

*207 Fletcher*
*Central Campus*
*(734) 763-1320*
*http://www.uhs.umich.edu*

The University Health Service (UHS) provides comprehensive outpatient medical services to all students, faculty, staff and dependents. As a highly utilized and essential student support unit, UHS is committed to help students stay healthy while accommodating students' demanding schedules.

Most services provided at UHS will be covered by the health service fee, even when they are not covered by a student's private health insurance. This fee is incurred every semester as part of each student's tuition. Thus, students will not be directly charged for most services received at UHS. Those services and products for which additional fees apply include: pharmaceuticals, routine optometric care, eyewear, contact lenses, orthopedic devices and certain immunizations.

For more details on UHS services, pick up a copy of the "Health Care for UM Students" brochure or call the Health Promotion and Community Relations Department at (734) 763-1320. The Health Service building is accessible to handicapped persons via the South entrance.

*Other University resources include:*

- Remedial training in speech is offered by the Speech Clinic.
- Religious congregations in the Ann Arbor area provide counseling.
- The Office of Student Services, 3010 Michigan Union, provides counsel and assistance on housing, employment, and other non-academic problems.
- The residence halls maintain a staff of advisors and student assistants who help students make an effective adjustment to the University community.
- The Office of Financial Aid provides counsel on financial issues.

## Student Activities and Co-curricular Opportunities

Students at the University of Michigan have many opportunities to participate in co-curricular activities. Some of these are associated with professional societies, others with social organizations, music and drama groups, sports or service groups. In addition, a great many cultural programs are offered throughout the year—more than anyone could possibly attend.

The College of Engineering encourages participation in the wide range of activities—University-wide as well as those within the College. College activities can provide opportunities for personal and professional development.

The following is a list of organizations of particular interest to students in Engineering. If you are interested in any of the following organizations or have questions about student organizations or leadership development opportunities contact the Director of Student Leadership and Academic Services, 1408 LEC. Those interested in exploring other University-wide opportunities may obtain information at the Student Activities and Leadership Office, 2209 Michigan Union, Ann Arbor, Michigan 48109; (734) 763-5900.

### Honor Societies

- Alpha Chi Sigma, Chemical Engineering honor society (AXE)
- Alpha Pi Mu, national Industrial Engineering honor society (APM)
- Alpha Sigma Mu, Materials Science and Engineering honor society (ASM)
- Chi Epsilon, Civil Engineering honor society (XE)
- Epeians, Michigan Engineering leadership honor society
- Eta Kappa Nu, national Electrical Engineering honor society (HKN)
- Golden Key, national honor society
- Mortar Board, national senior honor society
- Omega Chi Epsilon, national Chemical Engineering honor society (OXE)
- Phi Beta Kappa, national senior honor society, emphasis on education in the liberal arts
- Phi Kappa Phi, national honor society for seniors of all schools and colleges
- Pi Tau Sigma, national Mechanical Engineering honor society (PTS)

- Quarterdeck Honorary Society, honorary technical society for the Department of Naval Architecture and Marine Engineering (QD)
- Sigma Gamma Tau, national Aerospace honor society (SGT)
- Sigma Xi, national society devoted to the encouragement of research
- Tau Beta Pi, national engineering honor society (TBP)

### Professional Societies

- Aerospace Minority Engineering Society
- American Indians Science and Engineering Society (AISES)
- American Institute of Aeronautics and Astronautics (AIAA), student chapter
- American Institute of Chemical Engineers (AIChE), student chapter
- American Nuclear Society (ANS), student chapter
- American Society of Civil Engineers (ASCE), student chapter
- American Society for Engineering Education (ASEE), student chapter
- American Society of Mechanical Engineers (ASME), student chapter
- Association for Computing Machinery (ACM), student chapter
- Biomedical Engineering Student Association (BMES)
- Black Electrical Engineering and Computer Science Society (BEECS)
- Chemical Engineering Graduates Society (ChEGS)
- Chi Alpha Christian Fellowship (XA)
- Chinese Students and Scholars Association
- Computer Science and Engineering Graduates
- Earthquake Engineering Research Institute, student chapter (EERI)
- Global Engineers at Michigan (GLEAM)
- Institute of Electrical and Electronics Engineers (IEEE), student chapter
- Institute of Industrial Engineers (IIE), student chapter
- Intelligent Transportation Society of America, student chapter (ITSA)
- International Association for the Exchange of Students for Technical Experience (IAESTE)
- International Society for Pharmaceutical Engineering (ISPE)
- Mechanical Engineering Graduate Council (MEGrad)
- Michigan Engineering Consulting Club (MECC)
- Michigan Entrepreneurs (ME)
- Michigan Mars Society (MMS)
- Michigan Materials Society (MMS), student chapter
- Michigan Student Society of Professional Engineers (MSSPE)
- Movement of Underrepresented Sisters in Engineering and Science (MUSES)
- National Organization of Black Chemists and Chemical Engineers, student chapter (NOBCChE)
- National Society of Black Engineers (NSBE), student chapter
- Society of Automotive Engineers (SAE), student chapter
- Society of Earth and Space Students (SESS)
- Society of Hispanic Professional Engineers (SHPE), student chapter
- Society of Indian American Engineers
- Society of Manufacturing Engineers (SME)
- Society of Minority Engineering Students (SMES)
- Society of Minority Engineering Students—Graduate Component (SMES-G)
- Society of Plastics Engineers
- Society of Women Engineers (SWE)
- Taiwan Student Association (TSA)
- Unified Minority Mechanical Engineers (UMME)
- Vibrant Industrial Black Engineering Students (VIBES)
- Volunteer Computer Corps (VCC)

### Student Project Teams

Baja Car
Concrete Canoe
Formula Car
FutureCar
Human-Powered Helicoptor
Human-Powered Submarine
Micro Truck (SAE)
Michigan Mars Rover
Solar Car
Solar Electric Boat
Steel Bridge

### College Student Government and Judiciary

*Engineering Council*
*University of Michigan Engineering Council*
*1230 EECS Building*
*(734) 764-8511*

The University of Michigan Engineering Council (UMEC) is the student government of the College of

Engineering and serves as the representative for Engineering student opinions on College and University issues. The Council's work, done by committees and the executive board, includes efforts in student/faculty and student/society relations. Membership is open to all students of the College.

The Council welcomes the opinions of all students, from first-year students to graduate students, as well as their active participation in its projects. New ideas are always welcome. Those wishing to express opinions or to bring ideas to the Council should attend a Council Meeting or visit the UMEC office.

### Honor Council

The Student Honor Council, the student judiciary for the College, has the responsibility of conducting hearings and recommending action to the College of Engineering Discipline Committee in the case of alleged violations of the Honor Code or College rules of conduct.

### Honor Society

The criteria for election to an honor society is based on the rules and regulations of the respective society. In general, the criteria include a scholastic requirement.

Student members of a society are responsible for election of new members. On request, the College will provide to each society the names and local addresses of students who are eligible for election according to scholastic criteria specified by the respective society.

Membership in honor societies will be posted on the academic record upon receipt of the list of newly elected members from the secretary of the organization.

## Preparing for a Career

### Careers with an Engineering Degree

The main criteria in choosing engineering as a career are usually an interest in, and successful completion of, high school mathematics and science courses; a desire and ability to investigate the "why" as well as the "how" of things; and an interest in the creative development of devices or systems that meet specific needs.

The engineer of the future will be increasingly concerned with the preservation of our natural environment, the wise use of our natural resources, and the importance of individual creativity and initiative in the framework of a free democratic society. Certainly not all of these interests will apply to everyone, but they may be used as a rough guide.

Academic advisors of the College are glad to consult with high school or transfer students who are faced with a critical career choice or with the problem of choosing the school that best suits their interests and abilities.

First-year and undeclared students with questions in this regard may benefit from a visit to the Engineering Advising Center, College of Engineering, 1009 Lurie Engineering Center, Ann Arbor, Michigan 48109-2102.

*Registration as Professional Engineer*

Modern civilization has found it necessary to regulate the practice of persons whose activities deal with the protection of life, health, property, or other rights. A profession such as engineering is judged by the qualifications and competency of all who use its name; therefore, to provide the public with a clearly recognizable line of demarcation between the engineer and the non-engineer, the state establishes standards and provides the legal processes associated with the registration of individuals and their practices as professional engineers.

In Michigan, the State Board of Registration for Professional Engineers provides an opportunity for students during their senior year to take the first half of a 16-hour, two-part examination as the first step toward registration, provided: (1) the engineering degree is awarded within six months after the examination; and (2) the degree program has been accredited by the Accreditation Board for Engineering and Technology (ABET).

The first half of the exam covers the fundamentals common to all engineering fields of specialization including mathematics. After a minimum of four years of experience, which may include one year of graduate study, the applicant will take the second half of the examination, which will involve the application of engineering judgment and planning ability.

On completion of registration, an engineer establishes professional standing on the basis of legal requirements and receives authority to practice the engineering profession before the public. While state laws may differ in some respects, an engineer registered under the laws of one state will find that reciprocal agreements between states generally make possible ready transfer of privileges to other states.

### Other Careers

There are numerous career options with an engineering undergraduate degree. While most graduates go on to become engineers or continue with their schooling to receive an advanced engineering degree, an increasing number of Michigan Engineering graduates are pursuing nonengineering careers. Engineering is an excellent start to professional training in medicine, the law, or business.

Many engineering graduates continue their education in medical school, receive their J.D. degrees at a law school, or go after a master's degree in business. Still other graduates find that their engineering knowledge is put to good use in many communications fields, particularly journalism. A person's ability to clearly communicate increasingly technical information to mass and targeted audiences is a skill that is in much demand.

Whatever your career path, the College of Engineering has an excellent resource available to assist you in your search. Learning about careers and job-seeking skills is an education that runs right along with the engineering program. Those undergraduates—from their first year through graduation and beyond—who take advantage of the wealth of services offered through the Engineering Career Resource Center (ECRC) are among the College's most successful alumni and alumnae. These services range from skill-building to on-the-job experience.

### Engineering Career Resource Center

*230 Chrysler Center*
*Phone: (734) 647-7160*
*Fax: (734) 647-7161*
*http://career.engin.umich.edu/*

The College of Engineering considers the preparation and placement of its students in successful careers central to its overall mission. The opportunities and environments that require the comprehensive academic preparation received at the College of Engineering are broad and expanding.

As a result, students must become much more proactive in thinking about and securing careers that match their needs and goals.

The Engineering Career Resource Center (ECRC) recognizes that defining your career path can be a challenging goal, and ECRC is here to support students' efforts. Our services include the arrangement of employment interviews on campus (October-December and January-March) for graduating students and students seeking internships. ECRC provides information about position openings, career guidance and volumes of employer/career information. The center maintains EnginTrak, an on-line system for on campus interview sign-up and job postings specifically geared toward U of M students and graduates.

Students receive opportunities to explore careers in many industry sectors and to meet employers through multiple workshops and company days coordinated by the ECRC. In 2000-2001, workshops included: Strategies for Effective Interviewing, Negotiating the Job Offer, Job Search Strategies, Resume Writing and EnginTrak-Getting Started.

Internships and cooperative education positions are available and encouraged as a valuable way to identify and pursue potential careers, as well as a great source of additional income. Students may start searching and competing during their first year in anticipation of sophomore status (25-54 hours). The ECRC Office coordinates and provides support to registered internship and cooperative education students. See page 56 of this *Bulletin* for more details on cooperative education programs.

International students should be aware that some placement activity may be limited, by employer request, to United States citizens and permanent residents. In the past, employers involved in national defense work have usually interviewed only U.S. citizens.

### Other Career Advising

In addition to ECRC career services on North Campus, the Central Campus Career Planning and Placement (CP&P) office in the Student Activities Building is an excellent resource. The offices work cooperatively to provide a wide range of services for engineeering students. CP&P offers numerous workshops, employer information, a career library, and many additional services for your career development.

## Academic Rules, Rights and Responsibilities

### General Standards of Conduct for Engineering Students

In establishing a standard of student conduct, the University of Michigan is committed to the basic principles of entrusting each student with a high degree of freedom to govern his or her life and conduct while enrolled at the University.

The College of Engineering encourages its students to protect and use this freedom with wisdom and good judgment, and to accept and discharge the responsibility inherent to such freedom.

Students are expected to respect the rights and property of others and to comply with University regulations and public laws.

The College of Engineering welcomes the participation of students in decision making relevant to their affairs and provides channels of communication, both at the College and department level, for that purpose. To benefit from such activity, each student should recognize his or her responsibility to fellow students and to the faculty and staff, and should discharge all duties with the standards that make such student/college relationships effective and valuable.

The College of Engineering reserves the right to discipline, exclude from participation in relevant activities, or dismiss any student whose conduct or performance it considers unsatisfactory. Such a decision will be made only after review by the appropriate student and faculty committees. During this review, the student will have full opportunity to present his or her position. A student also has the right of appeal to the Executive Committee of the College.

The Honor Code of the College of Engineering (below) bears witness to the deep trust that characterizes the student/faculty relationships in one of the most important aspects of student conduct.

### Honor Code

The engineering profession has a long-standing record of fostering high standards of integrity in the performance of professional services. Not until the 1930s, however, was the first Canon of Ethics for Engineers developed and adopted by national professional engineering societies. The following statement relating to ethical conduct is part of the Canon as revised by the Engineers' Council for Professional Development in 1963.

"The Engineer, to uphold and advance the honor and dignity of the Engineering Profession and in keeping with high standards of ethical conduct:

1. Will be honest and impartial, and will serve with devotion his employer, his clients, and the public;
2. Will strive to increase the competence and prestige of the engineering profession, and
3. Will use his knowledge and skill for the advancement of human welfare."

In 1915, several years before the first Canon of Ethics was published, the students of the College of Engineering proposed an Honor Code. This was approved by the faculty in 1916 and has been in effect since its inception. The Honor Code truly is a distinguishing feature of enrollment in the College of Engineering. By observing the Code, students do their work in an environment conducive to establishing high standards of personal integrity and professional ethics.

As a basic feature of the Code, students are placed upon their honor during all examinations and written quizzes, and as required by the instructor, for computer questions, homework, and laboratory reports. Although the instructor is available for questions, the examination may not be proctored.

The student is asked to write and sign the following pledge at the end of the examination paper:

*"I have neither given nor received aid on this examination."*

With regard to assignments made in class, each class professor may have a different policy regarding what constitutes an Honor Code violation and it should be clearly outlined in the syllabus for the course. If a student is in doubt, the professor should be asked for clarification, not a Graduate Student Instructor (GSI). In particular, be aware that some professors allow and/or encourage group work, while others may not even allow discussion regarding homework problems.

Either a student or the instructor may report a suspected violation by calling 647-7013. The report is then investigated by the Student Honor Council and results in a recommendation to the Faculty Committee on Discipline.

The Honor Council has prepared a booklet that explains the principles and operation of the Honor

Code. The Honor Code booklet is available at the Engineering Student Services Office, 1401 Lurie Engineering Center (LEC).

*The Honor Code and Independent Study*
In general, the principles of the Honor Code also apply to homework when the instructor requires the material turned in to be the student's own work. While independent study is recognized as a primary method of effective learning, some students may find they benefit from studying together and discussing home assignments and laboratory experiments. When any material is turned in for inspection and grading, the students should clearly understand what cooperation among students, if any, is permitted by the instructor. When independent study and performance are expected, the deliberate attempt to present as one's own work any material copied from another student or from any source not acknowledged in the report is forbidden. In such cases, the instructor may require the signing of the pledge and expect the same high standards of integrity as during examinations. The instructor may report suspected violations.

## The University of Michigan Code of Student Conduct

All University of Michigan students are responsible for upholding the community standards expressed in the Code of Student Conduct (Code), which sets forth standards of non-academic conduct by students and a judicial process for resolving complaints of alleged violations of these standards.

If a student is alleged to have participated in behavior that violates both the professional standards of the College of Engineering and the standards of the Code, the College of Engineering may choose to resolve the allegations either through the College's procedures or through the procedures outlined in the Code.

Violations of the Code include: assault and battery; sexual assault; sexual harassment; hazing; stalking; harassing; possessing, use, or storing weapons; tampering with fire or other safety equipment; setting unauthorized fires; illegally possessing, using, distributing, manufacturing, or selling alcohol or other drugs; stealing, damaging, or destroying property; making or possessing falsified University documents; and violating University computer policies.

The Resolution Coordinator accepts complaints from individuals who believe a violation of the Code has occurred; investigates alleged violations; counsels students, faculty, and staff about the judicial process; assists complainants and accused students prepare for hearings and mediations; enforces sanctions and mediated agreements; and educates the University community about the Code.

The Code is published in the "University Policies Affecting Students" handbook or may be obtained on the Web at http://www.umich.edu/~oscr/. For further information, please contact the Office of Student Conflict Resolution at (734) 936-6308.

## Attendance and Absences

Regular and punctual attendance at classes is one of a number of expressions of interest and maturity. The reasons for good attendance should be obvious, and students may expect unexcused absences to be reflected in their final grade.

All students should account for their absences to their instructors. A student who has been absent from studies for more than one week because of illness or other emergency should consult the program advisor to determine the advisability of reducing elections.

A student with an unresolved problem related to absences may consult the Assistant Dean for Students.

## Examinations

Examinations may be given at any time, with or without notice, on any part of the work. An examination at the end of the term is an essential part of the work of the course. The instructor is required to observe the official final examination schedule established by the University.

Any student absent from an examination should report to the instructor as soon thereafter as possible. If a student presents a valid excuse for being absent, a make-up examination may be arranged by the instructor for another time.

## Election of Studies

### Term

A term (semester) extends over approximately four months, including examinations. The University's year-round calendar, by months, is approximately as follows:

| Term | Months | Indication |
|---|---|---|
| Fall | Sept., Oct., Nov., Dec. | I |
| Winter | Jan., Feb., Mar., Apr. | II |
| Spring/ Summer | May, June, July, Aug. | III |

The Spring-Summer term may be scheduled as two half terms, approximately as follows:

| | | |
|---|---|---|
| Spring | May, June | IIIa half term |
| Summer | July, Aug. | IIIb half term |

In the following rules and procedures, the word "term" also applies to half term unless otherwise indicated.

## Credit Hour

A credit hour (semester hour) generally represents one hour of recitation or lecture per week for a term, or two for a half term; preparation for each credit hour normally requires a minimum of three hours of study. Generally, one period of laboratory work is considered to be equal to one hour of credit.

## Course Offerings

The appropriate *Bulletin* and the *Time Schedule* prepared for each term will serve the student as a guide in planning each term's schedule. Course descriptions can be found in this *Bulletin* and on the web at: http://courses.engin.umich.edu/

The Faculty reserves the right to withdraw the offering of any elective course not chosen by at least eight persons.

## Registration (Official Enrollment)

All students must register to be officially enrolled in classes. This process includes meeting with a departmental advisor so that appropriate classes are selected. This is followed by the actual web registration process.

All students are required to have and use a Student Identification Number for registration and records purposes. More specific information about registration is available in the front of each term's *Time Schedule*.

Completion of both the advising and registration procedures is required before a student attends any classes or uses any University facilities. As of the first day of class, a $50 late registration fee will be assessed. Exceptions to the Late Registration Fee are late admissions, non-degree students, Ph.D. students registering to defend their dissertations, or students who have an official waiver based on a University action. The Late Registration Fee is increased by $25 at the beginning of each subsequent month.

Unless a student is registered, there is no obligation on the part of faculty members to permit attendance in their classes.

A student who completes the registration procedure (including early registration) and fails to attend classes must officially withdraw from the College at the Engineering Student Services Office, 1401 LEC, and pay the usual disenrollment fee as stated in the current *Time Schedule*.

## Half-Term Courses During Fall or Winter Terms (2 credits)

Begin and End dates:

- All departments will have the same begin and end dates for classes.
- For Fall and Winter Terms the first half-term course will begin on the regular first day of classes.
- For Fall, the second half term will start at the beginning of the 8th week whenever possible.
- For Winter, the start of the second half term will be the Monday immediately following Spring Break.
- Beginning days will be adjusted so that no class will begin on a Friday.

*Drop/Add Schedule*: Drop/Add periods without a "W" will end by the end of the 3rd week for both half terms.

*Fee Adjustments*: There is a three week deadline (coinciding with Drop/Add deadlines) for fee adjustments. Documentation is needed for fee adjustments after the deadline. Fee adjustments are finalized through the Registrar's Office.

***Important Note:*** Students should register for second half-term classes during the normal full-term registration period.

## Important Election Dates

***Third-week Deadline:***

- Registration portion of Wolverine Access closes.
- Election changes (drop, add, modification) need approval of instructor and program advisor and must be processed by Engineering Student Services (1401 LEC); no documentation needed for changes.
- Dropped classes recieve a grade of "W"; students must petition Scholastic Standing Committe (1420 LEC) and document non-attendance for drop without record.

***Ninth-Week Deadline:***

- Election changes must be petitioned through the Scholastic Standing Committee (1420 LEC); documentation needed for any change.
- Drop/Add Deadlines on page 3 of *Bulletin*.

## Drop/Add Policy (Change of Elections)

During the first three weeks of classes (first two weeks in a half term), students may drop without a "W." **The third week through the tenth week of classes (second week through the four-and-a-half week in a half term),** students must bring Drop/Add forms, that have been signed by the instructor and the program advisor, to the Engineering Student Services Office, 1401 LEC. A "W" will then appear on the transcript.

**After ten weeks up to the last day of class** the Drop/Add form must include a petition with documentation of extenuating circumstances and the signatures of the instructor and the program advisor. The petition must be turned in to the Scholastic Standing Committee (SSC) administrator in 1420 LEC. **All petitioned drops and adds will be ultimately reviewed and either approved or disapproved by the Scholastic Standing Committee.**

The only approved drops will be for those students who present written evidence of extenuating circumstances; i.e., severe health problems, prolonged illness in the family, etc. Poor performance is not an acceptable circumstance. Approved drops will be posted to the official record with a "W."

A form for petitioning to drop a class due to extenuating circumstances may be obtained from the SSC administrator, 1420 LEC, or the student's departmental advising office.

The grade for any course dropped without the permission of the program advisor or the College of Engineering Assistant Dean for Students will be recorded as "ED" (unofficial drop) and computed as "E" in the averages.

Junior and senior students enrolled in a Military Officer Education Program must also have approval of the Chairman in charge of the unit before they can drop a Military Officer Education Program course or be relieved of the obligation assumed when enrolling in the program.

## Pass/Fail Option

Elective courses in Humanities and Social Sciences or courses to be used as Unrestricted Electives can be taken pass/fail. The pass/fail total is not to exceed four courses or 14 credit hours and is limited to two courses per term or one in a half term. Any course that is offered only on a pass fail basis will not be counted in the above totals. The Engineering 100 and Senior Technical Communication courses cannot be elected as pass/fail courses. **Courses elected pass/fail which exceed the limitations stated above cannot be applied in any way to a degree program and will revert to the grade earned.** Passed courses, however, will appear in the cumulative totals. The following regulations will apply:

1. The decision to elect a course on a pass/fail basis or on a graded basis must be made within the first nine weeks of the term (or first four-and-one-half weeks of a half term). No changes in election as a graded course or as a pass/fail course can be made after the ninth week (or first four-and-one-half weeks) of a term.
2. Instructors are not notified of pass/fail elections; they will report grades as usual, "A+" through "E." The University of Michigan Registrar's Office will then translate grades as follows:
   a. A grade of "C-" through "A+" in a course elected on a pass/fail basis is considered satisfactory and will be recorded as "P" (pass—for credit toward the degree and no effect on the grade point average).
   b. A grade of "D+" or lower in a course elected on a pass/fail basis is considered unsatisfactory and will be recorded as "F" (fail—no credit and no effect on grade point average).
3. To be eligible for the Dean's Honor List, a minimum of 12 credit hours (6 for a half term) must be elected for grades, with a grade point average of 3.5 or better.

4. To be eligible for Recognition on the Diploma, a minimum of 45 hours of credit must be completed with a grade point average of 3.2 or better.
5. If a student completes a course for pass/fail and subsequently changes the degree program of study to one in which the course comes into conflict with the stated constraints for pass fail elections in the new program, the course will be accepted in the new program as follows:
   a. A record of "P" (pass) is regarded as a satisfactory completion of the program requirement.
   b. A record of "F" (fail) is regarded as unsatisfactory completion and the course must be repeated for grades.

### Courses Offered on a Pass/Fail Basis Only

A department or instructor may offer an undergraduate pass/fail course on the following bases:

1. The instructor will report the grade as pass fail for each student enrolled.
2. The grade will be treated the same as when the student chooses to elect a course on a pass/fail basis if the following conditions are satisfied:
   a. The course is not required for any program or department.
   b. It is the type of course which might be considered appropriate to a pass/fail grading system. Examples of such courses may include: design, survey-type, individual directed research, laboratory, or undergraduate seminars.
   c. The pass/fail nature of the course is announced by the instructor at the beginning of the term, and, with the exception of individual instruction courses, in the *Time Schedule*.

### Visit

With permission of the course instructor, a student may enroll in a course as a visitor. In such a case, the course will be entered on the permanent record with a "VI" instead of a letter grade. The same fee will be charged whether the student enrolls for credit or as a visitor.

A change in elections from credit to visit must be made during the first nine weeks of a term (the first three weeks of a half term). Signed petitions are required after this point. Required courses may not be elected as a visit.

### Program Selection

A student normally selects a program of study during the second term of the freshman year and is referred to the appropriate program advisor. Students who have not selected a program by the time they reach 55 credit hours, or who wish to change degree programs after they have reached 55 credit hours, must consult with the program advisor in the desired program. *Due to increasing enrollment pressures, the College of Engineering may restrict student enrollment in certain programs.*

### Changing or Adding a Program

When students wish to change from one program to another, or to elect an additional program, they must consult the program advisors of the programs involved and obtain the necessary approvals on a form supplied by the Engineering Student Services Office, 1401 LEC.

Transfer students or continuing students who have earned 55 credit hours or more are subject to grade point averages and quotas approved by the Executive Committee of the College of Engineering for admission to the various degree programs.

### Grade Grievances Procedure

If there is justification to question the accuracy of an assigned grade, the student should first pursue the matter with the instructor. The responsibility for the assignment of grades is primarily that of the instructor and should be settled between the student and instructor whenever possible. Further pursuit of a grade grievance should be addressed with the instructor's Department Chair. The final appeal at the College level is by petition to the Assistant Dean for Students

### Student Grievances

The College of Engineering has a grievance procedure to address student complaints. Students should follow these steps until a resolution is achieved:

1. Attempt to resolve the grievance directly with the individual involved (faculty member, staff member, or fellow student).
2. If the matter is unresolved, and the grievance is with a faculty member or teaching assistant, discuss the grievance with the appropriate department chair.
3. If the issue is still unresolved, undergraduate students should see the Associate Dean for Undergraduate Education. Graduate Students should see the Associ-

ate Dean for Graduate Education. Both are located in the Robert H. Lurie Engineering Center.

4. All students have the right to appeal to the Dean of the College if they feel their grievances have not been resolved satisfactorily by another dean.

### Substitution

Substitution of a course for one which is a requirement for graduation must be approved by the program advisor of the student's degree program.

## Transferring Out, Withdrawing, and Readmission

### Transferring Out

A student who wishes to pursue studies in another unit of the University must apply for admission to that unit and be accepted in order to continue enrollment in the University. A student must be in good scholastic standing to be eligible for admission to other colleges.

The College of Engineering Assistant Dean for Students may be consulted for transfer procedures.

### Withdrawing

Prior to the first day of classes, a student may disenroll through Wolverine Access. To withdraw after the beginning of classes, (through the tenth week) the student must complete a Withdrawal Notice form at the Engineering Student Services Office, 1401 LEC. **A "W" will appear on the transcript when it occurs after the first three weeks of the term (first two weeks for a half term).**

**After the tenth week of term (four-and-one-half weeks for a half term), a student requesting a term withdrawal must complete a withdrawal notice form from the Scholastic Standing Administrator's Office, 1420 LEC. Students who withdraw at this point will not be able to enroll for at least a full term**. If there are extenuating circumstances, a student may petition the Scholastic Standing Committee. Disenrollment fees vary. A fee schedule, including deadlines, is printed in the University *Time Schedule*.

### Readmission

A student who is not enrolled for 12 months or more must apply for readmission through the Office of Recruitment, Transfer Admissions and Scholarships, and should do so at least two months before the date of desired enrollment. Readmitted students are subject to the rules in effect at the time of readmission.

Students who have graduated from the College and wish to elect courses for an additional term, must seek readmission through the Office of Recruitment, Transfer Admissions and Scholarships. A student whose enrollment has been withheld must first be reinstated on probation by the Committee on Scholastic Standing.

## Grades and Scholastic Standing

### Academic Record

Each student's "Academic Report" is the cumulative record of courses elected and grades of the student while enrolled at the University of Michigan.

An individual may obtain an official copy of his or her academic record from the Office of the Registrar at no charge. An unofficial copy of the Academic Report may be obtained through Wolverine Access.

(See the *Time Schedule* for complete information about Wolverine Access.)

Students electing Study Abroad classes through the U-M Office of International Programs (OIP) will receive credit hours and the appropriate number of grade points (see below). OIP grades will be averaged into the student's overall GPA.

### Grade Reports

Unless withheld for infringement of rules, each term's grades are reported to the student. Students may also obtain their grades and class schedules through Wolverine Access.

### Good Scholastic Standing

To be in good scholastic standing at the end of any term a student must have a term and cumulative grade point aver-age of 2.00 or more. Each course which is graded with "A+" through "E," or "ED," is included in the computations.

### Averages

The term grade point average (GPA) and the cumulative grade point average are computed for each student at the end of each term and become part of the academic record. The grades are valued per hour of credit as follows:

A + ........................................ 4.0 grade points
A ........... excellent .............. 4.0 grade points
A - ........................................ 3.7 grade points
B + ........................................ 3.3 grade points
B .......... good ...................... 3.0 grade points
B - ........................................ 2.7 grade points
C + ........................................ 2.3 grade points
C .......... satisfactory ........... 2.0 grade points
C - ........................................ 1.7 grade points
D + ........................................ 1.3 grade points
D ........................................... 1.0 grade points
D - ........................................ 0.7 grade points
E ........... not passed ........... 0.0 grade points
ED ......... unofficial drop ...... 0.0 grade points

**These items do not affect grade point averages:**

P ........... passed (See Pass/Fail Option)
F ............ not passed (See Pass/Fail Option)
I ............ incomplete
W .......... approved drop
VI .......... audit
NR ......... no report

In the remainder of this section of the *Bulletin*, the term "A grade" applies to any of the grades "A+ through E.

**The grade point average is computed by dividing the grade points (Michigan Honor Points or MHP) by the hours attempted (Michigan Semester Hours or MSH).**

Grades associated with transfer credit are neither recorded nor used in computing the cumulative average. The only exception to this rule is for courses elected on the Ann Arbor campus (effective November 1986).

**A course elected under pass/fail option does not affect the grade point average.**

### Standards Governing Scholastic Standing for Unsatisfactory Performance

All students will be in one of the following classifications:

a. Good Standing—better than 2.00 GPA* for both the term and the cumulative average

b. On Probation—a deficiency up to 10 MHP*(0.001-9.999) for the term or cumulative

c. On Enrollment Withheld—a deficiency of 10 MHP* or above for the term or cumulative

d. Reinstated on Probation—10 or more MHP* deficiency or three times Probation-Enrollment Withheld, but reinstated by the Scholastic Standing Committee.

*GPA is Grade Point Average; MHP is Michigan honor points.

**Honor Point Deficit Calculation***

(Michigan Semester Hours x 2) - Michigan Honor Points = Honor Point Deficit

**Use cumulative totals to calculate cumulative deficit; use term totals to calculate term deficit. Totals reflect number of 'B' credits needed to raise cumulative or semester GPA above 2.0.*

**Example:**

| Fall 1999 | Grade | Hours | MSH | CTP | MHP |
|---|---|---|---|---|---|
| ECON 101 Principle Econ I | C- | 4.00 | 4.00 | 4.00 | 6.80 |
| ENGR 101 Comp&Prog | B | 4.00 | 4.00 | 4.00 | 12.00 |
| MATH 115 Calculus I | D | 4.00 | 4.00 | 0.00 | 4.00 |
| PHYS 140 General Phys I | D- | 4.00 | 4.00 | 0.00 | 2.80 |
| **Term Total GPA: 1.600** | | **16.00** | **16.00** | **8.00** | **25.60** |

The GPA is figured by dividing Michigan Honor Points (MHP) by Michigan Semester Hours (MSH): 25.6 MHP / 16.00 MSH = 1.600 GPA.

The term honor point deficit is calculated by multiplying MSH by 2 and subtracting MHP: (16.00 MSH x 2) - 25.60 MHP = 6.4 honor point deficit.

Thus, this student needs 6.4 credits of 'B' grades to raise his/her term GPA above 2.00.

Scholastic standing action will be determined as follows:

*Probation*

When a student has a deficiency of 0.001 to 9.999 MHPs on either the term or cumulative GPA, the student is placed on probation. The notation "Probation" will be entered on the Academic Record. A student on probation may continue enrollment, but must consult with a program advisor regarding course selection for the following term. Probation is a serious warning that there is a need to improve scholastic performance or further enrollment may be jeopardized.

*Enrollment Withheld*

A student will have the notation "Enrollment Withheld" put on his/her academic record and not be allowed to enroll for classes if: a) on Probation for the third time and each time thereafter; or, b) a deficiency of 10 MHP or more for either the term or the cumulative GPA.

Three (3) Enrollment Withheld (EW) notations will require a student to take a leave from the College of Engineering for one (1) full term (Fall or Winter)*. The student will receive a letter from the Scholastic Standing Committee (SSC) stating that he/she will not be eligible to enroll in the College of Engineering the full semester following the 3rd EW. If a student with 3 EW's intends to return to the University of Michigan after the required leave, he/she is expected to contact the Office of Student Leadership and Academic Services (SLAS). SLAS, in consultation with the student's academic advisor, will assist the student in developing a plan for addressing the factors that are impacting his/her academic performance. It is important that the student initiate the contact with SLAS within one month after leaving school to ensure full utilization of support resources. The only exception from the required leave policy is if the student was reinstated during the previous semester and met all requirements agreed to by the student and the SSC.

If granted reinstatement after a required leave, the student will have one term to meet the reinstatement conditions as determined by the student and the SSC. Failure to do so will result in permanent dismissal from the College.

*Students receiving their 3rd EW at the end of the Winter term will not be eligible to enroll in the Spring, Summer, Spring-Summer or Fall terms at the University of Michigan.

When a student is on "Enrollment Withheld," the student must submit a petition in writing to the Scholastic Standing Committee (SSC) requesting reinstatement. The petition must be discussed with the program advisor. It should document the reasons for the unsatisfactory performance, and it should offer sufficient and convincing evidence that another opportunity is warranted. If illness has been a factor, please include supporting information, including a statement (with dates) from your physician. Documentation supporting other contributing factors must also be included. This petition should be given to the SSC Administrator, 1420 LEC, by the end of the first week of the following term. Failure to petition the SSC in time and failure to follow the prescribed procedure will result in forfeit of the right to petition for reinstatement for that term and disenrollment from the college.

Petitions are reviewed by the Scholastic Standing Committee. Students may be called in for a meeting with the Committee. Arrangement for appointments and petition forms are done through the SSC, 1420 LEC, (734) 647-7115. Consultations and advice about the procedure can be obtained from the Director of Student Leadership and Academic Services, 1408 LEC.

### Scholastic Standing Committee

*1420 Lurie Engineering Center (LEC)*
*Phone: (734) 647-7115*
*Fax: (734) 647-7126*

The Scholastic Standing Committee (SSC) is comprised of faculty representatives (currently nine) and Student Leadership and Academic Services (SLAS) staff members (currently three). Faculty members are appointed for a threee-year term. The SSC studies problems related to scholastic performance and recommends criteria for defining scholastic deficiencies and for reinstating students whose enrollment is withheld according to the rules of the College. The SSC reviews the petitions of students seeking reinstatement, determining who is reinstated and the conditions thereof. Students seeking reinstatement may be required to meet with the SSC, where two Committee members (usually one staff representative and one faculty representative) hear the student's case and outline the conditions of reinstatement or the reasons for permanent or temporary dismissal. In addition, the SSC reviews all petitions within the College, including the Petition for Request for Late Drop/Add, the Petition for Exception to College Rules and the Petition for Retroactive Action for an Entire Term.

It is the policy of the College and the Scholastic Standing Committee not to reinstate students with 128 credit hours solely for the purpose of improving their grade point average or removing an honor point deficiency to meet the 2.0 cumulative grade point average requirement for the baccalaureate (B.S.E. or B.S.) degree requirements.

### C- and D Grades

Credit is allowed for a course in which a grade of "C-" or "D" is earned while enrolled in the College of Engineering. The "D" level of performance is not considered satisfactory for a course that is a prerequisite for a later-elected course; in this case, the course must be repeated before electing the next course unless waived by the Assistant Dean for Students in the Engineering Advising Center or the program advisor (for students who have declared a program). A grade of "C-" is not a satisfactory level of performance in some programs and is not acceptable in any program for the

Engineering 100 course. It is the student's responsibility to review such performance with the advisor as soon as the grade is known in order to make any changes that may be necessary in elections.

Transfer credit will be granted for courses taken outside the University of Michigan, Ann Arbor campus, provided a grade of "C" or better is earned. Transfer credit will be granted for courses taken in any academic unit at the University of Michigan, Ann Arbor campus, provided a grade of "C-" or better is earned. Students should be aware that some programs limit the number of "C-" grades or require that courses completed with a "C-" or lower grade be repeated.

### E Grades

Neither credit nor Michigan Honor Points are granted for a course in which a student earns the grade of "E." A course required by the student's program must be repeated as soon as possible.

### Incompletes

When a student is prevented by illness, or by any other cause beyond the student's control, from taking an examination or from completing any part of a course, or if credit in a course is temporarily withheld for good reason, the mark "I" may be reported to indicate the course has not been completed. This mark should be used only when there is a good probability that the student can complete the course with a grade of "D-" or better. As soon as possible the instructor and student should mutually understand the reasons for the "I" mark and agree on methods and timeline for completing the work.

No qualifying grade will be recorded on the student's academic record. The "I" mark will not be used in computing either the term or cumulative grade point averages. Scholastic standing at the end of any term is determined on the basis of work graded as "A+" through "E," or "ED."

The required work may be completed and the grade submitted by the instructor whether or not the student is enrolled. The student should plan to complete the work as soon as possible. To secure credit, the required work must be completed by the end of the first term (not including spring-summer term) in which the student is enrolled after the term in which the "I" mark was recorded. It is the student's responsibility to remind the instructor to send a supplementary grade report to the Office of the Registrar when the work is completed. If the final grade is not reported by the last day of exams, the Registrar will automatically change the "I" to an "E."

### Other Irregularities

Irregularities associated with a failure to submit changes in academic status are identified on the student's Academic Record by an appropriate designation such as "ED" (unofficial drop), or "NR" (no report). No credit will be granted to a student for work in any course unless the election of that course is entered officially on the proper form. Unofficial drop ("ED") will be considered the same as an "E" in computing the term and cumulative averages and will affect the scholastic standing.

If there has been an error, the student must consult the Assistant Dean for Students on the necessary procedures for resolving such cases. An "NR" (no report) will be changed to "ED" if the student initially elected the course and takes no action to have it cleared by the end of the next term enrolled.

### Repeating Courses

For "C-," "D" and "E" grades, see above. Except as provided for grades "C-" through "D-," a student may not repeat a course he or she has already passed. In exceptional cases, this rule may be waived by the student's program advisor (for first-year students, the Assistant Dean for Students) after consultation with the department of instruction involved. If the rule is waived, the course and grade will appear on the transcript, but no additional credit or Michigan Honor Points (MHPs) will be granted.

A student repeating a course in which a "C-" through "D-" was previously earned will receive MHPs but no additional credit. Both grades are used in computing the grade point average.

## Academic Honors and Awards

### The Dean's List (College of Engineering)

Students pursuing an undergraduate degree who elect courses and complete a minimum of 12 credit hours with grades (6 for a half term) and earn a 3.50 GPA term average or better, attain the distinction of the Dean's Honor List for the term.

### Class Honors (The University of Michigan)

Students who elect a minimum of 28 credits in courses taken on the Ann Arbor campus during a calendar year (January 1 through December 31), including a minimum 20 credits elected on a graded basis, and who earn a 3.5 grade point average, are eligible for Class Honors. Incoming first-year students and transfer students who elect a minimum of 14 credits during the fall term, including a minimum of 10 graded, and who earn at least a 3.5 grade point average, are also eligible for Class Honors. This distinction is posted on a student's transcript by the University Registrar's Office. Recipients of this honor are invited to attend the annual Honors Convocation.

### Angell Scholar (The University of Michigan)

James B. Angell Scholars are students who earn all "A+," "A," or "A-" grades for two or more consecutive terms based on a minimum 12 graded credits elected each term; all other grades must be "P," "S," or "CR." Terms of fewer than 12 credits completed with grades of "A+," "A," "A-," "P," "S," or "CR" enable a student to maintain standing as an Angell Scholar. Any other grades earned during a full or half term make a student ineligible for this honor. This distinction is posted on a student's transcript by the University Registrar's Office. Recipients of this honor are invited to attend the annual Honors Convocation.

### Branstrom Award (The University of Michigan)

Students in the top five percent of the freshman class are eligible for this honor, administered by the University Registrar's Office, if they have earned at least 14 graded credits at Michigan. A book with an inscribed nameplate is presented to each student. Recipients of this award are invited to attend the annual Honors Convocation.

### Marian Sarah Parker Scholars (College of Engineering)

The Marian Sarah Parker Scholars Program is a joint program of the College of Engineering and the U-M Women in Science and Engineering (WISE) Program. The Parker Scholars Program invites those women who have attained a cumulative grade point of 3.0 or better, by Fall Term of their junior year, to participate in a two-year exploration of graduate school. Participation as a Marian Sarah Parker Scholar leads to a greater understanding of the graduate-school process by means of seminars, panel discussions, and an academic research project.

### Special Awards (College of Engineering)

The College gives special recognition to students with high scholastic achievement, with records of service to the College and its student organizations, or with evidence of extraordinary potential for leadership. Information on qualification requirements can be obtained in the office of the Associate Dean for Undergraduate Education.

### Society Recognition (College of Engineering)

Distinguished scholarship and service to the College are also recognized by election to a number of honor societies that are listed under "Co-curricular Opportunities" on page 35. A student's election to a recognized society will be posted on the Academic Record.

### Recognition on Diploma (College of Engineering)

A student graduating with at least 45 hours of credit completed, with grades, while enrolled in this College (or as directed by the Executive Committee) will be recommended for a degree(s) with recognition on the diploma if the student qualifies according to the following:

| Grade Point Average | Distinction |
|---|---|
| 3.20–3.49 | *cum laude* |
| 3.50–3.74 | *magna cum laude* |
| 3.75–4.00 | *summa cum laude* |

## Requirements for a Bachelor's Degree

### Time Requirement

The time required to complete a degree program depends on the background, abilities, and interests of the individual student. Note: A full-time schedule averaging 16 hours of required subjects will allow a student to complete the degree requirements (128 credit hours) in eight terms as noted in the sample schedules appearing with the program descriptions.

A student who is admitted with advanced preparation, with demonstrated levels of attainment, or with ability to achieve at high levels may accelerate his or her progress. A student who elects a Military Officer Education Program or who is partially self-supporting while at the campus may find it desirable to plan a schedule longer than eight terms.

A student who plans to continue studies beyond the bachelor's degree may (after attaining senior standing) elect a limited number of graduate-level courses concurrently with the courses required for the bachelor's degree. A course required for the bachelor's degree generally cannot be used for graduate credit also. For details, refer to the regulations published by the University of Michigan Horace H. Rackham School of Graduate Studies.

(See additional options available within the "Simultaneous Graduate/Undergraduate Study" [SGUS] program, described on pages 200-203.)

### Requirements for a Bachelor's Degree

To obtain a bachelor's degree in the College of Engineering, Ann Arbor campus, 128 credit hours—120 credit hours for AOSS—must be earned and a student shall meet the following requirements, subject to approval of the program advisor:

1. The student must achieve a satisfactory level in those subjects specified by the program of his or her choice. A grade of "D" in a required course may not be considered satisfactory unless approved by the program advisor. A student may receive credit toward a degree in one or more of the following ways:
   a. By passing a course for credit on the Ann Arbor campus ("D" grades may not be acceptable as a proper level of attainment for a required course, as noted above.)
   b. By Advanced Placement Program examination for college-level work completed in high school (See "Advanced Placement," under "Admission.")
   c. By an examination regularly offered by a department of the University, or by a recognized testing service.
   d. By transfer of equivalent credit from another recognized college (See "Adjustment of Advanced Credit" on page 20.)
   e. By demonstrating qualification for enrollment in a higher-level course or series (e.g., honors-level).
   f. By demonstrating equivalent and parallel knowledge that enables the student to enroll at an advanced level: In this case, the student will not be allowed credit hours on the Academic Record, but may be excused from enrolling in courses in which the program advisor judges the student proficient. To qualify, the student must petition the program advisor and, as a condition, may be required to demonstrate his or her proficiency by an appropriate examination.
2. The student must accumulate a final grade point average of 2.00 or more for all credit hours not taken under the pass/fail option while enrolled in the College of Engineering. In addition, a student must earn a cumulative grade point average of 2.00 or higher in all courses taken within the student's academic department. Consult your department for additional information.
3. The student must complete at least 30 of the last 36 credit hours of work while enrolled in the College of Engineering, Ann Arbor campus.
4. The student must complete a minimum of 30 credit hours of advanced level (300 or higher) courses, as required by the degree program while enrolled in the College of Engineering, Ann Arbor campus.
5. The student must file formal application for the diploma. (See "Diploma and Commencement" below.)

### Requirements for an Additional Bachelor's Degree

1. To obtain two bachelor's degrees (including prescribed) in the College of Engineering, a student must complete the requirements of both degree programs. In addition, for the second degree, the student must complete at least a minimum of 14 credit hours in pertinent technical subjects over the number required for the first degree. The credit hours that are used to satisfy each of the two programs also must satisfy the cumulative grade point average requirement of 2.00 or more. Approval by involved departments is required.
2. To obtain an additional bachelor's degree in the College of Literature, Science, and the Arts (LS&A) or the School of Music, refer to program requirements under "Combined Programs" with LS&A.

## Diploma and Commencement

For the College of Engineering to recommend the granting of a degree, a student who satisfies all other requirements must also file formal application for the diploma. A student completing the requirements for more than one degree in the College of Engineering or a second degree in LS&A must file an application for each.

The application must be submitted to the student's department office at the beginning of the term in which the student is reasonably certain of completing the work for the degree.

When a student does not meet the requirements as planned, the student must renew the application at the appropriate time. Degrees are awarded at the end of the fall, winter, and spring-summer terms.

All students who are entitled to receive diplomas are expected to be present at the Commencement exercises appropriate to the date of graduation. Making all arrangements for attending is the student's responsibility.

## Undergraduate Education Mission

The Mission of the undergraduate degree programs of the University of Michigan College of Engineering is to prepare our graduates to begin a lifetime of technical and professional creativity and leadership in their chosen fields.

### Undergraduate Educational Objectives

Prepare students for professional creativity and leadership in their chosen fields by:

- Providing students with a comprehensive education that includes in-depth instruction in their chosen fields of study.
- Emphasizing analysis and problem solving, exposure to open-ended problems, and design studies
- Fostering teamwork, communication skills, and individual professionalism including ethics and environmental awareness.
- Providing adequate co-curricular opportunities that cultivate lifelong learning skills.

### Undergraduate Educational Outcomes

Graduates of the College's undergraduate programs will have:

1. An ability to apply knowledge of mathematics, science, and engineering within their chosen field.
2. An ability to formulate engineering problems and develop practical solutions.
3. An initial ability to design products and processes applicable to their chosen field.
4. An ability to design, conduct, and interpret the results of engineering experiments.
5. An ability to work effectively in diverse teams and provide leadership to teams and organizations.
6. An ability for effective oral, graphic, and written communication.
7. A broad education necessary to understand the impact of engineering decisions in a global society/economic/environmental context.
8. An understanding of professional and ethical responsibility.
9. A recognition of the need and an ability to engage in life-long learning.
10. A broad education necessary to contribute effectively beyond their professional careers.
11. A sense of responsibility to make a contribution to society.

In this edition of the College of Engineering *Bulletin*, our traditional "Sample Schedule for Required Programs" has been updated to reflect the current plans in each department and program for undergraduate engineering curriculum revision. It is important to note that the curriculum revision process is an ongoing one; therefore, the program requirements and specific course requirements, especially upper-division courses, listed here should be viewed as works-in-progress.

***Important Note:*** Each department's Program Advising Office and Web site information has been provided for your assistance in obtaining specific program changes.

## Undergraduate Degree Options

### Undergraduate Engineering Degrees

Each of the undergraduate degree programs has base core requirements that are common to all Programs. The remaining hours identify the majors or fields of specialization in which students will obtain a bachelor's degree as indicated for each program. In most cases, these may be classified as: Advanced Mathematics and Science; Related Technical Subjects; Program Subjects; Technical and Unrestricted Electives.

Many of the courses required for one program may be transferred to meet the requirements of another. This opportunity to obtain two undergraduate engineering degrees must be discussed with the pertinent program advisor.

There are 15 undergraduate programs of study. They are:

*Bachelor of Science in Engineering (B.S.E.) degree programs*

Aerospace Engineering
Chemical Engineering
Civil Engineering
Computer Engineering
Computer Science
Electrical Engineering
Engineering Physics
Industrial and Operations Engineering

Materials Science and Engineering
Mechanical Engineering
Naval Architecture and Marine Engineering
Nuclear Engineering and Radiological Sciences

*Bachelor of Science (B.S.) degree programs*
Atmospheric, Oceanic and Space Sciences
Biomedical Engineering
Interdisciplinary Program—Engineering

### Choosing One of the Degree Programs

While the entering first-year student does not need to select a specific field of engineering, there is some advantage to arriving at a decision early. To help the student with a choice, the departments will schedule a series of group meetings that provide information about each of the programs and related career opportunities. If additional help is needed, the student should consult with an academic or program advisor. The degree program in which a student plans to graduate should be selected during the second term.

Admission to a degree program depends on the student being in good standing and having completed the first-year-student-level mathematics, chemistry, physics and digital computing courses. Transfer to a program involves obtaining the necessary approval forms from the degree program office selected. In addition, the Executive Committee of the College of Engineering, following a request of a particular degree program, may find it necessary to restrict admission to that program, based on grade point averages in mathematics, chemistry, physics, and digital computing courses elected in the first year.

Students should contact the Engineering Advising Center if they have any questions concerning program changes.

Students who have not selected a program by the time they complete 55 credit hours, or who wish to change degree programs after they have reached 55 credit hours, are subject to grade point averages and restrictions approved by the Executive Committee of the College of Engineering for admission to the various degree programs. Due to increasing enrollment pressures, the College of Engineering may restrict student enrollment in certain programs.

### Dual Baccalaureate Degree Opportunities

Students with interest in more than one program offered by the College may work for two bachelor's degrees concurrently if they plan the course elections carefully. Students will find that it is possible to satisfy the subject requirements of both programs in a minimum amount of time by conferring early with the respective program advisors. Opportunities to obtain an additional bachelor's degree in the College of Literature, Science, and the Arts, the School of Music, and other academic units are also available.

### Combined Degree Programs

*Simultaneous Bachelor's Degrees from the College of Engineering and the College of Literature, Science, and the Arts*

Students enrolled for a bachelor's degree in the College of Engineering or the College of Literature, Science, and the Arts (LS&A) may obtain the degrees in both colleges simultaneously by enrolling in the Combined Degree Program that has been established by the two colleges, and by fulfilling the requirements as outlined on the next page. This program has been developed to make it convenient for students to obtain a broader education than would normally be possible by enrolling in only one college.

It is particularly advantageous for students who wish to develop some depth of understanding in both the technically oriented studies offered in the College of Engineering and the physical, natural, or social sciences and humanities available in LS&A. Such a combination can provide a truly liberal education in the contemporary sense and should be excellent preparation for meeting the challenges of modern society, which involve, to an ever-increasing extent, both technical and sociological issues.

*Program Requirements:*

Candidates for a Bachelor of Science in Engineering (B.S.E.) or Bachelor of Science (B.S.) combined with a Bachelor of Arts (B.A.) in LS&A must:

- satisfy the requirements of one of the degree programs in the College of Engineering;
- take a minimum of 90 credit hours of work in LS&A, satisfy the distribution requirements of LS&A, and fulfill the concentration requirements for one of the LS&A programs; and
- have a cumulative grade point average of 2.00 or higher.

Candidates for a Bachelor of Science in Engineering (B.S.E.) or Bachelor of Science (B.S.) in the College of Engineering, combined with a Bachelor of General Studies (B.G.S.) in LS&A must:

- satisfy the requirements of one of the degree programs in the College of Engineering;
- take a minimum of 90 credit hours of work in LS&A of which 40 credit hours must be for courses numbered 300 or higher and are passed with a grade of "C" or higher, with no more than 15 of these 40 credit hours to consist of courses in any one department; and
- have a cumulative grade point average of 2.00 or higher.

Students transferring to the University of Michigan with advanced standing and entering a Combined Degree Program must complete a minimum of 60 credit hours of work in LS&A in residence.

All students should consult the program advisors in their field of specialization in each college each term to develop an optimum set of courses for the particular combination of fields of specialization of interest to them.

In general, advisors working with students in this Combined Degree Program will attempt to minimize the total number of courses required by recommending those that will contribute toward fulfilling requirements in both colleges whenever possible. Thus, many of the courses needed to fulfill the requirements in mathematics, chemistry, and physics in the College of Engineering will contribute toward fulfilling natural science distribution requirements and prerequisites for concentration in fields such as astronomy, chemistry, geology-mineralogy, mathematics, and physics in LS&A.

Likewise, requirements in literature, humanities, and social sciences for the College of Engineering can be selected from courses taken to fulfill distribution requirements in LS&A. In this way, it is usually possible for students carrying average loads of 16 credit hours per term to complete the requirements of this Combined Degree Program in 10 or 11 terms.

In order to ensure that the courses selected apply effectively and efficiently to both degrees, students must assume responsibility for maintaining liaison between their two advisors. They should become thoroughly familiar with the general regulations and procedures of both colleges and with the academic requirements and course offerings in both fields of specialization as set forth in the *Bulletin* of each college. If unusual difficulties or special problems arise, students should consult the Combined Degree Program advisors who will work with the students and their faculty advisors in attempting to find a solution.

*Regulations*

The following regulations for enrollment will apply:

1. Students initially enrolled in either the College of Engineering or LS&A may enter this Combined Degree Program.
2. To be qualified for admission, students normally should have completed 30 credit hours of the appropriate course work. LS&A students must have an overall grade point average equal to, or higher than, the current minimum grade point average for cross-campus transfer for the particular engineering degree sought. Engineering students must have an overall grade point average of at least 2.7.
3. Students considering this program should consult the College of Engineering Assistant Dean for Students to apply for admission and to establish advising procedures as soon as their interests are firmly established, preferably by the end of the first year.
4. Upon applying for admission, students must choose a field of specialization in each college. Application for admission must then be approved by the assistant dean of each college and by the academic advisor in each of these fields of specialization.
5. After being admitted to this program, students will continue to register in the college in which they first enrolled, and that college will be responsible for maintenance of their primary academic records.
6. Students participating in this program should consult with the program advisor for their field of specialization in each college prior to classification each term, to obtain approval of course elections.
7. To be permitted to continue in this Combined Degree Program, students must satisfy the requirements of both colleges with regard to good scholastic standing.
8. Students in good scholastic standing who wish to withdraw from this Combined Degree Program may continue to enroll for a single degree in their original

college. If they wish to transfer, they may do so provided their record is acceptable to the other college. For instructions regarding transfers, students should consult the assistant dean of the college in which they are registered. Students not in good scholastic standing will normally remain in the college in which they initially enrolled and be subject to the rules of that college.

9. Upon satisfying the program requirements of both colleges, students will receive both degrees on the same date. At the beginning of the term in which they expect to graduate, they must file a diploma application in each college.

*Combined Degree in Music and Engineering*

This program is designed to allow students to develop a course of study that offers broader academic opportunities than those offered by either the College of Engineering or the School of Music. The program is intended for students who seek the technical studies associated with the College of Engineering in combination with the professional training in applied or academic musical studies associated with the School of Music. These dual degrees are open to students enrolled in either the College of Engineering or the School of Music. They lead to concurrent bachelor's degrees from both units, and are intended primarily for students who were admitted as first-year students to both units.

Each student should consult faculty advisors in both engineering and music to develop the best plan of study. Primary responsibility for planning the academic program and continued contact with academic advisors in the two fields rests with the student, who is also responsible for becoming familiar with the academic policies and procedures of both units and the academic requirements in both fields as described in the Bulletin of the College of Engineering and of the School of Music. The student is responsible for maintaining contact with the appropriate engineering department (Engineering Advising Center, if undeclared) in order to receive proper advising for course selection, etc.

Candidates for the combined Bachelor of Science in Engineering (B.S.E.) and music degree (B. Mus., B.M.A., or B.F.A.) must: (a) complete one of the degree programs in the College of Engineering; (b) complete one of the degree programs in the School of Music (usually 90 credits); and (c) maintain a minimum cumulative grade point average of 2.00 and good scholastic standing in both the College of Engineering and the School of Music. It is usually possible for students electing 16-17 credits per term to meet all requirements in 11 or 12 terms.

Students interested in this program will be admitted as first-year students into both the College of Engineering and the School of Music.

Students who are dually enrolled and decide not to pursue a degree from the School of Music do not have to reapply for admission to the College of Engineering.

*Simultaneous Graduate/Undergraduate Study (SGUS) in Engineering*

This program is designed to provide depth and breadth of subject and economies of time to the student. With careful planning, the student will work toward completion of both an engineering baccalaureate and master's degree within a five-year course of study. Admissions and course requirements vary substantially. See the section on "Graduate Studies" for additional information.

## LS&A Academic Minors

Beginning in 2001, students in the College of Engineering are given the option of electing one or more academic minors offered by departments within the College of Literature, Science and Arts. Minors are intended to recognize the completion of a coherent sequence of courses in a particular academic area and can serve both as a guide to you in a more careful selection of your non-engineering courses. They also serve as recognition, via a transcript notation, of the completion of a more in-depth course sequence.

In practice, a student will meet with the LS&A advisor in the minor discipline and together map out the minor courses. The certification that the appropriate courses have been completed will be communicated from the LS&A department offering the minor to a student's undergraduate program advisor in CoE, as well as the Engineering Student Services Office. The student will be responsible for making sure this paperwork arrives at the appropriate offices.

Below you will find a list of approved minors covering a diverse range of academic interests. This is followed by a statement of policies and procedures that should help a student through the process. We suggest that each student meet with an engineering program advisor to discuss this new interdisciplinary option.

LS&A Minors Approved by The College of Engineering

Afro-American and African Studies
Anthropology
Applied Statistics
Biology
Classical Archaeology
Czech Language, Literature and Culture
Earth Sciences - General
East European Studies
Economics
Environmental Geology
Environmental Studies
French and Francophone Studies
Geochemistry
German Studies
Global Change
History
Judaic Studies
Language, Literature and Culture of Ancient Greece
Language, Literature and Culture of Ancient Rome
Latin American and Caribbean Studies
Lesbian, Gay, Bisexual and Transgender Studies
Linguistics
Near Eastern Languages and Culture
Mathematics
Oceanography
Paleontology
Philosophy
Physics
Polish Language, Literature and Culture
Political Science
Russian Language, Literature and Culture
Russian Studies
Scandinavian Studies
Spanish Language, Literature and Culture
Statistics
Women, Race and Ethnicity

These minors with their requirements and other pertinent information are listed on the Student Affairs website at http:www.lsa.umich.edu/saa/minors.html

### Policies and Procedures for Declaring and Completing LS&A Academic Minors

As part of CoE's curriculum reform, engineering students now have greater flexibility in electing courses from other Colleges. In the interest of helping students make informed decisions in selecting these courses, we allow and encourage our student to pursue College-approved minors now offered in LS&A.

Students in the College of Engineering are given the option of electing one or more academic minors offered by units within the College of Literature, Science and the Arts. Electing to earn an academic minor is optional and there is no limit on the number of academic minors a student may elect.

The following is a statement of the policies and procedures to be followed for declaring and completing minors:

1. Each B.S.E. and B.S. student who wishes to complete an approved academic minor must develop a plan for the minor in consultation with the designated LS&A advisor, who must also approve it. The faculty and staff advisors in the LS&A units will advise Engineering students on course selection, and complete the minor declaration form and confirm completion of the minor. There will be no prior approval required from an Engineering advisor.

2. Students may not elect two academic minors offered by the same department or program.
3. The student must submit the minor declaration form to the Records Office in Engineering Student Affairs (ESA). Upon receipt of the declaration form, the staff member will enter the minor in the M-Pathways database. The form will be available through all Engineering academic departments, the Engineering Advising Center and all relevant LS&A departments.
4. Student Transcripts:
   - The M-Pathways Unofficial Transcript for an Engineering Student who has declared a minor will show the minor in the program action history section.
   - The Official Transcript issued by the Registrar's Office will show the minor at the beginning of the transcript when the student has completed the degree.

### Undergraduate Research Opportunity Program (UROP)

The UROP program enables students to work one-on-one or as part of a small group of students with faculty members conducting research. Students will choose research projects by looking through a catalog of faculty research projects, and will then interview for the positions with the faculty researcher. Students spend on an average nine to 10 hours per week working on their research projects. Students can participate in the program for academic credit through Engr. 280. Students receive one credit per three hours of work per week. Most students register for three credits, which is a nine-hour commitment per week. Students participating in the program are also required to attend a biweekly research peer group meeting, meet monthly with a peer advisor, read research-related articles (e.g., research ethics, research in specific disciplines, research methods) and keep a research journal.

All first- and second-year Engineering students are eligible to apply to UROP. Applications for first-year students will be sent out in May and accepted throughout the summer. Students are encouraged, however, to apply early. The deadline for sophomore applications is March 1. Applications can be picked up from the UROP office. Also, applications are mailed to students in February prior to the sophomore year. Selection is done on a rolling basis and determined by a student's level of interest in research, academic background, area of research interest, and availability of positions.

### Military Officer Education Program

Opportunities are offered through Reserve Officers' Training (ROTC) for officer training in military, naval, and air science leading to a commission on graduation. Enrollment is voluntary (see conditions of enrollment under the respective program on pages 290-296). If elected, the grades earned will be recorded and used in the computation of grade point averages, and credit hours for the 300- and 400-level courses will be included with the hours completed toward the degree. A maximum of 12 credit hours of 300- and 400-level ROTC courses may be used as unrestricted electives at the discretion of the program advisors.

### Cooperative Education

The Cooperative Education Program assists students in pursuing an optional program of work and study within the College of Engineering. Corporations, government agencies, and industry interview students who are interested in having a work-related learning experience that enhances their academic studies. Cooperative Education positions offer work experience relevant to the student's degree interests and enhance the student's opportunities for future permanent hire.

Students may tailor their work assignments for consecutive terms, for example May to December or January to August.

They may also stagger them and alternate work school semesters. Opportunities to co-op are available in manufacturing, design, production, software and hardware development, communications, and other technological fields.

*How the program works*

Employers provide the Engineering Career Resource Center (ECRC) with job descriptions and requirements for interviewing. The recruiter prescreens and ECRC coordinates the scheduling for interviews that are held either on campus or at the employer's location. On-campus interviews are held September through November and mid-January to March. The ECRC prescreens qualified applicants and matches them with the employer's needs.

Final selection of a student for a co-op work assignment is a mutual agreement entered into by the employer and the student, and the student becomes an employee of that company.

**Note:** The Engineering Career Resource Center does not guarantee placement for every applicant; however, every effort is made to place students in appropriate positions.

*Work assignment*
While on work-term assignment, students are subject to the rules and regulations of the employer. The employer will evaluate the student's performance at the end of the work term and forward the evaluation to the Engineering Career Resource Center. Students are also required to complete and return an evaluation report of their learning experience to ECRC.

*How to sign up*
Opportunities to interview will be available to students registered in the Engineering Career Resource Center's EnginTrak system. To learn more about the Cooperative Education Program and how to register for EnginTrak, please contact:
*Engineering Career Resource Center*
*230 Chrysler Center*
*Ann Arbor, Michigan 48109-2192*
*(734) 647-7140*
*http://career.engin.umich.edu*

### International Programs

The College of Engineering has arrangements with several educational institutions overseas at which our students may choose to study for a prescribed period of time. These agreements offer our students the opportunity to experience the educational, social, political, and professional climate of an outstanding foreign institution. Students who participate in these programs will gain global skills and a new level of personal self-reliance. Such experiences, no doubt, will be satisfying in their own right. Moreover, they can serve to meet the requirements for a degree from the College, and will attract the attention of future employers who seek self-confident, imaginative people having global experience. Those who desire placement in educational programs at overseas locations and industrial internships abroad should contact:
*Aparajita Mazumder, Director of International Programs*
*College of Engineering*
*245 Chrysler Center*
*2121 Bonisteel Blvd.*
*Ann Arbor, MI 48109-2092*
*(734) 647-7026*
or
*Professor Andrzej S. Nowak, Faculty Director of International Programs*
*College of Engineering*
*2370 G.G. Brown*
*Ann Arbor, MI 48109-2125*
*(734) 764-9299*

## Planning the Student's Program

Students vary in their goals and objectives, in their level of achievement, and in their high school or pre-engineering preparation. Considerable variety and flexibility are provided to plan each student's schedule so that the individual may reach graduation as efficiently as possible. The objective is to place each new student in courses commensurate with his or her academic profile, previous experience, and potential for academic success.

Most courses have prerequisites. The completion of courses on schedule and with satisfactory grades is essential to the student's progress.

The appropriate schedule for each student in each term will depend on a number of factors: past scholastic record, placement tests, extracurricular activities, election of Military Office Education Program, health, and need for partial self-support. A schedule of 12 to 18 hours is considered full-time.

### Minimum Common Requirements

Each of the degree programs offered by the College includes credit hours that are common to all programs, subject to appropriate adjustment for equivalent alternatives. See individual sample schedules for required programs in each program section of this *Bulletin*.

### First Year and Sophomore Programs

At the time of the first advising session, all of the high school and advanced placement records may not yet be in the student's file. It is the entering student's responsibility to make certain that all evidence is brought to the attention of the advising office before classes start.

With complete information available, the advisor and the student will be able to make carefully considered adjustments in course elections for the first-term course schedule.

### First Year

Assuming that a student has the necessary academic preparation and no advanced placement credit, he/she will be expected to complete some combination of the following courses:

1. Mathematics 115 and 116 or one of the honors Math sequences.
2. Chemistry 130 and 125, or, for some, 130, 210, and 211.
3. Engineering 100
4. Physics 140 and 141
5. Engineering 101
6. Additional course information will be available during the advising session.

### Second Year

All students will continue with the mathematics, physics, humanities, and social sciences courses common to all programs. First-year students should attend department orientations coordinated by the Engineering Advising Center. A second-term student who has selected a degree program should be meeting with that program advisor for third-term elections.

Students who have not selected a degree program should consult the Engineering Advising Center for their course selections.

### Honors-Level Courses

A student whose record indicates qualifications to perform at an advanced level may discuss this option with an advisor in the Engineering Advising Center.

### Mathematics

The mathematics courses of 115 (4), 116 (4), 215 (4), and 216 (4) provide an integrated 16-hour sequence in college mathematics that includes analytic geometry, calculus, elementary linear algebra, and elementary differential equations. Some students taking math courses preparing them for the election of the first calculus course (currently Math 105 and Math 110) may not use these courses as credit toward an Engineering degree; however, grades from these courses will be used in computing students' grade point averages.

All students with strong preparation and interest in mathematics are encouraged to consider the honors-level math sequence. Qualified and interested students should consult their engineering advisor about these options. It is not necessary to be in an honors program to enroll in these courses.

### Writing Assessment

All first-year students will do a writing sample the first day of Engineering 100 class.

The purpose of the evaluation process is to help ensure that all students in the College of Engineering have the best possibility of success. The assessment of your writing sample will have the following results:

- Placed into Engineering 100, your writing sample indicates that your current level of preparation puts you in a good position to do well in writing.
- Placed into Engineering 100 with a writing workshop.
- Your writing sample indicates that your current level of writing needs improvement. You will be required to attend a series of one-to-one conferences on your writing for Engineering 100.

*Advanced Placement English Credit*

Advanced Placement (AP) English credit is assessed as English departmental credit and can be used toward your Humanities requirement. AP English composition credit will not fulfill the Engineering 100 requirement.

### Engineering 100: Introduction to Engineering

Engineering 100 introduces students to the professional skills required of engineers and provides them with an overview of engineering at the beginning of their program. An important component of the course is the real-world engineering project. Important engineering skills developed in Engineering 100 include:

- Qualitative project-based work in an engineering discipline
- Written, oral and visual communication skills
- Team building and teamwork
- Ethical concerns in the engineering profession
- The role of engineers in society
- Environmental and quality concerns in the engineering profession.

***Important Note:*** Taking Engineering 100 does not exclude you from having to satisfy the Writing Assessment.

You must receive a grade of "C" or better in Engineering 100 to fulfill the composition requirement.

Transfer students must complete English composition as a prerequisite for transfer admission and therefore are not required to submit a writing portfolio. Their advanced credit will be used to satisfy the introductory composition requirement. Be sure to consult with Office of Recruitment, Transfer Admissions and Scholarships if you have questions.

### Foreign Languages

A student may take an examination in a foreign language regardless of how the language skills were developed; however, credit by examination for foreign languages, either at the University of Michigan or Advanced Placement, will be granted up to a maximum of eight credit hours. If the language credit earned is at the first-year level, then the credit hours may be used only as unrestricted electives. If the language credit earned is at the second-year level, then the credit hours may be used as humanities or unrestricted elective credits. Students earning language credit by completing qualifying courses at the University of Michigan, designated by LR or HU, or by transfer credit of equivalent courses from any other institution of higher learning, may apply all credits earned towards humanities.

### Introductory Computing

Four hours of introductory computing are required. All engineering students should take Eng 101 or equivalent.

### Chemistry

The minimum requirement in chemistry for most undergraduate degree programs is 5 credit hours. The Chemical Engineering and Materials Science and Engineering programs require additional chemistry. Students who enter a degree program requiring only 5 hours of chemistry would normally elect Chem 130 (3 credit hours) and Chem 125 (2 credit hours laboratory) during the freshman year. Students expecting to enter a degree program requiring additional chemistry would normally elect Chem 130 (3 credit hours), Chem 210 (4 credit hours), and Chem 211 (1 credit hour laboratory) during the freshman year.

**Note:** Students can place out of Chem 130. Refer to the current *First-Year Student Handbook* for details. This publication is available in the Engineering Advising Center.

### Physics

The usual first year schedule includes Physics 140 (4) with laboratory, Physics 141 (1). This course assumes knowledge of calculus. A second course, Physics 240 (4), with laboratory, is required by most programs and is normally scheduled in the third term. Electrical Engineering students do not take Physics 240 and 241 and should consult with the departmental program advisor.

***Important Note:*** All students with strong preparation and interest in physics are encouraged to consider the honors-level physics sequence.

### Humanities and Social Sciences

To provide a desirable breadth of education, each program in the College of Engineering specifies a certain number of credit hours of elective courses (minimum 16) concerned with human cultures and relationships—generally identified as humanities and social sciences (HU/SS). In general, the humanities include literature (English and others), philosophy, history of art, music history, classical civilization, etc.; the social sciences include economics, history, psychology, anthropology, sociology, etc.

Students are encouraged to select a cluster theme for their humanities/social science electives. This is a unifying theme (such as psychology, economics, or history) that focuses the student's HU/SS electives. Specific requirements for all students (with or without College Board Advanced Placement Program credit or transferred credit) are outlined below. For information on specific courses, see Humanities (HU) and Social Sciences (SS) course offerings in the College of Literature, Science, and the Arts *Bulletin*. Courses designated as (N.S.), (N.Excl.), (Excl.), (Experiential), and (Independent) cannot be used to fulfill humanities or social science credits.

1. Humanities (6 credit hours)—at least two courses in humanities, totaling at least 6 credit hours, selected from:
   a. Any non-performance course designated as Humanities (HU) in the LS&A *Bulletin*.
   b. Any non-performance course in the Schools of Music or Art.
   c. Any foreign language taken at the University or any other university or college designated FL, LR, or HU.

d. Advanced placement foreign-language credit at the second-year level or higher.

2. A sequence consists of at least two courses in either the humanities or the social sciences, or both, totaling at least 6 credit hours. The sequence must be taken from the same department or division (for example, History), one of which must be a 300-level, or higher, course. This requirement may overlap requirement 1.

3. The remaining credit hours may be satisfied with elective courses in either humanities or social sciences as follows:
   a. Any course designated as Humanities in requirement 1.
   b. Any course designated as Social Sciences (SS) in the LS&A *Bulletin*.
   c. Eng 451: Technology and Society (social sciences credit).

Note: Courses labeled as "NS," "N Excl," "Excl," "Experiential," and "Independent" in the LS&A *Bulletin* may not be used for this requirement.

### Unrestricted Electives

Unrestricted electives may be selected from the offerings of any regular academic unit of the University and from the Pilot Program. All undergraduate degree programs will accept a maximum of 3 credit hours in the following areas:

- Performance courses in the schools of music or art, including marching band;
- Courses which require tutoring of other students enrolled in courses offered under the Keller Plan or similar plans;
- All undergraduate degree programs in the College of Engineering will accept up to 12 credit hours toward unrestricted electives from credits earned by a student in 300- and 400-level courses in military, naval, or air science.
- Tutorial courses are not acceptable for credit or grade points but will be included on the student's official record.

## Course Titles and Descriptions

Courses and course descriptions are listed under each degree program. Course titles and numbers, prerequisites, other notes, credit hours, and descriptions approved by the Curriculum Committee are included. Course descriptions also are available on the College's Web site at:
http://courses.engin.umich.edu/.
They may be downloaded or printed.

The courses offered by the College of Engineering, and by certain closely associated departments of other units of the University, are listed. Time Schedules are issued separately, giving hours and room assignments for the courses and sections offered each term.

### Designations

- Each listing begins with the course number and title set in bold-face type. (Course number) indicates cross listed courses.
- Prerequisites, if any, are set in italics. They are followed by roman numerals, also set in italics, that indicate the times at which the department plans to offer the course:

See under "Term" for definitions relating to the several terms

| | |
|---|---|
| I | fall |
| II | winter |
| III | spring-summer |
| IIIa | spring half |
| IIIb | summer half |

- The italics in parentheses indicate the hours of credit for the course; for example, (3 credits) denotes three credit hours, or, (to be arranged) denotes credit to be arranged.

### What the Course Number Indicates

The number of each course is designated to indicate the general level of maturity and prior training expected.

| | |
|---|---|
| 100 | Freshman-level courses |
| 200 | Sophomore-level courses |
| 300 | Junior-level courses |
| 400* | Senior-level courses |
| 500 | Predominantly Graduate-level courses |
| 600 | Graduate-level courses and above |

Unless a phrase such as "junior standing," "senior standing," or "graduate standing" is part of the list of prerequisites for a course, a student may elect an advanced-level course relative to his/her current status if the other prerequisites are satisfied. If the difference in standing level is greater than one academic year, it is usually not wise to elect an advanced-level course without first consulting the department or the instructor offering the course.

In general, the prerequisites listed for a course designate specific subject materials and/or skills the student is expected to have mastered before electing the course (or, in some cases, concurrent with).

**A 400-level course listed in the* Bulletin *of the Horace H. Rackham School of Graduate Studies may be elected for graduate credit when approved by the student's graduate program advisor.*

### Course equivalence

Unless otherwise stated, the phrase "or equivalent" may be considered an implicit part of the prerequisite for any course. When a student has satisfactorily completed a course that is not listed but is believed to be substantially equivalent to one specified as a prerequisite for a course that the student wants to elect, the individual may consult the program advisor and upon determining if equivalency has been satisfied, election may be approved.

### Permission of Instructor

The phrase "or permission of instructor (or department)" may be considered an implicit part of the statement of prerequisites for any course. When permission is a stated requirement, or when a student does not have the stated prerequisite for a course but can give evidence of background, training, maturity, or high academic record, the student should present to the program advisor a note of approval from the instructor or department concerned.

## Representative Sample Schedules

In an effort to provide the interested student, both first-year and transfer, with a sample schedule, the information in this *Bulletin* for a number of the degree programs includes a schedule that is an example of one leading to graduation in eight terms. This sample schedule is for informational purposes only and should not be construed to mean that students are required to follow the schedule exactly.

A transfer student attending a community or liberal arts college and pursuing a pre-engineering degree program may not be able to follow a similar schedule because of a lack of certain offerings. Departmental program advisors should always be consulted when planning course selections.

*Program Advisors*

*Professor K.G. Powell*
*3029 François-Xavier Bagnoud Building*
*(734) 764-3331*

*Iain D. Boyd*
*3012 François-Xavier Bagnoud Building*
*(734) 615-3281*

Aerospace technology has grown out of the problems of design, construction, and operation of vehicles that move above the Earth's surface, vehicles ranging from ground-effect machines and helicopters to aircraft and spacecraft. Design of such vehicles has always been challenging, not only because of the requirement that they operate in a hostile environment, but also because of the high premium placed on light-weight vehicles performing efficiently and with great reliability. These same requirements exist not only for future spacecraft and high-performance transport aircraft, but also to the next generation of ground transportation, such as high-speed trains, over-water transportation, and automated motor vehicles. In addition to working on vehicle-oriented design problems, aerospace engineering graduates are often involved in systems management in the broadest sense. Because of the anticipated life mission of the aerospace student, the undergraduate curriculum at the University of Michigan is designed to convey a clear understanding of the fundamental aspects of the fields most pertinent to aerospace engineering. Real-life problems in aerospace and related areas are emphasized in the applications of theory. In the senior year, students select a design course in which they are given an appreciation of the interrelation of the various areas of study in the design of an overall system.

### Aerospace Engineering Program

The degree program gives the student a broad education in engineering by requiring basic courses in aerodynamics and propulsion (sometimes collectively referred to as "gas dynamics"), structural mechanics, flight dynamics and control systems. These courses cover fundamentals and their application to the design and construction of aircraft, spacecraft and other vehicular systems and subsystems. Courses in gas dynamics treat fluid and gas flow around bodies and through turbojet engines and rocket nozzles; also involved is the study of large- and small-scale air motion in the atmosphere and its relationship to environmental and noise problems. In courses on structural mechanics, lightweight structures are studied not only from the strength point of view but also in their elastic dynamic behavior. Flight dynamics and control systems deal with the dynamical behavior of vehicles and systems as a whole, their stability and controllability both by human and automatic pilots. Integration of all this material takes place in the design course in which the student has a wide choice of design topics. The aerospace engineering program offers considerable flexibility through technical and unrestricted electives, in which the student has an opportunity to study in greater depth any of the basic areas mentioned earlier. In addition, there are other technical elective areas which the aerospace engineering students are encouraged to consider, including aerophysical sciences, environmental studies, computers, person-machine systems, and transportation. Elective courses in each technical elective area include courses taught both inside and outside the aerospace engineering department.

### Accreditation

This program is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

## Our Mission, Goals, Objectives and Outcomes for Undergraduate Education

#### *Mission*

To provide internationally recognized leadership in aerospace engineering education, through a continuously improving educational program that graduates students with strong engineering science fundamentals while incorporating applied engineering aspects.

#### *Goals*

• Educate students who are widely known for exceptional strength in technical fundamentals across all aerospace disciplines, who are cognizant of modern aerospace technologies, and who are sought after by top graduate schools and by aerospace and related industries worldwide.

• Support vibrant and highly recognized research programs that serve the educational goals of the undergraduate and graduate degree programs, that make major contributions to the knowledge base in aerospace sciences and technology, and that are turned to by industry and government for solutions.

• Create an enviroment of intellectual challenge and excitement that at the same time is collegial and conducive to higher learning.

• Take full advantage of knowledge, technology, facilities and resources at The University of Michigan.

### *Objectives*

• Educate students in the following fundamental disciplines of aerospace engineering and how to apply them: aerodynamics, aerospace materials, structures, aircraft and rocket propulsion, flight mechanics, orbital mechanics, aircraft stability and control and spacecraft attitude determination and control.

• Educate students in the methodology and tools of design, and the synthesis of fundamental aerospace disciplines necessary to carry out the design of an aerospace vehicle.

• Educate students in the basics of instrumentation and measurement, laboratory techniques, and how to design and conduct experiments.

• Help students learn to function on multi-disciplinary teams, and provide them with teamwork experiences throughout their curriculum.

• Help students learn to communicate effectively.

• Expose students to environmental, ethical and contemporary issues in aerospace engineering.

• Expose students to other disciplines of engineering beyond the aerospace field.

### *Outcomes*

The outcomes we desire are that graduates of the University of Michigan Aerospace Program demonstrate:

• An ability to apply knowledge of mathematics, science, and engineering.

• An ability to design and conduct experiments, as well as to analyze and interpret data.

• An ability to design a system, component or process to meet desired needs.

• An ability to function on multi-disciplinary teams.

• An ability to identify, formulate, and solve engineering problems.

• An understanding of professional and ethical responsibility.

• An ability to communicate effectively.

• The broad education necessary to understand the impact of engineering solutions in a global and societal context.

• A recognition of the need for, and an ability to engage in life-long learning.

• A knowledge of contemporary issues.

• An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

• A knowledge of aerodynamics, aerospace materials, structures, aircraft and rocket propulsion, flight mechanics, orbital mechanics, aircraft stability and control, and spacecraft attitude determination and control.

• Competence in the integration of aerospace science and engineering topics and their application in aerospace vehicle design.

## Department Laboratories

Engineering knowledge is gained in part through experience with engineering problems and the experimental approach to their solution. In required laboratory courses, the student is introduced to the basic principles of operation and use of modern laboratory instrumentation. These courses, taken in the junior and senior year, may be followed by additional experimental work either in formal elective courses or in projects of the student's choosing. The department's laboratories include subsonic and supersonic wind tunnels; shock and detonation tubes; laser diagnostic equipment; structural test equipment; and a wide range of optical, electronic, and computer diagnostic equipment. Students also gain experience in the use of computers for computation, system design, and simulation.

Undergraduate students at Michigan profit by their contact with graduate students and faculty members, who carry out research work parallel to the areas of undergraduate instruction and student projects.

## Combined Degrees Program

For students with special interests, combined degree programs leading to two bachelor's degrees are available. The flexibility of the aerospace curriculum makes it feasible to obtain a second bachelor's degree. Favorite second-degree areas of concentration among aerospace engineers are Mechanical Engineering and Naval Architecture and Marine Engineering, but combined degrees with other departments can be arranged.

## Sample Schedule
## B.S.E. Aerospace Engineering

| | Credit Hours | Terms 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| **Subjects required by all programs (52 hrs.)** | | | | | | | | | |
| Mathematics 115, 116, 215, and 216 | 16 | 4 | 4 | 4 | 4 | – | – | – | – |
| Engr 100, Intro to Engr | 4 | 4 | – | – | – | – | – | – | – |
| Engr 101, Intro to Computers | 4 | – | 4 | – | – | – | – | – | – |
| [1]Chemistry 125 and 130 | (5) 4 | 4 | – | – | – | – | – | – | – |
| [2]Physics 140 with Lab 141; 240 with Lab 241 | (10) 8 | – | 4 | 4 | – | – | – | – | – |
| Humanities and Social Sciences | 16 | 4 | 4 | – | – | – | 4 | 4 | – |
| **Advanced Mathematics/Science (4 hrs.)** | | | | | | | | | |
| [3]Advanced Math/Science Elective | 4 | – | – | – | – | 4 | – | – | – |
| **Related Technical Core Subjects (12 hrs.)** | | | | | | | | | |
| ME 240, Intro to Dynamics and Vibrations | 4 | – | – | – | 4 | – | – | – | – |
| MSE 220, Intro to Materials and Manufacturing | 4 | – | – | 4 | – | – | – | – | – |
| EECS 210, Electrical Engr I or EECS 314, Cct Analy and Electronics | 4 | – | – | – | – | 4 | – | – | – |
| **Aerospace Science Subjects (20 hrs.)** | | | | | | | | | |
| Aero 225, Intro to Gas Dynamics | 4 | – | – | – | 4 | – | – | – | – |
| Aero 315, Aircraft and Spacecraft Structures | 4 | – | – | – | – | 4 | – | – | – |
| Aero 325, Aerodynamics | 4 | – | – | – | – | – | 4 | – | – |
| Aero 335, Aircraft and Spacecraft Propulsion | 4 | – | – | – | – | 4 | – | – | – |
| Aero 345, Flight Dynamics and Control | 4 | – | – | – | – | – | 4 | – | – |
| **Aerospace Engineering Subjects (20 hrs.)** | | | | | | | | | |
| Aero 245, Performance of Aircraft and Spacecraft | 4 | – | – | 4 | – | – | – | – | – |
| Aero 285, Intro to Solid Mechanics and Design | 4 | – | – | – | 4 | – | – | – | – |
| Aero 305, Aerospace Engr Lab I | 4 | – | – | – | – | – | 4 | – | – |
| Aero 306, Aerospace Engr Lab II | 4 | – | – | – | – | – | – | 4 | – |
| Aero 481, Airplane Design or Aero 483, Space System Design | 4 | – | – | – | – | – | – | – | 4 |
| **Electives (20 hrs.)** | | | | | | | | | |
| [4]Technical Electives | 8 | – | – | – | – | – | – | 4 | 4 |
| Unrestricted Electives | 12 | – | – | – | – | – | – | 4 | 8 |
| **Total** | 128 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 1 |

Candidates for the Bachelor of Science degree in Engineering (Aerospace Engineering)—B.S.E. (Aerospace E.)—must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

**Notes:**

[1]Chemistry: 125, 130 will count for 5 total credits, 1 of which will be applied according to individual program directives; for students who have advanced placement credit for freshman chemistry, a 100–level or above biology course may be used to fulfill this requirement.

[2]Physics: 140, 141; 240, 241 will count for 10 total credits, 2 of which will be applied according to individual program directives.

[3]Upper-level math or science course subject to approval of faculty advisor.

[4]Upper-level engineering course subject to approval of faculty advisor. To include at least two credits of engineering seminars.

## Aerospace Engineering Course Listings

Course descriptions are found also on the College of Engineering web site at http://courses.engin.umich.edu/

**Aero 225. Introduction to Gas Dynamics**
*Prerequisite: Math 215, Chem 125/130, Physics 140/141. I, II (4 credits)*
An introduction to gas dynamics, covering fundamental concepts in thermodynamics and fluid dynamics. Topics include molecular and continuum concepts for fluids, first and second laws of thermodynamics, conservation laws for moving fluids, one-dimensional compressible flows, shocks and expansion waves, flows in nozzles, and two- and three-dimensional compressible flows.

**Aero 245. Performance of Aircraft and Spacecraft**
*Prerequisite: preceded by Engr 100, Engr 101, Physics 140/141, and Math 116. I, II (4 credits)*
An introduction to the aerospace field. Introduces students to steady motion of aircraft and spacecraft and to methods for evaluating performance of aircraft and spacecraft systems. Students learn basic aerodynamics, propulsion, and orbital mechanics. Involves team projects that include written and oral reports.

**Aero 285. Introduction to Solid Mechanics and Design**
*Prerequisite: preceded by Math 215 and MSE 220. Preceded or accompanied by Aero 245. I, II (4 credits)*
An introduction to the fundamental phenomena of solid and structural mechanics in aerospace systems. Includes analysis, numerical simulation and experiments, and an introduction to design.

**Aero 305. Aerospace Engineering Laboratory I**
*Prerequisite: preceded or accompanied by EECS 210 or EECS 314. Preceded by Aero 225 and Aero 285. I, II (4 credits)*
First course of a two-semester sequence covering fundamentals of instrumentation and measurement and their application in engineering testing and experimentation. Includes principles of analog and digital data acquisition, analysis of discrete measurement data, statistical assessment of hypotheses, design of experiments, and similarity scaling of data. Emphasized development of skills for written communication and for working effectively in a team environment.

**Aero 315. Aircraft and Spacecraft Structures**
*Prerequisite: preceded by Aero 285 and Math 216. I, II (4 credits)*
Concepts of displacement, strain, stress, compatibility, equilibrium, and constitutive equations as used in solid mechanics. Emphasis is on boundary-value problem formulation via simple examples, followed by the use of the finite-element method for solving problems in vehicle design.

**Aero 325. Aerodynamics**
*Prerequisite: preceded by Math 216 and Aero 225. I, II (4 credits)*
Fundamental concepts in aerodynamics. Students learn how airfoils produce lift and how the pressure distribution about an airfoil can be calculated. Introduces the boundary-layer concept, how boundary layers lead to drag, and what makes them prone to instability and turbulence or separation. Effects of the wing platform shape on lift and drag. Introduction to airfoil design, high-lift devices and high-speed aerodynamics.

**Aero 335. Aircraft and Spacecraft Propulsion**
*Prerequisite: preceded by Aero 225 and Math 216. I, II (4 credits)*
Airbreathing propulsion, rocket propulsion, and an introduction to modern advanced propulsion concepts. Includes thermodynamic cycles as related to propulsion and the chemistry and thermodynamics of combustion. Students analyze turbojets, turbofans and other air-breathing propulsion systems. Introduces liquid- and solid-propellant rockets and advanced propulsion concepts such as Hall thrusters and pulsed plasma thrusters. Students also learn about

the environmental impact of propulsion systems and work in teams to design a jet engine.

### Aero 345. Flight Dynamics and Control

*Prerequisite: preceded by Math 216, Aero 245, and ME 240. I, II (4 credits)*

An introduction to dynamics and control of aircraft and spacecraft. Introduces concepts from linear systems theory (state equations, transfer functions, stability, time and frequency response). Includes aircraft longitudinal and lateral flight dynamics and control systems. Also includes spacecraft attitude dynamics and control. Involves a team design project.

### Aero 351. Computational Methods in Aerospace Vehicle Analysis and Design

*Prerequisite: Aero 245, Math 216. I (3 credits)*

Students learn to use computational methods for solving problems in aerospace engineering, in the areas of aerodynamics, structures, flight mechanics, and propulsion. Lectures cover the engineering analysis and design methods, basic numerical methods, and programming techniques necessary to solve these problems.

### Aero 385. Contemporary Aerospace Issues

*Prerequisite: preceded or accompanied by Aero 245. I (1 credit)*

A series of seminars by noted speakers, designed to acquaint undergraduates with contemporary technology and the aerospace industry. Involves a short term project or paper pertinent to one of the seminar topics.

### Aero 386. Aerospace Case Studies

*Prerequisite: preceded by Aero 245. II (1 credit)*

A series of seminars by noted speakers, designed to acquaint undergraduates with the detailed features of aerospace missions, systems, and sub-systems. Involves a short term project or paper pertinent to one of the seminar topics.

### Aero 390. Directed Study

*(to be arranged)*

Individual study of specialized aspects of aerospace engineering.

### Aero 405. Aerospace Laboratory II

*Prerequisite: preceded by Aero 305. Preceded or accompanied by Aero 315 and Aero 325. I, II (4 credits)*

Second course of a two-semester sequence covering fundamentals of instrumentation and measurement and their application in engineering testing and experimentation. Focuses primarily on application of the fundamental principles learned in Aero 305 to more advanced test and measurement applications. Involves instructor-designed experiments and one major project conceived, designed, conducted, analyzed, and reported by student teams. Emphasizes development of skills for written communication and for working effectively in a team environment.

### Aero 416. Theory of Plates and Shells

*Prerequisite: Aero 315. II alternate years (3 credits)*

Linear elastic plates. Membrane and bending theory of axisymmetric and non-axisymmetric shells. Approximate treatment of edge effects. Finite element techniques for plate and shell problems.

### Aero 445. Flight Dynamics of Aerospace Vehicles

*Prerequisite: Aero 345. II (3 credits)*

Flight-oriented models of aerospace vehicles. Analytical modeling principles, parameter identification methods. Open- and closed-loop control for command following and stabilization. Computer-based simulation, performance evaluation, and model validation. Flight properties of representative aerospace vehicles, including fixed-wing aircraft, rotorcraft, launch and reentry vehicles, orbiters, and interplanetary vehicles.

### Aero 447. Flight Testing

*Prerequisite: Aero 305 and Aero 345. II (3 credits)*

Theory and practice of obtaining flight-test data on performance and stability of airplanes from actual flight tests. Modern electronic flight test instrumentation, collection of flight test data, calibration procedures for air data sensors, estimation of stability derivatives from flight test data. Lectures and laboratory.

### Aero 464 (AOSS 464) (ENSCEN 464). The Space Environment

*Prerequisite: senior or graduate standing in a physical science or engineering. I (3 credits)*

An introduction to physical and aeronomical processes in the space environment. Discussion of theoretical tools, the Sun, solar spectrum, solar wind, interplanetary magnetic field, planetary magnetosphere, ionospheres and upper atmospheres. Atmospheric processes, densities, temperatures, and wind.

### Aero 471. Automatic Control Systems

*Prerequisite: Aero 340. I, II, IIIa (3 credits)*

Automatic control problems; solution approach using feedback. Transfer function and state space description of linear control systems. Control design criteria; stability, sensitivity, time response. Use of Routh-Hurwitz, root-locus, Nyquist, Bode methods for control design. Application to design of automatic control systems for flight vehicles.

### Aero 481. Aircraft Design

*Prerequisite: preceded by Aero 345. Preceded or accompanied by Aero 315, 325, and 335. I (4 credits)*

Integration of the disciplines of aircraft aerodynamics, performance, stability and control, structures, and propulsion in a single-system approach to create the configuration of an aircraft to perform a specific mission. Includes determination of takeoff weight, choice of aerodynamic configuration, selection and integration of powerplant, landing gear selection and design, control-surface sizing and cost analysis, among other topics. Involves individual and team assignments, and emphasizes further development of skills for communication and working effectively in teams.

### Aero 483. Space System Design

*Prerequisite: senior standing. II (4 credits)*

Introduction to the engineering design process for space systems. Includes a lecture phase that covers mission planning, launch vehicle integration, propulsion, power systems, communications, budgeting, and reliability. Subsequently, students experience the latest practices in space-systems engineering by forming into mission-component teams and collectively designing a space mission. Effective team and communication skills are emphasized. Report writing and presentations are required throughout, culminating in the final report and public presentation.

### Aero 484. Computer Aided Design

*Prerequisite: preceded by Aero 315, Aero 325, Aero 335, and Aero 345. I (4 credits)*

Advanced computer-aided design. Students learn about computer generation of geometric models, calculation of design parameters, trade-off diagrams, and finite-element modeling and analysis. Each student carries out a structural component design using industry-standard software. The course includes individual and team assignments.

### Aero 490. Directed Study

*(to be arranged)*

Individual study of specialized aspects of aerospace engineering. Primarily for undergraduates.

### Aero 495. Special Topics in Aerospace Engineering

*Prerequisite: permission of instructor. Term offered depends on special topic (to be arranged).*

### Aero 510. Finite Elements in Mechanical and Structural Analysis I

*Prerequisite: Aero 315. II (3 credits)*

Introductory level. Finite element solutions for structural dynamics and nonlinear problems. Normal modes, forced vibrations, Euler buckling (bifurcations), large deflections, nonlinear elasticity, transient heat conduction. Computer laboratory based on a general purpose finite element code.

**Aero 511. Finite Elements in Mechanical and Structural Analysis II**
*Prerequisite: Aero 510 or AM 505, (ME 505). II (3 credits)*
Intermediate level. Finite element solutions for structural dynamics and nonlinear problems. Normal modes, forced vibration, Euler buckling (bifurcation), large deflections, nonlinear elasticity, transient heat conduction. Computer laboratory based on a general purpose finite element code.

**Aero 512. Experimental Solid Mechanics**
*Prerequisite: Aero 305, Aero 315 or equivalents. II (3 credits)*
Lectures and experiments that demonstrate historical and contemporary methods of measurement in solid mechanics. A review of classical experiments that substantiate many typical assumptions (e.g., material linearity or Hooke's Law") concerning the response of solids. An introduction to contemporary techniques of process measurement involving piezoresistivity.

**Aero 513. Foundations of Solid and Structural Mechanics I**
*Prerequisite: Aero 315, ME 311 or equivalent. I (3 credits)*
Introduction to linear continuum and structural mechanics. Three-dimensional analysis of stress and infinitesimal strain, including transformation of tensors, equations of motion, and kinematic compatibility. Boundary value problem formation. Constitutive relations for isotropic and anisotropic linear elastic materials. Introduction to variational calculus and energy methods. Applications to thin-walled and slender aerospace structures.

**Aero 514. Foundations of Solid and Structural Mechanics II**
*Prerequisite: Aero 315 or equivalent. II (3 credits)*
Introduction to nonlinear continuum and structural mechanics. Elements of tensor calculus, basic kinematics, conservation laws (mass, linear and angular momentum, energy, etc.), constitutive equations in continual applications in hyperelastic solids, numerical (f.e.m.) methods for the corresponding nonlinear boundary value problems, derivation of nonlinear shell theories from 3-D considerations.

**Aero 515. Mechanics of Composite and Microstructured Media**
*Prerequisite: Aero 514 or equivalent. I (3 credits)*
An introduction to the mechanics of composite (more than one phase) solids with an emphasis on the derivation of macroscopical constitutive laws based on the microstructure. Eshelby transformation theory, self consistent methods, homogenization theory for periodic media, bounding properties for effective moduli of composites. Applications of aerospace interest.

**Aero 516. Mechanics of Fibrous Composites**
*Prerequisite: Aero 315 or ME 412. I (3 credits)*
Effective stiffness properties of composites. Constitutive description of laminated plates. Laminated plate theory. Edge effects in laminates. Nonlinear theory of generally laminated plates. Governing equations in the Von Karman sense. Laminated plates with moderately large deflections. Postbuckling and nonlinear vibration of laminated plates. Failure theories and experimental results for laminates.

**Aero 518. Theory of Elastic Stability I**
*Prerequisite: Aero 315 or AM 412 (ME 412) or the equivalent. I (3 credits)*
Concepts of stability and bifurcation. Simple examples to illustrate buckling and instability mechanisms in structures. Both equilibrium and time dependent problems discussed. General theory for stability in continuum, conservative elastic solids. Applications to bars, rings, plates and shells.

**Aero 520. Compressible Flow I**
*Prerequisite: Aero 325. I (3 credits)*
Elements of inviscid compressible-flow theory: review of thermodynamics; equations of frictionless flow; analysis of unsteady one-dimensional and steady supersonic two-dimensional flows; including the method of characteristics; small-disturbance theory with applications to supersonic thin-airfoil theory.

**Aero 521. Experimental Methods in Fluid Mechanics**
*Prerequisite: senior standing. II (3 credits)*
Fundamental principles of modern flow facilities and advanced instrumentation: mechanics, analog and digital electronics, optics. Digital data acquisition and analysis; turbulent flow measurement; power spectrum estimation; conditional sampling techiques. Flow visualization, two- and three-dimensional velocity field measurement. Digital image analysis, contrast enhancement, pattern recognition. Lecture and laboratory.

**Aero 522. Viscous Flow**
*Prerequisite: Aero 325. II (3 credits)*
The Navier-Stokes equations, including elementary discussion of tensors; exact solutions. Laminar boundary-layer theory; three-dimensional and compressible boundary layers. Laminar-flow instability theory; transition. Introduction to the mechanics of turbulence; turbulent free shear flows and boundary layers.

**Aero 523. Computational Fluid Dynamics I**
*Prerequisite: Aero 325 or preceded or accompanied by ME 520. I (3 credits)*
Physical and mathematical foundations of computational fluid mechanics with emphasis on applications. Solution methods for model equations and the Euler and the Navier-Stokes equations. The finite volume formulation of the equations. Classification of partial differential equations and solution techniques. Truncation errors, stability, conservation, and monotonicity. Computer projects and homework.

**Aero 524. Aerodynamics II**
*Prerequisite: Aero 420. II (3 credits)*
Two- and three-dimensional potential flow about wings and bodies; complex-variable methods; singularity distributions; numerical solution using panel methods. Unsteady aerodynamics; slender-body theory. Viscous effects: airfoil stall, high-lift systems, boundary-layer control. Wings and bodies at transonic and supersonic speeds; numerical methods.

**Aero 525. Introduction to Turbulent Flows**
*Prerequisite: Aero 522. I (3 credits)*
Mathematical description of turbulent flow phenomena. Flow equations, vorticity dynamics, Reynolds-averaged equations, engineering turbulence models. Theory of homogeneous turbulence, spectral dynamics. Shear flow turbulence, mean and luctuating structure of free and wall-bounded turbulent flows.

**Aero 530. Gas-Turbine Propulsion**
*Prerequisite: Aero 335 II (3 credits)*
Advanced analysis of turbojet engines: effect of altitude parameters on engine performance; off-design equilibrium running of a turbojet engine; dynamics of engine considered as a quasi-static system; fluid mechanics of a rotating axial blade row; centrifugal compressors; transonic flow problems.

**Aero 532 (AOSS 596). Gaskinetic Theory**
*Prerequisite: graduate standing. I (3 credits)*
Maxwell-Boltzmann distribution, kinetic determination of equation of state, specific heats of gases. Dynamics of two-particle collisions. Elementary transport theory, molecular effusion, hydrodynamic transport coefficients, mean free path method. Advanced transport theory, the Boltzmann equation, collision terms, Chapman-Enskog transport theory. Aerodynamics of free-molecular flow. Shock waves.

**Aero 533 (ENSCEN 533). Combustion Processes**
*Prerequisite: Aero 225. (3 credits)*
This course covers the fundamentals of combustion systems, and fire and explosion phenomena. Topics covered include thermochemistry, chemical kinetics, laminar flame propagation, detonations and explosions, flammability and ignition, spray combustion, and the use of computer techniques in combustion problems.

**Aero 535. Rocket Propulsion.**
*Prerequisite: Aero 335. I (3 credits)*
Analysis of liquid and solid propellant rocket powerplants; propellant thermochemistry, heat transfer, system considerations. Low-thrust rockets, multi-stage rockets, trajectories in powered flight, electric propulsion.

**Aero 540 (ME 540). Intermediate Dynamics**
*Prerequisite: ME 240. I (3 credits)*
Newton/Euler and Lagrangian formulations for three dimensional motion of particles and rigid bodies. Principles of dynamics applied to various rigid-body and multi-body dynamics problems that arise in aerospace and mechanical engineering.

**Aero 541. Computational Dynamics**
*Prerequisite: Aero 540. I (3 credits)*
Formulation of dynamics problems for computer solution. Kinematic preliminaries. Matrix and dyadic notation. Constraints, generalized coordinates, and quasi-coordinates. Generalized speeds. Rigid and flexible multi-body dynamics. Computational efficiency.

**Aero 543. Structural Dynamics**
*Prerequisite: Aero 315 or Aero 540. (3 credits)*
Natural frequencies and mode shapes of elastic bodies. Nonconservative elastic systems. Structural and viscous damping. Influence coefficient methods for typical flight structures. Response of structures to random and shock loads. Lab demonstration.

**Aero 544. Aeroelasticity**
*Prerequisite: Aero 315 or Aero 540. (3 credits)*
Introduction to aeroelasticity. Vibration and flutter of elastic bodies exposed to fluid flow. Static divergence and flutter of airplane wings. Flutter of flat plates and thin walled cylinders at supersonic speeds. Oscillations of structures due to vortex shedding.

**Aero 545. Principles of Helicopter and V/STOL Flight**
*Prerequisite: preceded or accompanied by Aero 325. I (3 credits)*
Introduction to helicopter performance, aerodynamics, stability and control, vibration and flutter. Other V/STOL concepts of current interest.

**Aero 546. Advanced Dynamics**
*Prerequisite: Aero 540 or ME 443. II (3 credits)*
Hamilton's equations, canonical transformations, and Hamilton-Jacobi theory. Applications to orbital problems. General perturbation theory. Introduction to special relativity.

**Aero 548. Astrodynamics**
*Prerequisite: Aero 443. II (3 credits)*
Motion of aerospace vehicles in space. Orbit determination. Orbit transfer. The restricted three-body problem. Canonical equations of motion. Perturbation theory with application to the motion of artificial satellites.

**Aero 550 (EECS 560) (ME 564). Linear Systems Theory**
*Prerequisite: graduate standing. I (4 credits)*
Linear spaces and linear operators. Bases, subspaces, eigenvalues and eigenvectors, canonical forms. Linear differential and difference equations. Mathematical representations: state equations, transfer functions, impulse response, matrix fraction and polynomial descriptions. System-theoretic concepts: causality, controllability, observability, realizations, canonical decomposition, stability.

**Aero 551 (EECS 562). Nonlinear Systems and Control**
*Prerequisite: graduate standing. II (3 credits)*
Introduction to the analysis and design of nonlinear systems and nonlinear control systems. Stability analysis using Liapunov, input-output and asymptotic methods. Design of stabilizing controllers using a variety of methods: linearization, absolute stability theory, vibrational control, sliding modes and feedback linearization.

**Aero 552 (EECS 501). Probability and Random Processes**
*Prerequisite: EECS 401 or graduate standing. I, II (4 credits)*
Introduction to probability and random processes. Topics include probability axioms, sigma algebras, random vectors, expectation, probability distributions and densities. Poisson and Wiener processes, stationary processes, autocorrelation, spectral density, effects of filtering, linear least-square estimation, and convergence of random sequences.

**Aero 553 (EECS 502). Stochastic Processes**
*Prerequisite: EECS 501. II (3 credits)*
Correlations and spectra. Quadratic mean calculus, including stochastic integrals and representations, wide-sense stationary processes (filtering, white noise, sampling, time averages, moving averages, auto-regression). Renewal and regenerative processes, Markov chains, random walk and run, branching processes, Markov jump processes, uniformization, reversibility, and queueing applications.

**Aero 564 (Mfg 564). Computer Aided Design and Manufacturing**
*Prerequisite: Aero 484 or ME 454 or permission of instructor based on familiarity with industrial standard CAE software. II (3 credits)*
Computer generation of geometric models, optimal design for manufacturing, manufacturing methods based on geometric models such as numerical control tool path generation, plastic mold design and rapid prototyping using stereolithography. Testing and redesign.

**Aero 565. Optimal Structural Design**
*Prerequisite: Aero 315, a course in advanced calculus. II (3 credits)*
Optimal design of structural elements (bars, trusses, frames, plates, sheets) and systems; variational formulation for discrete and distributed parameter structures; sensitivity analysis; optimal material distribution and layout; design for criteria of stiffness, strength, buckling, and dynamic response.

**Aero 570. Guidance and Navigation of Aerospace Vehicles**
*Prerequisite: Aero 550. II (3 credits)*
Principles of guidance and navigation in two and three dimensions. Explicit, linear perturbation, and velocity-to-be gained guidance modes. Mechanization by inertial and other means, including strapped-down and stable-platform inertial systems. Celestial navigation procedures with redundant measurements. Application of Kalman filtering to recursive navigation theory.

**Aero 572. Dynamics and Control of Aircraft**
*Prerequisite: Aero 345. II (3 credits)*
Introduction to flight mechanics and control of flight vehicles in the atmosphere. Translational and rotational motion, coordinate frames. Rigid-body dynamics. Control effectors. Linearized equations and linear control methods. Nonlinear control methods. Flight maneuvers. Guidance, navigation, and flight performance.

**Aero 573. Dynamics and Control of Spacecraft**
*Prerequisite: Aero 345. I (3 credits)*
Introduction to spacecraft dynamics and control. Spacecraft orbit and attitude representations, kinematics, dynamics. Perturbation equations for near circular orbits. Spacecraft maneuvers formulated and solved as control problems.

**Aero 575. Optimization of Space Trajectories**
*Prerequisite: permission of instructor. I (3 credits)*
Introduction to optimal control. Switching theory. Applications to aerospace trajectories: orbital transfer and rendezvous, atmospheric reentry, aero-assisted transfer.

**Aero 576 (EECS 563). Optimal Control**
*Prerequisite: Aero 550 (EECS 560). II (3 credits)*
Definition of optimal control problems. Formulation of discrete time optimal control problems as constrained mathematical programming problems. Formulation of continuous time optimal control problems as variational problems. The Pontryagin necessary condition. Application to a variety of specific optimal control problems from diverse disciplines. Introduction to computational methods in optimal control.

**Aero 578 (EECS 564). Estimation, Filtering, and Detection**
*Prerequisite: EECS 501. II (3 credits)*
Principles of estimation, linear filtering and detection. Estimation: linear and nonlinear minimum mean squared error estimation, and other strategies. Linear filtering: Wiener and Kalman filtering. Detection: simple, composite, binary and multiple hypotheses. Neyman-Pearson and Bayesian approaches.

**Aero 579. Control of Aerospace Structures**
*Prerequisite: Aero 471, Aero 414, Aero 550. II (3 credits)*
Equations of motion of controlled elastic structures; modal and finite element formulations; shape control; active damping using feedback; application to control of flexible aircraft and flexible space structures.

**Aero 580 (EECS 565). Linear Feedback Control Systems**
*Prerequisite: EECS 460 or Aero 345 or ME 461 and Aero 550 (EECS 560). II (3 credits)*
Control design concepts for linear multivariable systems. Review of single variable systems and extensions to multivariable systems. Purpose of feedback. Sensitivity, robustness, and design trade-offs. Design formulations using both frequency domain and state space descriptions. Pole placement/observer design. Linear quadratic Gaussian based design methods. Design problems unique to multivariable systems.

**Aero 581 (AOSS 581). Space System Management**
*Prerequisite: graduate standing. I (3 credits)*
The first part of the course will offer a comprehensive introduction to modern management methods used in large projects. The second part will concentrate on successful management examples of complex space projects. This course will usually be taught by adjunct faculty with extensive experience in successful management of large space projects.

**Aero 582 (AOSS 582). Spacecraft Technology**
*Prerequisite: graduate standing. I (3 credits)*
A systematic and comprehensive review of spacecraft and space mission technology, including trajectory and orbital mechanics, propulsion systems, power and thermal systems, structures, control, and communications.

**Aero 583. Management of Space Systems Design**
*Prerequisite: graduate standing. II (4 credits)*
Meets with Aero 483 (Space System Design), or other senior design course when appropriate topic is chosen. Students in this course lead teams in high level project design of a space system. Modern methods of concurrent engineering manufacturing, marketing and finance, etc., are incorporated.

**Aero 590. Directed Study**
*(to be arranged)*
Individual study of specialized aspects of aerospace engineering. Primarily for graduates.

**Aero 592. Space Systems Projects**
*Prerequisite: senior or graduate standing. (3-5 credits)*
Industry related team project for students enrolled in Master of Engineering in Space Systems degree program. Student teams will conduct aerospace related projects in conjunction with an industry or government partner.

**Aero 595. Seminar**
*Prerequisite: senior or graduate standing. (1-3 credits)*
Speakers will emphasize systems engineering, manufacturing, team building practices, business and management, and other topics which broaden the student's perspective. Mandatory for all Master of Engineering in Aerospace Engineering students; open to all seniors and graduate students.

**Aero 596. Projects**
*Prerequisite: graduate standing in Master of Engineering program. (3-5 credits)*
Industrial related team project for students enrolling in Master of Engineering degree program. Student teams will conduct design projects for and in conjunction with industrial or government customer.

**Aero 597 (AOSS 597). Fundamentals of Space Plasma Physics**
*Prerequisite: senior-level statistical physics course. II (3 credits)*
Basic plasma concepts, Boltzmann equation, higher order moments equations, MHD equations, double adiabatic theory. Plasma expansion to vacuum, transonic flows, solar wind, polar wind. Collisionless shocks, propagating and planetary shocks. Fokker-Planck equation, quasilinear theory, velocity diffusion, cosmic ray transport, shock acceleration. Spacecraft charging, mass loading.

**Aero 611. Advanced Topics in Finite Element Structural Analysis**
*Prerequisite: Aero 511 or ME 605. I (3 credits)*
Cyclic symmetry, design sensitivities and optimization. Applications to stress analysis, vibration, heat conduction, centrifugal effects, buckling. Introduction to high-level matrix-oriented programming languages (e.g., Direct Matrix Abstraction Program). Use of a large, general purpose finite element code as a research tool.

**Aero 614. Advanced Theory of Plates and Shells**
*Prerequisite: Aero 416. II alternate years (3 credits)*
Differential geometry of surfaces. Linear and nonlinear plate and shell theories in curvilinear coordinates. Anisotropic and laminated shells. Stability and post-buckling behavior. Finite element techniques, including special considerations for collapse analysis.

**Aero 615 (CEE 617) (ME 649). Random Vibrations**
*Prerequisite: Math 425 or equivalent, CEE 513 or ME 541 (AM 541) or Aero 543 or equivalent. II alternate years (3 credits)*
Introduction to concepts of random vibration with applications in civil, mechanical, and aerospace engineering. Topics include: characterization of random processes and random fields, calculus of random processes, applications of random vibrations to linear dynamical systems, brief discussion on applications to nonlinear dynamical systems.

**Aero 618. Theory of Elastic Stability II**
*Prerequisite: Aero 518 or equivalent and graduate standing. II (3 credits)*
Koiter's theory for buckling, post-buckling, mode interaction and imperfection sensitivity behavior in nonlinear solids. Applications to thin-walled beams, cylindrical and spherical shells as well as to 3-D hyperelastic solids. Loss of ellipticity in finitely strained solids. Hill's theory on bifurcation, uniqueness and post-bifurcation analysis in elastic-plastic solids with applications..

**Aero 623. Computational Fluid Dynamics II**
*Prerequisite: Aero 523 or equivalent, substantial computer programming experience, and Aero 520. II (3 credits)*
Advanced mathematical and physical concepts in computational fluid dynamics, with applications to one- and two-dimensional compressible flow. Euler and Navier-Stokes equations, numerical flux functions, boundary conditions, monotonicity, marching in time, marching to a steady state, grid generation.

**Aero 625. Advanced Topics in Turbulent Flow**
*Prerequisite: Aero 525. II (3 credits)*
Fundamentals of turbulent shear flows, with emphasis on dimensional reasoning and similarity scaling. Development of laminar shear flows, instability and transition to turbulent flow, kinetic and scalar energy transport mechanisms in turbulent shear flows, critical examination of numerical methods for turbulent flows, comparisons with experiments

**Aero 627. Advanced Gas Dynamics**
*Prerequisite: Aero 520, Aero 522. I (3 credits)*
Linear and nonlinear surface waves. Flow instabilities; nonlinear stability analysis. Vorticity dynamics: vortex motions, instabilities, and breakdown. Boundary layers: steady and unsteady interactions; nonlinear instability.

**Aero 633. Advanced Combustion**
*Prerequisite: Aero 533. II (3 credits)*
Thermodynamics of gas mixtures, chemical kinetics, conservation equations for multi-component reacting gas mixtures, deflagration and detonation waves. Nozzle flows and boundary layers with reaction and diffusion.

**Aero 672 (EECS 662) (ME 662). Advanced Nonlinear Control**
*Prerequisite: EECS 562 or ME 548 (AM 548). I (3 credits)*
Geometric and algebraic approaches to the analysis and design of nonlinear control systems. Nonlinear controllability and observability, feedback stabilization and linearization, asymptotic observers, tracking problems, trajectory generation, zero dynamics and inverse systems, singular perturbations, and vibrational control.

**Aero 714. Special Topics in Structural Mechanics**
*Prerequisite: permission of instructor. Term offered depends on special topic (to be arranged)*

**Aero 729. Special Topics in Gas Dynamics**
*Prerequisite: permission of instructor.*
*(to be arranged).*
Advanced topics of current interest.

**Aero 740. Special Topics in Flight Dynamics and Control Systems**
*(to be arranged)*

**Aero 800. Seminar**
*(to be arranged)*

**Aero 810. Seminar in Structures**
*(to be arranged)*

**Aero 820. Seminar in Aerodynamics**
*(to be arranged)*

**Aero 830. Seminar in Propulsion**
*(to be arranged)*

**Aero 840. Dynamics and Control Systems**
*(to be arranged)*

**Aero 850. Space Systems Seminar Mandatory**
*satisfactory/unsatisfactory. I (1-3 credits)*
Participating students, faculty, and invited speakers give seminars about selected space engineering related topics. The speakers will emphasize systems engineering, management, and operations of complex space systems.

**Aero 990. Dissertation/Pre-Candidate**
*I, II (2-8 credits); IIIa, IIIb (1-4 credits)*
Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**Aero 995. Dissertation/Candidate**
*Prerequisite: Graduate School authorization for admission as a doctoral candidate. I, II (8 credits); IIIa, IIIb (4 credits)*
Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

## Aerospace Engineering Faculty

David C. Hyland, Ph.D., *Chair and Professor*

### Professors

Dennis S. Bernstein, Ph.D.
Werner J.A. Dahm, Ph.D.
James F. Driscoll, Ph.D.
Gerard M. Faeth, Ph.D., *Arthur B. Modine Professor of Aerospace Engineering*
Peretz P. Friedmann, Sc.D., *François-Xavier Bagnoud Professor of Engineering*
Pierre T. Kabamba, Ph.D.; *also Electrical Engineering and Computer Science*
C. William Kauffman, Ph.D.
N. Harris McClamroch, Ph.D.; *also Electrical Engineering and Computer Science*
Kenneth G. Powell, Sc.D.
Philip L. Roe, B.A.
Nicolas Triantafyllidis, Ph.D.
Bram van Leer, Ph.D.
Anthony M. Waas, Ph.D.

### Adjunct Professor

Jack R. Lousma, B.S.E., Hon. Ph.D.

### Professors Emeritus

Thomas C. Adamson, Jr., Ph.D.
William J. Anderson, Ph.D.
Frederick L. Bartman, Ph.D.; *also Atmospheric, Oceanic and Space Sciences*
Frederick J. Beutler, Ph.D.; *also Electrical Engineering and Computer Science*
Harm Buning, M.S.E.
Joe G. Eisley, Ph.D.
Elmer G. Gilbert, Ph.D.
Donald T. Greenwood, Ph.D.
Paul B. Hays, Ph.D., *Dwight F. Benton Professor of Advanced Technology; also Atmospheric, Oceanic and Space Sciences*
Robert M. Howe, Ph.D.
Vi-Cheng Liu, Ph.D.
Arthur F. Messiter, Jr., Ph.D.
James A. Nicholls, Ph.D.
Richard L. Phillips, Ph.D.
Lawrence L. Rauch, Ph.D.
William L. Root, Ph.D.; *also Electrical Engineering and Computer Science*
Pauline M. Sherman, M.S.
Martin Sichel, Ph.D.

John E. Taylor, Ph.D.; *also Mechanical Engineering*
Nguyen X. Vinh, Ph.D., Sc.D.
William W. Willmarth, Ph.D.

### Associate Professors

Luis P. Bernal, Ph.D.
Iain D. Boyd, Ph.D.
Alec D. Gallimore, Ph.D.; *also Applied Physics*
Peter D. Washabaugh, Ph.D.

### Assistant Professor

Daniel J. Scheeres, Ph.D.
John A. Shaw, Ph.D.

### Lecturer

Donald M. Geister, M.S.E.; *also Mechancial Engineering*

## Aerospace Engineering Contact Information

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# ATMOSPHERIC, OCEANIC AND SPACE SCIENCES

*Program Advisor*
*Professor S. R. Drayson (Atmospheric Science)*
*2207 Space Research Building*
*(734) 647-3660*

Atmospheric, Oceanic and Space Sciences (AOSS) is concerned with the description and explanation of phenomena in the atmosphere and oceans of the Earth and other planets. Both theoretical and applied problems are treated.

The increased recognition of the importance of the Earth's atmosphere and oceans in a wide range of human activity has created a demand for atmospheric scientists, oceanographers, and space scientists with a broad knowledge of the many processes that take place in the earth-ocean-atmosphere system, ranging from the sea floor to the altitude of orbiting satellites. This knowledge is necessary to understand and manage weather and climate changes caused by natural and anthropogenic modifications of our environment.

The sub disciplines treated within AOSS cover a wide range of activities and interests. The atmospheric scientist is concerned with solving problems relating to forecasting, air pollution, industrial plant location and processes, the design of structures and the wind loading of them. Many important decisions on transportation, whether by land, water, or air, depend critically on meteorological factors. The oceanographer is concerned with solving problems relating to water supply and control, water pollution, wave action on structures and beaches, and many other oceanographic and ocean engineering problems. Areas of interest in space science include the construction of satellite-platform instruments for observation of the earth-atmosphere-ocean system. The B.S. degree in AOSS will prepare graduates for employment in the National Weather Service, private weather forecasting companies, air- and water-quality management firms, or NASA; and for continued studies in graduate school.

## Degree Program in Atmospheric, Oceanic and Space Sciences

The course of study leading to the B.S. is designed to be flexible and to accommodate a wide variety of interests. All students in the undergraduate program take a sequence of 9 core courses (32 credit hours) that introduce the various aspects of atmospheric, oceanic and space sciences, emphasizing the common elements of and the interactions between, the various disciplines and the scientific basis of the phenomena that are observed.

An additional 31 credit hours, split between technical and unrestricted electives, are selected by the student with the advice and consent of the program advisor, to allow the student to specialize in a particular subdiscipline. The technical electives (18 credit hours) must be at 300 level or above.

The technical electives may be optionally chosen to satisfy the requirements of one of four concentrations offered in the undergraduate program. Completion of a concentration will be noted on the students transcript. The concentrations are:

### Meteorology Concentration

*This concentration, for students interested in weather and forecasting, is designed to meet the requirements of the American Meteorological Society and the National Weather Service.*

**Required (15 credit hours):**

*AOSS 310 Synoptic Laboratory I (1)*
*AOSS 311 Synoptic Laboratory II (2)*
*AOSS 414 Weather Systems (3)*
*AOSS 424 Mesometeorology (3)*
*AOSS 454 Weather Analysis and Forecasting Laboratory (3)*
*Remote Sensing (3)*

*The Remote Sensing course may be selected from AOSS 458, 459, 465 or other courses in the College of Engineering, or SNRE. Students should select a statistics course to fulfill the advanced mathematics or statistics requirement in the core. Statistics 412 (3) or IOE 265 (4) are recommended. Additional recommended courses to complete technical electives are AOSS 399, 411, 422, 479.*

*Students electing this concentration are encouraged to complete an internship in a weather forecasting office.*

### Environmental Atmospheric Science Concentration

*For students who intend to pursue a career in air quality or an associated field. It meets the American Meteorological Society's guidelines for a career in air pollution.*

**Required (15 credit hours):**

*AOSS 411 Cloud and Precipitation Processes (3)*
*AOSS 414 Weather Systems (3)*
*AOSS 463 Air Pollution Meteorology (3)*
*AOSS 467 Biogeochemical Cycles (3)*
*AOSS 479 Atmospheric Chemistry (3)*

*Students should select a statistics course to fulfill the advanced mathematics or statistics requirement in the core. Statistics 412 (3) or IOE 265 (4) are recommended.*

### Computational Geophysics

*For students who want a basic science degree with an emphasis on mathematical and computational skills.*

**Required (16 credit hours):**

*AOSS 401 Geophysical Fluid Dynamics (3)*

*AOSS 408 Environmental Problem Solving with Computers (3)*

*Math 417 Linear Algebra (3)*

*Eng. 403 Scientific Visualization (3)*

*EECS 380 Data Structures (4)*

*Students should select Math 450 Advanced Mathematics for Engineers (4) to fulfill the advanced mathematics requirement in the core. Math 417 should be taken before or concurrently with AOSS 408.*

**Space Science**

*This concentration strongly emphasizes the fundamental physical concepts needed by a space scientist.*

**Required (17 credit hours):**

*Physics 340 Waves, Heat and Light (3)*

*Physics 341 Waves, Heat and Light Lab. (2)*

*Physics 390 Introduction to Modern Physics (3)*

*Physics 405 Intermediate Electricity and Magnetism (3)*

*AOSS 464 The Space Environment (3)*

*NERS 471 Introduction to Plasmas (3)*

*Students should select Math 450, Advanced Mathematics for Engineers (4), to fulfill the advanced mathematics requirement in the core, and Physics 406 for the thermodynamics course.*

## Facilities

Laboratories include Air Pollution Meteorology; Meteorological Instrumentation; a Synoptic Meteorology Laboratory weather station where current weather data including satellite information are received over a satellite link; and a dynamic Meteorology Laboratory where numerical simulations of various atmospheric and oceanic phenomena are performed. The Weather Underground and the Weather Net provide current weather information and forecasts to users of the World Wide Web (http://groundhog.sprl.umich.edu).

The department also operates a Radiation Measurement Analysis Facility, which includes comprehensive solar and infrared radiation measuring devices with automatic data acquisition. The Space Physics Research Laboratory houses teaching and research activities for studies of all regions of Earth's atmosphere and space probe studies of the atmospheres of other planets.

Other facilities include laboratories for the study of atmospheric chemistry and for field measurements of atmospheric constituents, as well as modeling of the transport and dispersion of pollutants. Remote sensing of the atmosphere and ocean from satellites and other platforms is a strong area of research in the department. In the space sciences there is an emphasis on the upper atmosphere, the atmospheres of the planets, the interplanetary medium, and the study of comets. Facilities for the construction and testing of satellite instruments are part of the laboratory.

Undergraduates are encouraged to participate in research programs in one of the areas discussed above. Additionally, state-of-the-art classroom facilities and several computer labs are located in the department.

## Sample Schedule B.S. Atmospheric, Oceanic and Space Sciences

| | Credit Hours | Terms 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| **Subjects required by all programs (57 hrs.)** | | | | | | | | | |
| Mathematics 115, 116, 215, and 216 | 16 | 4 | 4 | 4 | 4 | - | - | - | - |
| Engr 100, 101 | 8 | 4 | 4 | - | - | - | - | - | - |
| Chemistry 125 and 130 or 210 and 211 | 5 | 5 | - | - | - | - | - | - | - |
| Physics 140 with Lab 141; 240 with Lab 241 | 10 | - | 5 | 5 | - | - | - | - | - |
| Humanities and Social Science | 18 | 3 | 3 | 4 | 4 | - | - | 4 | - |
| **AOSS Core Courses (32 hrs.)** | | | | | | | | | |
| 304, Atmos and Ocean Environment | 4 | - | - | - | - | 4 | - | - | - |
| 305, Intro to Atmos and Ocean and Space Dynamics | 4 | - | - | - | - | - | 4 | - | - |
| 335, Space Science and Spacecraft Applics. | 3 | - | - | - | - | 3 | - | - | - |
| EECS 283, Programming Concepts II or EECS 280 | 4 | - | - | - | 4 | - | - | - | - |
| [1]Thermodynamics, AOSS 430 or Phys 406 | 3 | - | - | - | - | - | 3 | - | - |
| 432, Radiative Transfer | 3 | - | - | - | - | - | 3 | - | - |
| 462, Instrumentation for Atmos and Space Sci | 4 | - | - | - | - | - | - | - | 4 |
| 475, Earth-Ocean-Atmos Interactions | 4 | - | - | - | - | - | - | - | 4 |
| [2]Advanced Mathematics or Statistics | 3 or 4 | - | - | - | - | 3 | - | - | - |
| **Technical Electives (18 hrs.)** | | | | | | | | | |
| 300-level of above | 18 | - | - | - | - | 3 | 3 | 6 | 6 |
| **Unrestricted Electives (13 hrs.)** | 13 | - | - | 3 | 3 | 3 | - | 4 | - |
| **Total Hours** | **120** | **16** | **16** | **16** | **15** | **16** | **13** | **14** | **14** |

Candidates for the Bachelor of Science degree in Atmospheric, Oceanic and Space Sciences—B.S. (A.O.S.S.)—must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

**Notes:**

[1]Students in the Space Science concentration must elect Physics 406, all other concentration elect AOSS 430

[2]Students in the Space Science and Geophysical Computation concentrations must elect advanced mathematics, Meterology and Environmental Atmospheric Science elect statistics

# Atmospheric, Oceanic and Space Sciences Course Listings

Course descriptions are found also on the College of Engineering web site at http://courses.engin.umich.edu/

**AOSS 105 (Chem 105). Our Changing Atmosphere**
*Prerequisite: none. I, II (3 credits)*
The science of the greenhouse effect, stratospheric ozone depletion, polar ozone holes, and urban smog. These phenomena and their possible consequences are discussed, along with the properties and behavior of the atmosphere and its interactions with other components of the environment.

**AOSS 111. Diving Science and Technology**
*Prerequisite: none. I, II (3 credits)*
Principles and practices of conducting engineering and research operations underwater: human performance; use of diving equipment; underwater safety; underwater engineering and research techniques. Lecture only.

**AOSS 123 (Geol Sci 123) (SNRE 123). Life and the Global Environment**
*Prerequisite: none. II (2 credits)*
Life has affected the global environment throughout Earth's history, but the changes brought about by human beings are much more rapid than any the planet has experienced before. This course views the global change of the present from the perspective of planetary history, emphasizing environmental constraints on biological evolution and possible constraints on human activity in the future.

**AOSS 171 (Biol 110) (Univ Course 110) (SNRE 110) (Geol Sci 171). Introduction to Global Change–Part I**
*Prerequisite: none. I (4 credits)*
The course will consider the evolution of the universe, the Earth and its environments, and the evolution of living organisms. Consideration will be given to fundamental processes by which organisms grow and reproduce, how they interact with their environments, and the distribution of major groups of organisms on earth.

**AOSS 172 (Univ Course 111) (SNRE 111) (Soc 111). Introduction to Global Change–Part II**
*Prerequisite: none. II (4 credits)*
An introduction to the evolution of life and the human species on earth, with focus on problems of global change produced by recent human advances in technology and institutions.

**AOSS 202. The Atmosphere**
*Prerequisite: none. I, II (3 credits)*
Elementary description of the atmosphere: characteristics and behavior, changes over generations and hours, destructive capability, and response to human activity.

**AOSS 203. The Oceans**
*Prerequisite: none. I, II (3 credits)*
Elementary descriptions of the oceans: characteristics and behaviors; the sea as a world resource, and as an influence on civilizations.

**AOSS 204 (Astron 204) (Geol Sci 204). The Planets: Their Geology and Climates**
*Prerequisite: none. I (3 credits)*
Structure, composition, and evolutionary history of the surfaces and atmospheres of the planets and their satellites, with special emphasis given to comparative aspects of geology and climatology. Intended for non-science majors with a background in high school math and science.

**AOSS 280. Environmental Impact of Technological Change**
*Prerequisite: sophomore standing in engineering or natural science. I (2 credits)*
An exploration of the unexpected environmental side effects of technological innovation, with a comparison of benefits and costs. How science and engineering have remade the world with good intentions that sometimes have had bad results. Methods that can be used to estimate environmental consequences, distinguishing between serious problems and false alarms.

**AOSS 304. Atmospheric and Oceanic Environment**
*Prerequisites: Physics 140, Math 116, Chem 130. I (4 Credits)*
Morphology of the atmosphere and oceans ranging from global to local scales, and the physical processes responsible for temperature, winds, currents, composition, and heat transport. Topics will include the equation of state, energy balance, boundary layers, stability, geostrophy, global circulation, air and water masses, and fronts and mid-latitude cyclones.

**AOSS 305. Introduction to Atmospheric, Oceanic and Space Dynamics**
*Prerequisites: AOSS 304, Math 215. II (4 Credits)*
Fluid kinematics and thermodynamics; equations of motion; hydrostatic and geostrophic approximations; convective instability; atmospheric boundary layer; Gulf Stream theory; wave motions; barotropic and baroclinic instability; introductory kinetic theory; electromagnetic forces.

**AOSS 310. Synoptic Laboratory I**
*Prerequisite: AOSS 202 or preceded or accompanied by AOSS 304. I (1 credit)*
An introduction to weather observations, analyses, displays and forecasting.

**AOSS 311. Synoptic Laboratory II**
*Prerequisite: AOSS 310, preceded or accompanied by AOSS 305. II (2 credits)*
Analysis of meteorological data in space and time; vertical distribution of different elements in the atmosphere; weather forecasting.

**AOSS 335. Space Science and Spacecraft Applications**
*Prerequisite: junior standing in engineering. I, II (3 credits)*
The sun, solar radiation and the solar wind. The terrestrial atmosphere and ionosphere: general structure and controlling processes. Aurora and radiation belts. Useful spacecraft orbits, lifetime and causes of decay. Remote sensing principles and the performance of sensors. Representative examples of remote sensing satellites.

**AOSS 399. Weather Forecasting Practicum**
*Prerequisite: permission of instructor. I, II (1 credit)*
Students gain valuable forecasting experience through daily ~30 minutes of weather discussions, forecasting for different U.S. cities and participation in a yearly National Collegiate Weather Forecasting Contest (NCWFC). Students should elect this course during consecutive fall and winter semesters to be eligible for NCWFC ranking.

**AOSS 401. Geophysical Fluid Dynamics**
*Prerequisite: Physics 240, preceded or accompanied by Aero 350 or Math 450. I (3 credits)*
Dynamics of the oceans and atmosphere. Equations of motion in spherical coordinates, beta-plane approximation, wave properties in the oceans and atmosphere.

**AOSS 407. Mathematical Methods in Geophysics**
*Prerequisite: Math 216. I (3 credits)*
Vector calculus and Cartesian tensors; Sturm-Liouville systems, Green's functions, and solution of boundary value problems; Fourier series, Fourier and Laplace transforms, discrete Fourier transform, fast Fourier transforms, and energy spectra.

**AOSS 408. Environmental Problem Solving with Computers**
*Prerequisite: Eng 103, Math 216. I (3 credits)*

# ATMOSPHERIC, OCEANIC AND SPACE SCIENCES

Solution of meteorological, oceanographic, and general environmental problems using computers. Applications of numerical analysis, statistics, and data handling to geophysics and environmental numerical output in terms of observed phenomena.

**AOSS 411. Cloud and Precipitation Processes**
*Prerequisite: AOSS 430. I (3 credits)*
The special nature of water substance; nucleation of phase changes in the free atmosphere; the structure and content of clouds; the development of physical characteristics of precipitation; and the dynamics of rain systems.

**AOSS 412. Dynamics of Climate**
*Prerequisite: none. I (3 credits)*
Climatic fluctuations and change; paleo and historical climates; construction of climatic models; and the climatic implications of human activity.

**AOSS 414. Weather Systems**
*Prerequisite: AOSS 305 or AOSS 401. I (3 credits)*
Identification and description of significant weather systems from satellite imagery and from data sources. These systems are examined further through application of theoretically derived dynamical concepts to datasets from actual events. A range of phenomena including mid-latitude cyclones, hurricanes, lake-effect storms, and tornadoes will be addressed.

**AOSS 420 (NA 420). Environmental Ocean Dynamics**
*Prerequisites: NA 320 or AOSS 305 or CEE 325. I (4 credits)*
Physical conditions and physical processes of the oceans; integration of observations into comprehensive descriptions and explanations of oceanic phenomena. Emphasis on wave and current prediction, optical and acoustical properties of sea water, currents, tides, waves and pollutant trasport.

**AOSS 422. Micrometeorology I**
*Prerequisite: Physics 240 or Math 215. I (3 credits)*
Physical processes responsible for the thermal and moisture conditions in the air layer near the ground. Components of net radiation exchange, heat transfer in soil, wind structure and turbulence near the ground, turbulent transfer of sensible heat and water vapor, evapotranspiration; forest climatology, transitional microclimates.

**AOSS 424. Mesometeorology**
*Prerequisite: AOSS 305 or AOSS 401. I (3 credits)*
An introduction to mesometeorological phenomena including organized convection, thunderstorms, tornadoes, foehns, lee waves, orographic blocking, sea breezes, urban heat islands, and effects from the Great Lakes.

**AOSS 425 (NA 425). Environmental Ocean Dynamics**
*Prerequisite: NA 320 or AOSS 305 or CEE 325. I (4 credits)*
Physical conditions and physical processes of the oceans; integration of observations into comprehensive descriptions and explanations of oceanic phenomena. Emphasis on wave and current prediction, optical and acoustical properties of sea water, currents, tides, waves and pollutant transport.

**AOSS 430. Thermodynamics of the Atmosphere**
*Prerequisite: preceded or accompanied by Math 216. II (3 credits)*
Physical principles of thermodynamics with emphasis on atmospheric applications. Topics include atmospheric statics; first and second principles of thermodynamics; adiabatic processes; thermodynamics of moist air; equilibrium with droplets and crystals; fundamentals of cloud and precipitation processes.

**AOSS 432. Environmental Radiative Processes**
*Prerequisite: Math 216, Physics 240. II (3 credits)*
The nature of electromagnetic radiation. Solar and terrestrial radiation. The transfer of radiation including absorption, emission and scattering. Radiation and climate. Satellite observations and remote sounding.

**AOSS 434. Mid-Latitude Cyclones**
*Prerequisite: AOSS 414 or AOSS 451. II (3 credits)*
A dynamical approach is used to describe the development of mid-latitude cyclones. Various aspects of these cyclones are examined through application of theoretically derived dynamical concepts to datasets from actual storms. Topics including the Norwegian cyclone model, explosive coastal cyclogenesis, lee cyclo-genesis, and recent cyclone models will be discussed.

**AOSS 442. Oceanic Dynamics I**
*Prerequisite: AOSS 401. II (3 credits)*
Wave motions; group velocity and dispersion. Gravity waves, wave statistics and prediction methods; long period waves; the tides. Steady state circulation, including theories of boundary currents and the thermocline.

**AOSS 451. Atmospheric Dynamics I**
*Prerequisite: AOSS 401. II (3 credits)*
Quasi-geostrophic energetics; fronts; the mean circulation; planetary and equatorial waves: overview of the dynamics of the middle atmosphere; wave-mean flow interaction; spectral methods; and tropical meteorology.

**AOSS 454. Weather Analysis and Forecasting Laboratory**
*Prerequisite: AOSS 311, preceded or accompanied by AOSS 414. II (3 credits)*
Principles of meteorological analysis. Structure of wave cyclones and fronts; vorticity, divergence, and vertical velocity; quasi-geostrophic theory and diagnostics; cyclogenesis and fronto-genesis. Description of operational numerical forecast models and facsimile products. Daily weather discussion and forecasting.

**AOSS 458. Principles and Applications of Visible and Infrared Remote Sensing**
*Prerequisite: Math 216, Physics 140 or equivalent. I (3 credits)*
Principles of visible and infrared remote sensing are discussed, beginning with electromagnetic wave propagation, emission, absorption and scattering, followed by air and spacecraft instruments. These principles are applied to case studies in environmental science and protection, global change, urban metabolism, surveillance and treaty monitoring as well as law enforcement.

**AOSS 459. Principles and Applications of Radio and Active Remote Sensing**
*Prerequisite: Math 216, Physics 140. II (3 credits)*
Principles of radio and lidar remote sensing are discussed, beginning with electromagnetic wave propagation, emission, absorption and scattering, followed by air and spacecraft instruments. These principles are applied to case studies in environmental science and protection, global change, urban metabolism, military surveillance and treaty monitoring as well as law enforcement.

**AOSS 460. Satellite Meteorology**
*Prerequisite: none. I (3 credits)*
Topics selected from characteristics of meteorological satellite orbits and of instruments used for the measurement of meteorological parameters using visible, infrared, and microwave radiation. Application of satellite measurements to Earth's radiation balance and albedo, surface temperature, atmospheric temperature structure, cloud heights and types, minor atmospheric constituents, aerosols and precipitation, winds, and circulation.

**AOSS 461. Meteorological Instrumentation for Air Pollution Studies**
*Prerequisite: none. II (2 credits)*
Analysis of meteorological factors that affect dispersion directly and indirectly. Guidelines in selecting wind speed, wind direction, turbulence, temperature, and humidity measuring instruments. Significance of rate of response of sensors. Methods of measuring these parameters above the heights of towers. Methods of measuring diffusion by tracer experiments, both visible and invisible. Wind tunnel modeling of urban problems.

**AOSS 462. Instrumentation for Atmospheric and Space Sciences**
*Prerequisite: AOSS 305. II (4 Credits)*

Introduction to fundamentals of atmospheric, space-based, and meteorological instrumentation. Includes basics of electronic sensors, optics, lasers, radar, data acquisition/management, error analysis, and data presentation. Consists of two lectures and one lab each week, and a team-based term project.

**AOSS 463. Air Pollution Meteorology**

*Prerequisite: none. II (3 credits)*

Weather and motion systems of the atmosphere; topographic influences on winds, atmospheric stability and inversions; atmospheric diffusion; natural cleansing processes; meteorological factors in plant location, design, and operation.

**AOSS 464 (Aero 464). The Space Environment**

*Prerequisite: senior or graduate standing in a physical science or engineering. I (3 credits)*

An introduction to physical and aeronomical processes in the space environment. Discussion of theoretical tools, the Sun, solar spectrum, solar wind, interplanetary magnetic field, planetary magnetosphere, ionospheres and upper atmospheres. Atmospheric processes, densities, temperatures, and wind.

**AOSS 465. Space System Design for Environmental Observations**

*Prerequisite: senior standing. I (3-4 credits)*

A space system is designed to address a defined problem in environmental observations, e.g. remote sensing from spacecraft for public health applications. Information is gathered from speakers, literature, and university and industrial contacts. Team members complete a design, and report formally to interested parties on a national scale.

**AOSS 466 (Geol Sci 466). Computational Models of Geochemical Processes**

*Prerequisite: ability to program in BASIC. I (3 credits)*

Computational models of the processes that govern the composition of ocean and atmosphere. Geochemical reservoirs, mechanisms of transfer, chemical interactions, and feedback processes. The impact of organisms on the global environments geological history of atmospheric and oceanic composition.

**AOSS 467 (Chem 467) (Geol Sci 465). Biogeochemical Cycles**

*Prerequisite: Math 116, Chem 210, Physics 240. I (3 credits)*

The biogeochemical cycles of water, carbon, nitrogen, and sulfur; the atmosphere and oceans as reservoirs and reaction media; the fate of natural and man-made sources of carbon, nitrogen, and sulfur compounds; the interactions among the major biogeochemical cycles and resultant global change; greenhouse gases, acid rain and ozone depletion.

**AOSS 469 (NA 469). Underwater Operations**

*Prerequisite: none. II (3 credits)*

Survey of manned undersea activities in oceanography and ocean engineering. The tools of underwater operations: decompression chambers, habitats, submarines, diving apparatus; pertinent design criteria and applications as based on humanhyperbaric physiology and performance. Topics in research diving for engineering and oceanographic studies.

**AOSS 475. Earth-Ocean-Atmosphere Interactions**

*Prerequisite: Senior standing in science or engineering. II (4 Credits)*

To develop students' abilities to integrate processes important to global change; surface characteristics, hydrology, vegetation, biogeochemical cycles, human dimensions. Analysis of current research advances. Interdisciplinary team projects with oral and poster presentations.

**AOSS 479. Atmospheric Chemistry**

*Prerequisite: Chem 130, Math 216. I (3 credits)*

Thermochemistry, photochemistry, and chemical kinetics of the atmosphere; geochemical cycles, generation of atmospheric layers and effects of pollutants are discussed.

**AOSS 480 (Geol Sci 480). The Planets: Composition, Structure, and Evolution**

*Prerequisite: Math 216, Physics 240, Chem 130. II (3 credits)*

Origin of the solar system, composition and radial distribution of material in planets and satellites; relationship of gravity fields to shape and density distribution; magnetism; origin and significance of topography; structure of planetary atmospheres; energetics and dynamics of interiors and atmospheres, thermal histories and evolution of interiors, devolatization, origin, and evolution of atmospheres.

**AOSS 495. Thermosphere and Ionosphere**

*Prerequisite: AOSS 464. II alternate years (3 credits)*

Basic physical processes significant to the structure and characteristics of the upper atmosphere; photo-chemistry, diffusion, ionization, distribution of neutral and charged particles; thermal structure of the upper atmosphere; atmospheric motions, geomagnetic storms.

**AOSS 498. Practicum in Atmospheric, Oceanic and Space Sciences**

*Prerequisite: permission of instructor. I, II, III, IIIa, IIIb (1 or 2 credits)*

Course may be repeated to a maximum of 8 credit hours. Students taking this course will participate in research and/or engineering tasks. Supervision will be undertaken by faculty and engineers of the AOSS department. Reporting requirements include a final written summary. Diverse tasks include aircraft spacecraft and rocket payload design field campaign support calibration simulation test. Students will join an active research program of AOSS for a given semester.

**AOSS 499. Directed Study for Undergraduate Students**

*Prerequisite: permission of instructor. I, II, III, IIIa, IIIb (to be arranged)*

Directed reading, research, or special study for advanced undergraduate students.

**AOSS 501. Seminars in Limnology and Oceanography**

*Prerequisite: graduate standing. I, II (1 credit)*

Current research efforts will be presented by graduate students and faculty dealing with all phases of limnology and oceanography.

**AOSS 524. General Circulation**

*Prerequisite: previous or concurrent with AOSS 401. I alternate years (3 credits)*

Processes that maintain the general circulation of the Earth's atmosphere; the observed general circulation; energetics; balance requirements; comparison of observations with simple theories and results from general circulation model simulations.

**AOSS 528 (NA 528). Remote Sensing of Ocean Dynamics**

*Prerequisite: AOSS 425 (NA 425) or permission of instructor. II (3 credits)*

The dynamics of ocean wave motion, both surface and internal waves, and ocean circulation are explored utilizing active and passive remote sensing techniques. Emphasis is placed upon the synoptic perspective of ocean dynamics provided by remote sensing which is not obtainable by conventional means.

**AOSS 532. Radiative Transfer**

*Prerequisite: graduate standing. I (3 credits)*

Radiative transfer (thermal and scattering) applicable to planetary atmospheres. Macro and microscopic form of transfer equation. Line broadening mechanisms, band models, Rayleigh and Mie scattering. Discrete ordinate, successive order of scattering and adding and doubling methods of solution. Non LTE formulation. Applications to, and results from, climate studies.

**AOSS 550 (NA 550). Offshore Engineering Analysis II**

*Prerequisite: NA 420 (AOSS 420). II (3 credits)*

Design and analysis requirements of offshore facilities. Derivation of hydrodynamic loads on rigid bodies. Loads on long rigid and flexible cylinders. Viscous forces on cylinders, experimental data, Morison's equation, Stokes wave theories. Shallow water waves. Selection of appropriate wave theory. Diffraction of waves by currents. Hydrodynamic loads on risers, cables, pipelines and TLP's.

**AOSS 551. Advanced Geophysical Fluid Dynamics**

*Prerequisite: AOSS 451. I alternate years (3 credits)*

Advanced topics in dynamic meteorology and oceanography including frontogenesis, stability and instability, dynamics of the equatorial ocean, CISK and hurricanes, modons and Gulf Stream rings, strange attractors.

**AOSS 555. Spectral Methods**

*Prerequisite: Math 216, Eng 103 or knowledge of FORTRAN. II alternate odd years (4 credits)*

An introduction to numerical methods based on Fourier Series, Chebyshev polynomials, and other orthogonal expansions. Although the necessary theory is developed, the emphasis is on algorithms and practical applications in geophysics and engineering, especially fluid mechanics. Many homework assignments will be actual problem-solving on the computer.

**AOSS 556. Space System Design for Space Sciences**

*Prerequisite: graduate standing. II (4 credits)*

Team leadership in high level project design of a space system, including launch facilities, booster systems, spacecraft subsystems and their integration, communications, ground control, data processing, project management, safety, environmental impact, economic, and political factors. One hour is spent on topics such as concurrent engineering, manufacturing, marketing and finance, etc.

**AOSS 563. Air Pollution Dispersion Modeling**

*Prerequisite: AOSS 463. II (3 credits)*

Principles of modeling air pollution transport and dispersion. Discussion of models for line sources, area sources and point sources. Analysis of individual model data requirements, founding assumptions, and inherent limitations. Practical experience using currently operational models.

**AOSS 564. The Stratosphere and Mesosphere**

*Prerequisite: AOSS 464. II odd years (3 credits)*

The physical, chemical, and dynamical properties of the atmosphere between the tropopause and the turbopause. Among the topics covered are the heat and radiation budgets, atmospheric ozone, stratospheric warmings, the biennial stratospheric oscillation, airglow.

**AOSS 565. Planetary Atmospheres**

*Prerequisite: graduate standing. I (3 credits)*

Radiative, photochemical, thermodynamic, and aeronomical processes in the atmospheres of the planets and satellites, with the objective of understanding the composition, structure, origin, and evolution of the atmospheres; theoretical and empirical results, including planetary observations by space probes.

**AOSS 567 (Chem 567). Chemical Kinetics**

*Prerequisite: Chem 461 or AOSS 479. I (3 credits)*

A general course in chemical kinetics, useful for any branch of chemistry where reaction rates and mechanisms are important. Scope of subject matter: practical analysis of chemical reaction rates and mechanisms, theoretical concepts relating to gas and solution phase reactions.

**AOSS 575. Air Pollution Monitoring**

*Prerequisite: AOSS 463, AOSS 578, NRE 538 (previously or concurrently). II (3 credits)*

A practical introduction to the fundamentals of gas and aerosol measurements with a focus on ozone and acidic gases, their precursors, and aerosols; operation of the suite of instruments, detection and sampling techniques, and calibration practices. An important feature will be team-oriented tasks involving air quality monitoring.

**AOSS 576. Air Quality Field Project**

*Prerequisite: AOSS 578, NRE 538, AOSS 575, or AOSS 563. IIIa (4 credits)*

Practical experience in all aspects of air quality field measurements from the design and planning stage through implementation and data analysis and interpretation. Emphasis on research design, sampling, data management systems, sample tracking, computerized data acquisition and processing, error analysis and reporting; team-oriented practicum for modelers and experimentalists.

**AOSS 578 (EIH 666). Air Pollution Chemistry**

*Prerequisite: AOSS 479 or Chem 365. II (3 credits)*

Tropospheric and stratospheric air pollution are discussed following a review of thermo-chemistry, photo-chemistry, and chemical kinetics. Gaseous and particulate air pollutants are considered in terms of their origins and transformations.

**AOSS 580. Remote Sensing and Geographic Information System Project Laboratory**

*Prerequisite: Math 216, Physics 140. II (2 hours)*

Lectures and hands-on demonstrations train students in acquiring and processing remote sensing and field data using computer based image processing and geographic information systems. Students apply this knowledge in individual and small team projects oriented toward student interests. Research project results are communicated in formal presentations and written reports.

**AOSS 581 (Aero 581). Space System Management**

*Prerequisite: graduate standing. I (3 credits)*

The first part of the course will offer a comprehensive introduction to modern management methods used in large projects. The second part will concentrate on successful management examples of complex space projects. This course will usually be taught by adjunct faculty with extensive experience in successful management of large space projects.

**AOSS 582 (Aero 582). Spacecraft Technology**

*Prerequisite: graduate standing. I (3 credits)*

A systematic and comprehensive review of spacecraft and space mission technology, including trajectory and orbital mechanics, propulsion systems, power and thermal systems, structures, control, and communications.

**AOSS 585. Introduction to Remote Sensing and Inversion Theory**

*Prerequisite: graduate standing. II (3 credits)*

An introduction to the techniques of remote sensing in the optical spectral region. Atmospheric sounding and spectroscopic study of the atmosphere. Methods of inversion of measurements to yield model parameters. Optimal estimation, non-linear inversion, and sequential estimation.

**AOSS 590. Space Systems Projects**

*Prerequisite: graduate standing. IIIa (4 credits)*

Space science and application mission related team project. Student teams will participate in ongoing projects in the Space Physics Research Laboratory in conjunction with industry and government sponsors.

**AOSS 595 (EECS 518). Magnetosphere and Solar Wind**

*Prerequisite: graduate standing. I even years (3 credits)*

General principles of magnetohydrodynamics; theory of the expanding atmosphere; properties of solar wind, interaction of solar wind with the magnetosphere of the Earth and other planets; bow shock and magnetotail, trapped particles, auroras.

**AOSS 596 (Aero 532). Gaskinetic Theory**

*Prerequisite: graduate standing. I (3 credits)*

Maxwell-Boltzmann distribution, kinetic determination of equation of state, specific heats of gases. Dynamics of two-particle collisions. Elementary transport theory, molecular effusion, hydrodynamic transport coefficients, mean free path method. Advanced transport theory, the Boltzmann equation, collision terms, Champman-Enskog transport theory. Aerodynamics of free-molecular flow. Shock waves.

**AOSS 597 (Aero 597). Fundamentals of Space Plasma Physics**
*Prerequisite: senior-level statistical physics course. II (3 credits)*
Basic plasma concepts, Boltzmann equation, higher order moments equations, MHD equations, double adiabatic theory. Plasma expansion to vacuum, transonic flows, solar wind, polar wind. Collisionless shocks, propagating and planetary shocks. Fokker-Planck equation, quasilinear theory, velocity diffusion, cosmic ray transport, shock acceleration. Spacecraft charging, mass loading.

**AOSS 605. Current Topics in Atmospheric, Oceanic and Space Sciences**
*Prerequisite: permission of instructor. I, II (1-4 credits)*
Advances in specific fields of atmospheric and oceanic sciences, as revealed by recent research. Lectures, discussion, and assigned reading.

**AOSS 606. Computer Applications to Geo-Fluid Problems**
*Prerequisite: AOSS 442 or AOSS 451, Eng 103, Math 450. II (3-4 credits)*
Solution of geo-fluid problems by numerical techniques using a digital computer. Lectures, laboratory, exercises using the digital computer.

**AOSS 651. Dynamics of Planetary Atmospheres and the Upper Atmosphere**
*Prerequisite: AOSS 451. I alternate years (3 credits)*
Dynamic meteorology of other planets (Mars, Venus, Jupiter, and Titan), the Earth's middle atmosphere, and thermosphere. Tides, solitary waves, quasi-geostrophic turbulence, and dynamics and chemistry are among the phenomena discussed.

**AOSS 701. Special Problems in Meteorology and Oceanography**
*Prerequisite: permission of instructor. I, II (to be arranged)*
Supervised analysis of selected problems in various areas of meteorology and oceanography.

**AOSS 731 (EECS 731). Space Terahertz Technology and Applications**
*Prerequisite: none; mandatory satisfactory/unsatisfactory. I (1 credit)*
Study and discussion of various topics related to high frequency applications in space exploration. Topics will be chosen from the following areas: planetary atmospheres and remote sensing, antennas, active and passive circuits, space instrumentation.

**AOSS 747. Atmospheric Science and Environment Seminar**
*Prerequisite: none; mandatory satisfactory/unsatisfactory. I, II (1 credit)*
Student and faculty presentations about current research results, research papers, and new ideas related to our atmospheric environment. Each enrolled student will give a presentation.

**AOSS 749. Space Science Seminar**
*Prerequisite: none. I, II (1 credit)*
Student and faculty presentations about current research results, classic" research papers and new ideas."

**AOSS 990. Dissertation/Pre-Candidate**
*I, II, III (2-8 credits); IIIa, IIIb (1-4 credits)*
Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**AOSS 995. Dissertation/Candidate Graduate School**
*Prerequisite: authorization for admission as a doctoral candidate. I, II, III (8 credits); IIIa, IIIb (4 credits)*
Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

## Atmospheric, Oceanic and Space Sciences Faculty

Lennard A. Fisk, Ph.D., *Chair and Professor*
S. Roland Drayson, Ph.D., *Associate Chair and Professor*

### Professors

Sushil K. Atreya, Ph.D.
John R. Barker, Ph.D.; *also Chemistry*
John P. Boyd, Ph.D.
R. Paul Drake, Ph.D.
Anthony W. England, Ph.D.; *also Electrical Engineering and Computer Science*
Tamas I. Gombosi, Ph.D.; *also Aerospace Engineering*
Stanley J. Jacobs, Ph.D.; *also Mechanical Engineering*
William R. Kuhn, Ph.D.
Guy A. Meadows, Ph.D.; *also Naval Architecture and Marine Engineering*
Andrew F. Nagy, Ph.D.; *also Electrical Engineering and Computer Science*
Joyce E. Penner, Ph.D.
Perry J. Samson, Ph.D.
Jack Hunter Waite, Ph.D.
David T. Young, Ph.D.

### Adjunct Professors

George R. Carignan
Kenneth W. Fischer, Ph.D.
George Gloeckler, Ph.D.
Timothy L. Killeen, Ph.D.
Robert G. Onstott, Ph.D.
Robert A. Shuchman, Ph.D.
Kyle Vaught, Ph.D.
John Vesecky, Ph.D.

### Professors Emeritus

Frederick L. Bartman, Ph.D.; *also Aerospace Engineering*
Albert Nelson Dingle, Ph.D.
Thomas M. Donahue, Ph.D., *Edward H. White II Distinguished University Professor Emeritus of Planetary Science; also Physics*
Paul B. Hays, Ph.D., *Dwight F. Benton Professor of Advanced Technology; also Aerospace Engineering*
Donald J. Portman, Ph.D.
James C. G. Walker, Ph.D.; *also Geological Sciences*

### Associate Professors
Dennis G. Baker, Ph.D.
Mary Anne Carroll, Sc.D.; *also Chemistry*
Brian E. Gilchrist, Ph.D.; *also Electrical Engineering and Computer Science*
Gerald J. Keeler, Ph.D.; *also School of Public Health and Civil and Environmental Engineering*
Christopher Ruf, Ph.D.; *Atmospheric Science*

### Research Scientists
Larry H. Brace
George R. Carignan
John T. Clarke, Ph.D.
C. Robert Clauer, Ph.D.
Michael R. Combi, Ph.D.
Janet U. Kozyra, Ph.D.
Vladimir O. Papitashvili, Ph.D.
Tong W. Shyn, Ph.D.

### Research Scientist Emeritus
Ernest G. Fontheim, Ph.D.

### Adjunct Research Scientist
Vincent J. Abreu, Ph.D.
Alan G. Burns, Ph.D.

### Visiting Research Scientist
Gabor Toth, Ph.D.

### Associate Research Scientists
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Jason M. Daida, Ph.D.
Darren L. De Zeeuw, Ph.D.
Rick J. Niciejewski, Ph.D.
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Wilbert R. Skinner, Ph.D.

### Assistant Research Scientists
Michael Herzog, Ph.D.
Julie F. Kafkalidis, Ph.D.
Michael W. Liemohn, Ph.D.
Frank J. Marsik, Ph.D.
Aaron Ridley, Ph.D.
Nathan A. Schwadron, Ph.D.
Thomas H. Zurbuchen, Ph.D.

### Adjunct Assistant Research Scientists
James J. Carroll, Ph.D.
Clinton P.T. Groth, Ph.D.
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## What is Biomedical Engineering?

Students who enjoy math, physics and chemistry, but who also have a keen interest in biology and medicine, should consider a career in biomedical engineering. Synthetic heart valves, the MRI scanner, automatic bio-sensors for rapid gene sequencing are each examples of biomedical engineering. Biomedical engineering is the newest engineering discipline, integrating the basic principles of biology with the tools of engineering.

With the rapid advances in biomedical research, and the severe economic pressures to reduce the cost of health care, biomedical engineering will play an important role in the medical environment of the 21st century. Over the last decade, biomedical engineering has evolved into a separate discipline bringing the quantitative concepts of design and optimization to problems in biomedicine.

The opportunities for biomedical engineers are wide ranging. The medical-device and drug industries are increasingly investing in biomedical engineers. As gene therapies become more sophisticated, biomedical engineers will play an important role in bringing these ideas into real clinical practice. Finally, as technology plays an ever-increasing role in medicine, there will be a larger need for physicians with a solid engineering background. From biotechnology to tissue engineering, from medical imaging to microelectronic prosthesis, from biopolymers to rehabilitation engineering, biomedical engineers are in demand.

## Degree Programs

At this time Biomedical Engineering does not offer an undergraduate degree program other than a Simultaneous Undergraduate/Graduate Studies (SGUS) program. Qualified undergraduates can pursue a combined undergraduate/graduate program in one of six concentrations: bioelectronics, biomaterials, biomechanics, biomedical imaging, biotechnology, and rehabilitation engineering, leading to a Bachelor of Science in Biomedical Engineering degree (B.S. BiomedE.) and a Master of Science in Biomedical Engineering degree. (M.S. BiomedE.).

Alternately, through the SGUS program, a student may pursue an undergraduate program in another engineering discipline such as chemical engineering, computer engineering, electrical engineering, industrial and operations engineering, materials science and engineering, mechanical engineering, and nuclear engineering combined with an M.S.E. BiomedE. degree. At the end of either program, a student has a B.S.E. in an engineering discipline and an M.S.E. in Biomedical Engineering.

## Concentrations

### Bioelectronics

The Bioelectrical concentration has two components: 1) *BioMEMS:* A track emphasizing the technology of micro-machined measurement and activation devices which are components of implantable devices such as Neuroprostheses or pacemakers. This program will give students a circuits background with some experience in the fabrication of solid-state devices. 2) *Biosystems:* The theory and practice of systems related to modeling of physiological systems and the design of integrated sensor and actuator systems.

Students graduating from biomedical engineering with a concentration in bioelectronics will be able to work as engineers in the rapidly expanding medical diagnostic, therapeutic and systems industry. Others could pursue Ph.D. programs in either Electrical Engineering: Systems or biomedical fields or advanced degrees in medicine or basic medical science.

### Biomaterials

Biomaterials is the study of interactions between living and nonliving materials. Students trained in biomaterials must have a thorough understanding of the materials they work with, knowledge of the properties of the biological system, and knowledge of the properties of the biological system they seek to replace. Biomaterials is an integral component in tissue engineering and life-science initiatives. Biomaterials research areas include: design of orthopaedic, dental, cardiovascular and neuro-sensory prostheses, artificial organs, blood-surface interactions, cellular and tissue engineering, drug delivery, biosensors, microencapsulation technology, and implant retrieval analysis. Students graduating from biomedical engineering with a concentration in biomaterials will be capable of working in the medical-device industry, academic or government laboratories, or pursuing further education in Ph.D. or professional programs.

### Biomechanics

Biomechanics is a hybrid discipline requiring a thorough understanding of classic engineering mechanics, physiology and cell biology, and the interface between the two. Biomechanics also has important applications in cutting-edge fields like tissue engineering and mechanotransduction. In tissue engineering, one tries to regenerate new tissues to replace defects in existing tissues. This requires knowledge of tissue-mechanical function. Mechanotransduction is the study of how cells sense and react to mechanical stimulus, a field with applications in such diverse areas as hearing (hair-cell movement in fluids) and orthopaedics (bone and tendon response to physical stress). Graduates in this concentration will be prepared for a wide range of industries concerned with mechanical affects on the human body including surgical-device industries, automotive safety, and biotech industries concerned with mechanically functional tissue. Students will also have excellent preparation to attend medical school or pursue a Ph.D.

### Biomedical Imaging

Since the invention of x-ray Computerized Tomography more than 25 years ago, imaging has become the primary noninvasive diagnostic tool available to the clinician. Although many principles are common to all imaging modalities, biomedical imaging scientists and engineers must understand the basic physics and operating principles of all primary modalities including magnetic resonance imaging (MRI), radiography and nuclear medicine, optics, and ultrasound. Major biomedical imaging companies require such multi-modality expertise to design new devices and procedures. In addition, clinical problems increasingly require the techniques of cell and molecular biology to design both new contrast agents and imaging methods for a wider range of applications. The biomedical imaging curriculum recognizes these trends and requires students to have a solid background in signal processing and imaging science, and simultaneously be literate in both the basic life sciences and the basic operating principles of several imaging modalities. Graduates of this program will be well prepared to work in the medical imaging industry, to attend medical school, or to study for a Ph.D. in Biomedical Engineering.

### Biotechnology

Advances in cellular and molecular biology have changed and expanded the ways therapeutic devices and drugs are designed. Modern biotechnology depends on scientists and engineers who study the fundamental properties of cell, molecular, and tissue biology, and apply these to engineer chemicals and materials to interact with living systems. Goals include production of improved biomaterials for medical implants and prosthetics, tissues engineered for specific functionality, and new therapeutic drugs. The biotechnology curriculum emphasizes critical areas of chemistry, molecular biology, and cell biology, but also exposes students to a broad range of engineering approaches necessary for this interdisciplinary field. Graduates of this program will be well prepared for jobs in the pharmaceutical or medical-device industries, to attend professional schools, or study for a Ph.D.

### Rehabilitation Engineering

The program in rehabilitation engineering and ergonomics is concerned with finding ways to maximize participation of all persons in activities of work, leisure, and daily living with minimal risk of injury or illness. Persons completing this program will acquire specific skills for evaluating activities of work and daily living, equipment, environments, and safety and health issues, and for applying that information to the design of equipment and procedures, so as to maximize participation by all persons, and maximize performance and minimize risk of injury. A unique aspect of the program in rehabilitation and ergonomics is, that more than other fields, it affords an overview of people in their various shapes, sizes, and ability levels, and how they interact with the world around them to accomplish a given goal. Biomedical engineers specializing in rehabilitation and ergonomics can expect to find employment with industry, government agencies, labor groups, consulting groups, insurance companies, and health-care facilities among others.

## Facilities

The facilities available for student research include state-of-the-art, well-equipped laboratories in the College of Engineering and the Medical School, the clinical facilities of the University of Michigan Hospitals, and the Ann Arbor Veteran's Administration Hospital. Students have access to patients and real medical problems with the University of Michigan Hospital on the campus. The University of Michigan College of Engineering and Medical School have long been regarded among the finest in the country. Bridging these two worlds is the Biomedical Engineering Department, consistently ranked in the top ten nationally in recent years.

## Sample Schedule
## B.S./M.S. Biomedical Engineering

| | Credit Hours | Terms 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Subjects required by all programs (55 hrs.)** | | | | | | | | | | | |
| Mathematics 115, 116, 215, and 216 | 16 | 4 | 4 | 4 | 4 | - | - | - | - | | |
| Engr 100, Intro to Engr | 4 | 4 | - | - | - | - | - | - | - | | |
| Engr 101, Intro to Computers | 4 | - | 4 | - | - | - | - | - | - | | |
| [1]Chemistry 125 and 130 | 5 | 5 | - | - | - | - | - | - | - | | |
| [2]Physics 140 with Lab 141; Physics 240 with Lab 241 | 10 | 5 | 5 | - | - | - | - | - | - | | |
| Humanities | 16 | - | 4 | - | - | 4 | 4 | 4 | - | | |
| **Required Program Subjects B.S.E. (41 hrs.)** | | | | | | | | | | | |
| Biology 162, Intro to Biology | 5 | - | - | 5 | - | - | - | - | - | | |
| Biology 310 | 4 | - | - | - | 4 | - | - | - | - | | |
| BME 418, Quantitative Cell Biology | 4 | - | - | - | - | 4 | - | - | - | | |
| Quantitative Physiology 519/419 | 4 | - | - | - | - | - | 4 | - | - | | |
| BME 458 or IOE 432, Bioinstrumentation | 4 | - | - | - | - | 4 | - | - | - | | |
| IOE 265, Intro to Statistics | 4 | - | - | - | 4 | - | - | - | - | | |
| EE314 or EE215, Circuits | 4 | - | - | 4 | - | - | - | - | - | | |
| [3]Choose **two** courses: | 8 | | | | | | | | | | |
| Mechanical Sciences I | 4 | - | - | 4 | - | - | - | - | - | | |
| Mechanical Sciences II | 4 | - | - | - | 4 | - | - | - | - | | |
| BME 450, Eng. Design | 4 | - | - | - | - | - | - | - | 4 | | |
| **Unrestricted Electives (12 hrs.)** | 12 | - | - | - | - | - | 8 | 4 | - | | |
| **B.S. Concentration Requirements and Electives (20 hrs.)** | 20 | - | - | - | - | | - | 8 | 12 | | |
| **B.S. Total Hours** | 128 | 16 | 16 | 17 | 16 | 16 | 16 | 16 | 16 | - | - |
| **Required Program Subjects M.S. (14 hrs.)** | | | | | | | | | | | |
| Choose from two Advanced Math and/or Advanced Statistics | 6 | - | - | - | - | - | - | - | - | 3 | 3 |
| BME 500, Seminar | 1 | - | - | - | - | - | - | - | - | 1 | - |
| BME 550, Ethics | 1 | - | - | - | - | - | - | - | - | - | 1 |
| BME 590, Directed Study | 3 | - | - | - | - | - | - | - | - | - | 3 |
| Life Sciences | 3 | - | - | - | - | - | - | - | - | 3 | - |
| **M.S. Concentration Requirements (8 hrs.)** | 8 | - | - | - | - | - | - | - | - | 4 | 4 |
| **M.S. Total Hours in Combined B.S./M.S. Program** | 22 | - | - | - | - | - | - | - | - | 11 | 11 |

Candidates pursuing a five-year simultaneous undergraduate/graduate program in biomedical engineering leading to the Bachelor of Science degree (Biomedical Engineering)—B.S. (BiomedE.)—and the Master of Science (Biomedical Engineering)—M.S. (BiomedE.)—must complete the program listed above.

**Note:** The Department of Biomedical Engineering anticipates that its undergradute program will be available beginning Fall Term 2001.

Students interested in pursuing the five-year simultaneous undergraduate/graduate program in biomedical engineering should consult with a Program Advisor.

**Notes:**

[1]Chemistry 125, 130 will count for 5 total credits, 1 of which will be applied according to individual program directives; for students who have advanced placement credit for freshman chemistry, a 100-level or above biology course may be used to fulfill this requirement.

[2]Physics 140, 141, 240, 241 will count for 10 total credits, 2 of which will be applied according to individual program directives.

[3]These mechanical science courses allow substitution in concentrations. Biotechnology students must take ChE 230 for Thermodynamics. Biomaterials students may elect Fluid Mechanics (e.g., ME 230) as one of the required courses. Other courses to choose from are CEE 211, ME 211, ChE 230, ME 230, ME 240.

[4]Substitution of 500-level course allowed by area of concentration, but required if considering Ph.D.

## Bioelectrics (BioMEMS) Concentration

### Concentration Requirements

EECS 211, Electrical Engineering II (4)

EECS 316, Signals and Systems or EECS 320, Intro to Semiconductor Device Theory (4)

EECS 401, Probabilistic Methods in Engineering or IOE 366, Linear Statistical Models (4)

**Choose two of the following four courses:**

- EECS 425, Integrated Microsystems Laboratory (3)
- EECS 423, Solid-State Device Lab (4)
- EECS 422, Electronic Properties of Semiconductor Materials (3)
- EECS 427, VLSI Design I (4)

### Concentration Electives

BME 417, Electrical Biophysics (4)

EECS 459, Adv Electronic Instrumntation (3)

EECS 522, Analog Integrated Circuits (4)

EECS 523, Digital Integrated Technology (4)

EECS 623, Integrated Sensors and Sensing Syst. (4)

EECS 627, VLSI Design II (4)

## Bioelectronics (Biosystems) Concentration

### Concentration Requirements

EECS 211, Electrical Engineering II (4)

EECS 316, Signals and Systems or EECS 320, Intro to Semiconductor Device Theory (4)

[1]EECS 401, Probabilistic Methods in Engineering or IOE 366, Linear Statistical Models (4)

**Choose two of the following four courses:**

- EECS 451, Digital Signal Processing and Analysis (4)
- EECS 452, Digital Signal Processing Design Laboratory (4)
- EECS 460, Fundamentals of Control Syst. (4)
- BME 417, Electrical Biophysics (4)

[2]EECS 501, Prob and Random Processes (4)

### Concentration Electives

BME 548, Advanced Bioinstrumentation and Computation (3)

EECS 551, Wavelets and Time-Frequency Distrib. (3)

EECS 559, Advanced Signal Processing (3)

EECS 560, Linear Systems Theory (4)

EECS 564, Estimation, Filtering, Detection (3)

EECS 565, Linear Feedback Control Sys (3)

EECS 658, Fast Algorithms for Signal Processing (3)

EECS 659, Adaptive Signal Processing (3)

[1]Not required if SGUS with 501.

[2]Math/Stat requirement reduced by one.

## Biomaterials Concentration

### Concentration Requirements

MSE 250, Prin of Engineering (4)

MSE 350, Fundamentals of MSE (4)

MSE 360, Experimental Meth in MSE Lab I (3)

BME 410, Biomed Materials Considerations (4)

### Concentration Electives

MSE 422, Mech Behavior of Materials (3) or

MSE 435, Kinetics and Transport (4)

MSE 412, Polymer Materials (3) or

MSE 440, Ceramic Materials (3)

MSE 512, Polymer Physics (3)

BME 575, Seminar in Biomaterials (2)

BME 583, Biocompatibility of Materials (2)

BME 584, Tissue Engineering (3)

## Biomechanics Concentration

### Concentration Requirements

BME 456, Tissue Mechanics (3)

BME 479, Biotransport (4)

BME 556, Molecular and Cellular Biomech (3)

### Concentration Electives

**Choose five of the following CE courses:**

- ME 311, Strength of Materials (3)
- ME 320, Fluid Mechanics I (3)
- ME 305, Intro to Finite Elements (3)
- ME 360, Modeling, Analysis and Control of Dynamics Systems (4)

ME 440, Intermed Dynamics and Vibrations (4)

BME 410, Biomaterials (3)

BME 417, Electrical Biophysics (4)

IOE 433, Occupational Ergonomics (3)

BME 476, Thermal-Fluid Sciences in Bioeng. (3)

BME 499, Pulmonary Mech and Transport (1-4)

ME 412, Advanced Strength of Materials (3)

BME 506, Comput Modeling of Bio Tissues (3)

ME 505, Finite Element Methods in Mechanical Engineering and Applied Mechanics (3)

ME 511, Theory of Solid Continua (3)

ME 517, Mechanics of Polymers I (3)

ME 520, Advanced Fluid Mechanics I (3)

ME 521, Advanced Fluid Mechanics II (3)

ME 523, Computational Fluid Dynamics I (3)

BME 534, Occupational Biomechanics (3)

ME 540, Intermediate Dynamics (4)

ME 560, Modeling Dynamic Systems (3)

ME 605, Adv Finite Element Meth in Mech (3)

ME 617, Mechanics of Polymers II (3)

BME 635, Laboratory in Biomechanics and Physiology of Work (2)

BME 646, Mechanics of Human Movement (3)

Tissue/Organ Culture Lab

Biomaterials Processing Lab

**Important Note:** *SGUS students should choose 3 classes at the 400 level and above. Non-SGUS M.S.E. students should choose at least 3 classes at the 500 level. No classes below the 400 level will be counted for degree requirements.*

## Biomedical Imaging Concentration

### Concentration Requirements

EECS 316, Signals and Systems (4)

EECS 451, Digital Signal Processing and Analysis (4)

EECS 334, Principles of Optics (4)

BME Imaging Courses (4 hrs. selected from BME 481, 482, 483, 485) (2/2)

BME 516, Medical Imaging Systems (3)

EECS 501, Prob and Random Processes (4)

### Concentration Electives

**Choose two of the following CE courses:**

BME Imaging Courses (4 additional hrs. selected from BME 481, 482, 483, 485) (2/2)

EECS 280, Programming and Introductory Data Structures (4)

EECS 330, Electromagnetics II (4)
EECS 211, Electrical Engineering II (3)
**Graduate CE courses (at least two hours):**
EECS 435, Fourier Optics (3)
EECS 556, Image Processing (3)
EECS 559, Advanced Signal Processing (3)
BME 417, Electrical Biophysics (4)
BME 510, Medical Imaging Laboratory (2)
EECS 438, Advanced Lasers and Optics Lab. (4)

## Biotechnology Concentration

### Concentration Requirements
ChE 330, Thermodynamics II (4)
ChE 342, Heat and Mass Transfer (4)
Chem 210, Organic Chem I (4)
ChE 344, Reaction Engineering and Design (4)

### Concentration Electives
**Choose two CE courses:**
Choose one of the following:
BME 556, Molecular and Cellular Biomechanics (3)
BME 584, Tissue Engineering (3)
ChE 517, Biochemical Science and Technology (3)
ChE 617, Advanced Biochemical Technology (3)
CEE 582, Environmental Microbology (3)
Choose one of the following:
Bio 429, Laboratory in Cell and Molecular Biology (3)
Bio Chem 516, Introductory Biochemistry Laboratory (3)
BME 458, Biomedical Instrumentation and Design (4)
BME 548, Advanced Bioinstrumentation and Computation (3)
Physics 608, Biophysical Principles of Microscopy (3)
Any Life Sciences course (3)
Choose one from the following:
Biol Chem 515, Intro Biochem or BME 519/419, Quant Physiology (4)
Biol 427, Molecular Biology (4)
Biol 429, Lab in Cell, Molecular Biology (3)
ChE 517, Biochemical Science and Tech (3)
BME 456, Biomechanics (3)
BME 417, Electrical Biophysics (4)
BME 476, Thermal-Fluid Science in Bioengineering (3)
Chem 211, Organic Chem Lab (1)
Chem 215, Organic Chem II (4)
ChE 616, Analysis of Chemical Signaling (3)

## Rehabilitation Engineering Concentration

### Concentration Requirements
IOE 316 or 366, Statistics (4)
IOE 333/334, Human Performance or Psych 340 (4)
IOE 463, Work Measurement/IOE 491, Applied Anthropometry (2/2)
IOE 373 or EECS 484, Information Systems (4)
BME 530, Rehabilitation Ergonomics (3)
BME 534, Occupational Biomechanics (3)
IOE 533, Human Factors (3)
IOE 634, Upper Extremity (2)
BME 635, Biomechanics Lab (2)

### Concentration Electives
IOE 436, Human Computer Interaction (4)
IOE 439, Safety (4)
BME 401, Anatomy (4)
BME 456, Biomechanics (4)
Psych 340, Intro to Cognitive Psychology (4/3 in the half term)
Psych 443, Learning and Memory (3)
Psych 444, Perception (3)
Psych 445/Ling 447, Psychology of Language
Psych 446, Human Factors Psychology (3)
Psych 447, Psychology of Thinking (3)

## Biomedical Engineering Course Listings

Course descriptions are found also on the College of Engineering web site at http://courses.engin.umich.edu/

**BiomedE 280. Undergraduate Research**

*Prerequisites: permission of instructor. I, II, IIIa, IIIb (1-4 credits)*

This course offers research experience to first- and second-year Engineering students in an area of mutual interest to the student and to a faculty member within the College of Engineering. For each hour of credit, it is expected that the student will work three hours per week. The grade for the course will be based on a final project/report evaluated by the faculty sponsor and participation in other required UROP activities, including bimonthly research group meetings and submission of a journal chronicling the research experience.

**BiomedE 295. Biomedical Engineering Seminar**

*II (1 credit)*

This is a seminar for students interested in the Concurrent Undergraduate/Graduate Study (CUGS) programs between Biomedical Engineering and other participating departments. The seminar will explore the various biomedical engineering sub-disciplines with the goal of helping students choose an appropriate undergraduate degree program.

**BiomedE 350. Introduction to Biomedical Instrumentation Design**

*Prerequisite: none. III (4 credits)*

Fast-paced introductory course open to all students interested in circuit design. Two terms introductory physics recommended, programming skills helpful. Topics: basic analog and digital circuit applications, sensors, micro power design, data acquisition, computer I/O, electro-mechanical and electro-optical devices, applications to biological and medical research.

**BiomedE 401 (Anatomy 401). The Human Body: Its Structure and Function**

*I (4 credits)*

A lecture-oriented, multi-media course that highlights the basic fabric of the human body as a functioning biological organism. A blend of gross anatomy, histology, developmental anatomy and neuroanatomy that takes the human body from conception to death while dealing with organization at all levels from cells to systems, system interrelations, and key features of select anatomical regions.

**BiomedE 410 (MSE 410 ). Design and Applications of Biomaterials**

*Prerequisite: MSE 220 or 250 or permission of instructor. I (4 credits)*

Biomaterials and their physiological interactions. Materials used in medicine/dentistry: metals, ceramics, polymers, composites, resorbable smart, natural materials. Material response/degradation: mechanical breakdown, corrosion, dissolution, leaching, chemical degradation, wear. Host responses: foreign body reactions, inflammation, wound healing, carcinogenicity, immunogenicity, cytotoxicity, infection, local/systemic effects.

**BiomedE 417 (EECS 417). Electrical Biophysics**

*Prerequisite: EECS 211 or EECS 314, preceded or accompanied by EECS 316. I (4 credits)*

Electrical biophysics of nerve and muscle; electrical conduction in excitable tissue; quantitative models for nerve and muscle including the Hodgkin Huxley equations; biopotential mapping, cardiac electrophysiology, and functional electrical stimulation; group projects. Lecture and recitation.

**BiomedE 420. Introduction to Biomechanics**

*Prerequisite: ME 211, ME 240, ME 320 or graduate standing. I (4 credits)*

This course is intended for senior undergraduate or first year graduate students as an introduction to biomechanics. The three major areas of mechanics, solid mechanics, fluid mechanics and rigid body dynamics, will be applied to analyze whole body, organ, and tissue level mechanics of living systems.

**BiomedE 434. Microbiology for Engineers**

*Prerequisite: Chem 225. I, II (4 credits)*

Principles and techniques of microbiology with an introduction to their application in the several fields of engineering. Lectures and laboratory.

**BiomedE 450. Biomedical Design**

*Prerequisite: senior or graduate standing. II (4 credits)*

Interdisciplinary design groups carry out biomedical instrumentation design projects. Projects are sponsored by Medical School and College of Engineering research labs and local industry. Students are exposed to the entire design process: design problem definition, generation of a design specification, documentation, design review process, prototype fabrication, testing and calibration.

**BiomedE 456 (ME 456). Tissue Mechanics**

*Prerequisite: ME 211, ME 240. II (3 credits)*

Definition of biological tissue behaviors, including elastic, viscoelastic, and plastic properties, with emphasis on bone; dynamics of gait, impact and tolerance criteria in vehicle design for human safety; prosthetic and orthotic mechanics and design.

**BiomedE 458 (EECS 458). Biomedical Instrumentation and Design**

*Prerequisite: EECS 215 or EECS 314, or consent of instructor. I (4 credits)*

Measurement and analysis of biopotentials and biomedical transducer characteristics; electrical safety; applications of FET's, integrated circuits, operational amplifiers for signal processing and computer interfacing; signal analysis and display on the laboratory minicomputer. Lectures and laboratory.

**BiomedE 464 (Math 464). Inverse Problems**

*Prerequisite: Math 217, Math 417, or Math 419; and Math 216, Math 256, Math 286, or Math 316. II (3 credits)*

Mathematical used in the solution of inverse problems and analysis of related forward operators is discussed. Topics include ill-posedness, singular-value decomposition, generalized inverses, and regularization. Inverse problems considered (e.g., tomography, inverse scattering, image restoration, inverse heat conduction) are problems in biomedical engineering with analogs throughout science and engineering.

**BiomedE 476 (ME 476). Thermal-Fluid Science in Bioengineering**

*Prerequisite: ME 235, ME 320, and ME 370. II (3 credits)*

Dynamics, measurements and simulation of vascular pressure and flow in health and disease, microcirculation, design of prosthetic flow-regulation devices, cellular energetics and body metabolism, thermal modeling and measurements, cell hyperthermia and hypothermia, design of blood heat exchangers thermal probes, cryoprobes, prosthetic mass transfer devices, medical visualization and medical image processing.

**BiomedE 481 (NERS 481). Engineering Principles of Radiation Imaging**

*Prerequisite: none. II (2 credits) (7-week course)*

Analytic description of radiation production, transport and detection in radiation imaging systems. Measurements methods for image quality and statistical performance of observers. Systems for radiographic and radioisotope imaging, including film/screen, storage phosphor, and electronic radiography, fluoroscopy, computed tomography, Anger camera, and PET systems. Emphasis on impact of random process on observer detection.

**BiomedE 482 (NERS 482). Fundamentals of Ultrasonics with Medical Applications**

*Prerequisite: EECS 230. II (2 credits) (7-week course)*

Basic principles; waves, propagation, impedance, reflection, transmission, attenuation, power levels. Generation of ultrasonic waves; transducers, focusing, Fraunhofer and Fresnel zones. Instrumentation; display methods, Doppler techniques, signalprocessing. Medical applications will be emphasized.

**BiomedE 483. Introduction to Magnetic Resonance Imaging**
*Prerequisite: EECS 316 or permission of instructor. II (2 credits) (8-week course)*

Introduction to the physics, techniques and applications of magnetic resonance imaging (MRI). Basics of nuclear magnetic resonance physics, spectral analysis and Fourier transforms, techniques for spatial localization, MRI hardware. Applications of MRI including magnetic resonance properties of biological tissues and contrast agents, imaging of anatomy and function.

**BiomedE 484 (NERS 484). Radiological Health Engineering Fundamentals**
*Prerequisite: NERS 312 or equivalent or permission of instructor. I (4 credits)*

Fundamental physics behind radiological health engineering and topics in quantitative radiation protection. Radiation quantities and measurement, regulations and enforcement, external and internal dose estimation, radiation biology, radioactive waste issues, radon gas, emergencies, and wide variety of radiation sources from health physics perspective.

**BiomedE 485. Introduction to Optical Imaging**
*II (2 credits)*

Optical imaging is an important diagnostic tool in biomedical engineering. This course first briefly summarizes the principles of optics at an introductory level, then discusses different optical imaging techniques. Students are also exposed to the principles of optical system design, such as paraxial matrix optics and ray tracing.

**BiomedE 490. Directed Research**
*I, II, IIIa, IIIb, III (1-4 credits)*

Provides an opportunity for undergraduate students to perform directed research devoted to Biomedical Engineering.

**BiomedE 495. Introduction to Bioengineering**
*Prerequisite: permission of instructor; mandatory pass/fail. I (1 credit)*

Definition of scope, challenge, and requirements of the bioengineering field. Faculty members review engineering-life sciences interdisciplinary activities as currently pursued in the College of Engineering and Medical School.

**BiomedE 499. Special Topics**
*I, II, IIIa, IIIb, III (1-4 credits)*

Topics of special interest selected by faculty. Lecture, seminar or laboratory.

**BiomedE 500. Biomedical Engineering Seminar**
*Mandatory, satisfactory/unsatisfactory. I (1 credit)*

This seminar will feature various bioengineering-related speakers.

**BiomedE 506 (ME 506). Computational Modeling of Biological Tissues**
*Prerequisite: ME 511 or equivalent or permission of instructor. I, II (3 credits)*

Biological tissues have multiple scales and can adapt to their physical environment. This course focuses on visualization and modeling of tissue physics and adaptation. Examples include electrical conductivity of heart muscle and mechanics of hard and soft tissues. Homogenization theory is used for multiple scale modeling.

**BiomedE 510. Medical Imaging Laboratory**
*Prerequisite: BiomedE 516 or permission of instructor. II (3 credits)*

This course provides the student practical, hands-on experience with research grade, medical imaging systems including x-ray, magnetic resonance, nuclear medicine, and ultrasound. Participants rotate through each of the respective areas and learn about and perform experiments to support previous theoretical instruction.

**BiomedE 516 (EECS 516). Medical Imaging Systems**
*Prerequisite: EECS 451. I (3 credits)*

Principles of modern medical imaging systems. For each modality the basic physics is described, leading to a systems model of the imager. Fundamental similarities between the imaging equations of different modalities will be stressed. Modalities covered include radiography, x-ray computed tomography (CT), NMR imaging (MRI) and real-time ultrasound.

**BiomedE 518 (ChE 518). Engineering Fundamentals in Biological Systems**
*Prerequisite: ChE 517 or Biol 311 or permission of instructor. II alternate years (3 credits)*

Application of fundamental chemical engineering principles (mass, heat and momentum transport, kinetics) to the study of biological systems. Focus will be on current bioengineering research in the department.

**BiomedE 519 (Physiol 519). Bioengineering Physiology**
*Prerequisite: Biol 105 or Biol 112 or equivalent, permission of instructor. (4 credits)*

Quantitative description of the structure and function of mammalian systems, including the neuromuscular, cardiovascular, respiratory, renal and endocrine systems. Mathematical models are used to describe system performance where applicable. Lectures, laboratories, and problem sessions.

**BiomedE 520. Structure-Function Relationships in Skeletal Muscle**
*Prerequisite: permission of instructor. II (1 credit)*

The course is organized in a journal club format with an associated lecture/discussion period in the same topic. The course provides students with an opportunity to interact with senior graduate students, postdoctoral fellows, and faculty discussing topics of advanced skeletal muscle physiology, including skeletal muscle tissue engineering and muscle biomechanics.

**BiomedE 525 (Microb 525). Cellular and Molecular Networks**
*Prerequisite: Biol 105 or Biol 112 and Math 215. II (3 credits)*

This course is designed to equip the student with appropriate concepts and techniques for the quantitative analysis of the integrated behavior of complex biochemical systems. A general approach is developed from the basic postulates of enzyme catalysis and is illustrated with numerous specific examples, primarily from the microbial cell.

**BiomedE 530. Rehabilitation Engineering and Technology I**
*Prerequisite: PM&R 510 or permission of instructor. I (3 credits)*

This is a lecture course which surveys the design and application of rehabilitation technologies in a wide range of areas, including wheeled mobility, seating and positioning, environmental control, computer access, augumentative communication, sensory aids, worksite modification, adapative driving aids, as well as emerging rehabilitation technologies.

**BiomedE 534 (IOE 534) (Mfg 534). Occupational Biomechanics**
*Prerequisite: IOE 333, IOE 334 or IOE 433 (EIH 556). II (3 credits)*

Anatomical and physiological concepts are introduced to understand and predict human motor capabilities, with particular emphasis on the evaluation and design of manual activities in various occupations. Quantitative models are developed to explain: (1) muscle strength performance; (2) cumulative and acute musculoskeletal injury; (3) physical fatigue; and (4) human motion control.

**BiomedE 548 (EECS 548). Advanced Bioinstrumentation and Computation**
*Prerequisite: EECS 458, EECS 451. I (3 credits)*

Application of computer hardware and software to acquisition, pattern recognition, analysis, and diagnosis of physiological signals. These include, but are not restricted to, the electrocardiogram, the electroencephalogram, the electromyogram, and blood pressure measurement. This course will teach skills required for computer-based analysis of clinical signals, and computer modelling of physiological systems. Lecture and laboratory.

**BiomedE 550. Ethics and Enterprise**
*Prerequisite: none. II (1 credit)*
Ethics, technology transfer, and technology protection pertaining to Biomedical engineering are studied. Ethics issues range from the proper research conduct to identifying and managing conflicts of interest. Technology transfer studies the process and its influences on relationships between academia and industry. Technology protection covers legal issues such as patents, copyrights, and contracts.

**BiomedE 569 (EECS 569). Signal Analysis in Biosystems**
*Prerequisite: EECS 451 and EECS 501 or permission of instructor. II (3 credits)*
This course will present a variety of techniques for the analysis and understanding of biological signals and biosystems. Both signals of biological nature and images will be discussed. Techniques will include signal representation, time frequency and wavelet analysis, nonlinear filtering (median and rank order) and pattern recognition including neural networks.

**BiomedE 575 (Dentistry 575). Seminar in Biomaterials**
*Prerequisite: senior standing. II (1-8 credits)*
Discussion-oriented course which offers a forum for biomaterials students and faculty to exchange ideas. Students become familiar with biomaterials literature, enhance critical thinking and analysis, and communication of ideas. Readings, oral and written presentations. Students present, summarize and critically evaluate biomaterials literature; define biomaterials problems, pose research questions and methodologies; written mini-proposals; present/update/brainstorm about current research.

**BiomedE 580 (NERS 580). Computation Projects in Radiation Imaging**
*Prerequisite: preceded or accompanied by NERS 481. II (1 credit)*
Computational projects illustrate principles of radiation imaging from NERS 481(BiomedE 481). Students will model the performance of radiation systems as a function of design variables. Results will be in the form of computer displayed images. Students will evaluate results using observer experiments. Series of weekly projects are integrated to describe the performance of imaging systems.

**BiomedE 582 (NERS 582). Medical Radiological Health Engineering**
*Prerequisite: NERS 484 (BiomedE 484) or permission of instructor. II (3 credits)*
This course covers the fundamental approaches to radiation protection in radiology, nuclear medicine, radiotherapy, and research environments at medical facilities. Topics presented include health effects, radiation dosimetry and dose estimation, quality control of imaging equipment, regulations, licensing and health physics program design.

**BiomedE 583 (ChemE 583) (MSE 583). Biocompatibility of Materials**
*Prerequisite: undergraduate course in biology and/or physiology; undergraduate course in biochemistry, organic chemistry, or molecular biology. II (2 credits)*
This course describes the interactions between tissue and materials and the biologic/pathologic processes involved. In addition, specifications which govern biocompatibility testing, various strengths and weaknesses of a number of approaches to testing, and future directions are discussed.

**BiomedE 584 (ChemE 584) (Biomaterials 584). Tissue Engineering**
*Prerequisite: Bio 311, ChemE 517, or equivalent biology course; senior standing. I (3 credits)*
Fundamental engineering and biological principles underlying field of tissue engineering are studied, along with specific examples and strategies to engineer specific tissues for clinical use (e.g., skin). Student design teams propose new approaches to tissue engineering challenges.

**BiomedE 588. Structure-Function Relationships in Musculoskeletal Tissues**
*Prerequisite: ME 211, ME 311, Math 216, ME 456, or Physiol 519. I, II (3 credits)*
Presentation and discussion of relationships between musculoskeletal tissue structure and tissue mechanics is the focus of the course. Examination of structure-function relationships in bone, cartilage, ligament, skeletal muscle, and tendon with particular attention to the hierarchical nature of these tissues.

**BiomedE 590. Directed Research**
*Mandatory, satisfactory/unsatisfactory. (to be arranged)*
Provides opportunity for bioengineering students to participate in the work of laboratories devoted to living systems studies.

**BiomedE 591. Thesis**
*Prerequisite: 2 hrs of BiomedE 590; mandatory satisfactory/unsatisfactory. I, II, III (credit to be arranged)*
To be elected by Bioengineering students pursuing the master's thesis option. May be taken more than once up to a total of 6 credit hours. Graded on a satisfactory/unsatisfactory basis only.

**BiomedE 599. Special Topics I, II**
*I, II (1-6 credits)*
Topics of current interest selected by the faculty. Lecture, seminar or laboratory.

**BiomedE 616 (ChemE 616). Analysis of Chemical Signalling**
*Prerequisite: Math 216, Biochemistry 415. II (3 credits)*
Quantitative analysis of chemical signalling systems, including receptor/ligand binding and trafficking, signal transduction and second messenger production, and cellular responses such as adhesion and migration.

**BiomedE 635 (IOE 635). Laboratory in Biomechanics and Physiology of Work**
*Prerequisite: IOE 534 (BiomedE 534). II (2 credits)*
This laboratory is offered in conjunction with the Occupational Biomechanics lecture course (IOE 534) to enable students to examine experimentally: (1) musculoskeletal reactions to volitional acts; (2) the use of electromyography (EMG's) to evaluate muscle function and fatigue; (3) biomechanical models; (4) motion analysis systems; and (5) musculoskeletal reactions to vibrations.

**BiomedE 646 (ME 646). Mechanics of Human Movement**
*Prerequisite: ME 540 (Aero 540) or ME 543 or equivalent. II alternate years (3 credits)*
Dynamics of muscle and tendon, models of muscle contraction. Kinematics and dynamics of the human body, methods for generating equations of motion. Mechanics of proprioceptors and other sensors. Analysis of human movement, including gait, running, and balance. Computer simulations and discussion of experimental measurement techniques.

**BiomedE 800. Biomedical Engineering Research Seminar**
*Prerequisites: graduate standing or permission of instructor. II (1 credit)*
Invited speakers will present seminars focusing on recent developments, research or methodologies in biomedical engineering or related studies.

**BiomedE 990. Dissertation/Pre-Candidate**
*I, II, III (1-8 credits); IIIa, IIIb (1-4 credits)*
Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**BiomedE 995. Dissertation/Candidate**
*Prerequisite: Graduate School authorization for admission as a doctoral candidate.*
*I, II, III (8 credits); IIIa, IIIb (4 credits)*
Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

## Biomedical Engineering Faculty

Matthew O'Donnell, Ph.D., *Jerry W. and Carol L. Levin Professor of Engineering and Chair; also Electrical Engineering and Computer Science*

### Professors

David J. Anderson, Ph.D.; *also Electrical Engineering and Computer Science and Otorhinolaryngology*
Thomas J. Armstrong, Ph.D.; *also Environmental Industrial Health*
James Baker Jr., M.D.; *also Internal Medicine, and Co-Director, Center for Biomedical Engineering*
Robert H. Bartlett, M.D.; *also General and Thoracic Surgery*
Charles A. Cain, Ph.D.; *also Electrical Engineering and Computer Science*
Paul L. Carson, Ph.D.; *also Department of Radiology; Director, Basic Radiologic Sciences*
Don B. Chaffin, Ph.D.; *also Industrial and Operations Engineering and Environmental and Industrial Health*
Thomas L. Chenevert, Ph.D.; *also Radiology*
John A. Faulkner, Ph.D.; *also Physiology; and Research Scientist, Institute of Gerontology*
Stephen Feinberg, DDS, Ph.D.; *also Dental*
Ari Gafni, Ph.D.; *also Biological Chemistry*
Steven A. Goldstein, Ph.D.; *also Surgery and Mechanical Engineering; Director of Orthopaedic Research; Assistant Dean for Research and Graduate Studies; and Director, Center for Biomedical Engineering Research*
Daniel G. Green, Ph.D.; *also Electrical Engineering and Ophthalmology*
James Grotberg, Ph.D., M.D.; *also Surgery*
Alfred O. Hero, Ph.D.; *also Electrical Engineering and Computer Science*
H. David Humes, M.D.; also *John G. Searle Professor and Chair, Internal Medicine*
Janice M. Jenkins, Ph.D.; *also Electrical Engineering and Computer Science*
Kimberlee J. Kearfott, Sc.D.; *also Nuclear Engineering and Radiological Sciences*
Josef M. Miller, Ph.D.; *also Communication Disorders and Otorhinolaryngology*
Michael D. Morris, Ph.D.; *also Chemistry*
Khalil Najafi, Ph.D.; *also Electrical Engineering and Computer Science*
Matilde Peters, D.M.D., Ph.D.; *also Dentistry*
Michael A. Savageau, Ph.D.; *also Microbiology and Immunology, and Chemical Engineering*
Paul A. Sieving, M.D., Ph.D.; *also The Paul R. Lichter Professor of Ophthalmic Genetics*
Henry Y. Wang, Ph.D.; *also Chemical Engineering*
Roger Wiggins, M.D.; *also Nephrology*
William J. Williams, Ph.D.; *also Electrical Engineering and Computer Science*
Alan S. Wineman, Ph.D.; *also Mechanical Engineering and Macromolecular Science and Engineering*
Kensall D. Wise, Ph.D.; *also J. Reid and Polly Anderson Professor of Manufacturing Technology; Director, NSF Engineering Research Center for Wireless Integrated MicroSystems; also Electrical Engineering and Computer Science*
Victor Yang, Ph.D.; *also Pharmacy*
Wen-Jei Yang, Ph.D.; *also Mechanical Engineering*

### Professors Emeritus

Clyde Owings, M.D., Ph.D.
W. Leslie Rogers, Ph.D.
Albert Schultz, Ph.D.

### Associate Professors

Neil Alexander, M.D.; *also Geriatric Medicine*
Mark Burns, Ph.D.; *also Chemical Engineering*
Steven L. Ceccio, Ph.D.; *also Mechanical Engineering*
Jeffrey A. Fessler, Ph.D.; *also Electrical Engineering and Computer Science and Nuclear Medicine*
Karl Grosh, Ph.D.; *also Mechanical Engineering*
Melissa Gross, Ph.D.; *also Kinesiology*
Scott J. Hollister, Ph.D.; *also Mechanical Engineering and Surgery*
Tibor Juhasz, Ph.D.; *also Ophthalmology*
David Kohn, Ph.D.; *also Dentistry*
Arthur D. Kuo, Ph.D.; *also Mechanical Engineering*
Simon P. Levine, Ph.D.; *also Physical Medicine and Rehabilitation*
Jennifer J. Linderman, Ph.D.; *also Chemical Engineering*
Bernard Martin, Ph.D., D.S.; *also Industrial and Operations Engineering*
Carlos Mastrangelo, Ph.D.; *also Electrical Engineering and Computer Science*
Laurie McCauley, D.D.S., Ph.D.; *also Dentistry*
Charles R. Meyer, Ph.D.; *also Radiology*

David J. Mooney, Ph.D.; *also Dentistry, and Chemical Engineering*
Doug Noll, Ph.D.; *also Radiology*
Ann Marie Sastry, Ph.D.; *also Mechanical Engineering*
Victor C. Yang, Ph.D.; *also Pharmaceutics*

### Assistant Professors

Susan V. Brooks, Ph.D.; *also Physiology; Assistant Research Scientist, Institute of Gerontology*
Bret A. Hughes, Ph.D.; *also Ophthalmology and Physiology*
Richard Hughes, Ph.D.; *also Surgery*
Alan J. Hunt, Ph.D.; *also Biophysics; Assistant Research Scientist, Institute of Gerontology*
Denise Kirschner, Ph.D.; *also Microbiology and Immunology*
John E. Kuhn, M.D.; *also Orthopaedic Surgery*
Ron Kurtz, M.D.; *also Ophthalmology*
William M. Kuzon, Jr., M.D., Ph.D.; *also Plastic and Reconstructive Surgery*
Peter Ma, Ph.D.; *also Macromolecular Science and Engineering, and Dentistry*
Beth Malow, Ph.D.; *also Neurology*
Malini Raghavan, Ph.D.; *also Department of Microbiology and Immunology*
Christoph F. Schmidt, Ph.D.; *also Physics*
Shuichi Takayama, Ph.D.
J. Stuart Wolf, Jr., M.D.; *also Surgery*

### Senior Research Scientists

James A. Ashton-Miller, Ph.D.; *also Mechanical Engineering and Institute of Gerontology*
Duncan G. Steel, Ph.D.; *Peter S. Fuss Professor of Engineering; also Industrial Operations and Engineering, Electrical Engineering and Computer Science and Physics*

### Assistant Research Scientists

Tien-Men Gabe Chu, Ph.D.
Robert G. Dennis, Ph.D.; *also Institute of Gerontology*
Stanislav Emelianv, Ph.D.
J. Brian Fowlkes, Ph.D.; *also Senior Associate Research Scientist, Radiology*
Luis Hernandez, Ph.D.; *also FMRI Laboratory*
Jane Huggins, Ph.D.
Vijendra K. Singh, Ph.D.; *also Department of Pharmaceutics and Center for BioEngineering Research*
Greg Spooner, Ph.D.; *also Electrical Engineering and Computer Science*

### Research Investigator

Maria Moalli, D.V.M.; *also Surgery and Unit for Laboratory Animal Medicine*

## Biomedical Engineering Contact Information

Biomedical Engineering
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The degree program in chemical engineering was established in 1898 at the University of Michigan, one of four schools to introduce the profession in the United States during the last decade of the nineteenth century. The University of Michigan student chapter of the American Institute of Chemical Engineers was the first established by that professional society.

Chemical engineering, among all branches of engineering, is the one most strongly and broadly based upon physical and life sciences. It has been defined by the directors of the American Institute of Chemical Engineers as "the profession in which a knowledge of mathematics, chemistry, and other natural sciences gained by study, experience, and practice is applied with judgment to develop economical ways of using materials and energy for the benefit of mankind." Because of a broad and fundamental education, the chemical engineer can contribute to society in many functions: research, development, environmental protection, process design, plant operation, marketing, sales, and corporate or government administration.

The work of the chemical engineer encompasses many industries, from the manufacture of chemicals and consumer products and the refining of petroleum, to biotechnology, nuclear energy, and space technology. Because of this breadth, there are many fields in which chemical engineers may specialize.

The program allows 10 hours of unrestricted electives, 6 hours of technical electives, and 16 hours of humanities and social science electives. A student may use this elective freedom to develop individual abilities and interests, and to prepare for graduate studies or for other professional programs such as law, business administration, or medicine. The electives also provide the opportunity for combined degree programs or for preparation in fields within or related to chemical engineering such as polymers, pharmaceuticals, environmental engineering, chemical-reaction engineering, computers, biochemical processes, natural resource usage, and biotechnology.

This program is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

## Our Mission, Goal, Objectives and Outcomes for Undergraduate Education

### *Mission*

To provide a solid and current technical foundation that prepares students for a career in chemical engineering or related fields.

### *Goal*

To educate and support diverse students and prepare them to be leaders in chemical engineering or related fields.

### *Objectives*

- To provide students with a solid foundation in chemical engineering, while preparing them for a broad range of career opportunities. The program's primary emphasis is on chemical engineering fundamentals, while allowing students to personalize their curriculum to prepare them for traditional chemical engineering careers and diverse careers in areas such as medicine, law, the environment, and biotechnology.
- To provide opportunities for teamwork, open ended problem solving and critical thinking.

### *Outcomes*

The outcomes we desire are that graduates of the University of Michigan Chemical Engineering Program demonstrate:

- an ability to apply knowledge of mathematics, science, and engineering to chemical engineering problems
- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs
- an ability to function on multi-disciplinary teams

- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility
- an ability to communicate effectively orally and in writing
- the broad education necessary to understand the impact of engineering solutions in a global and societal context
- a recognition of the need for, and an ability to engage in life-long learning
- a knowledge of contemporary issues
- an ability to use the techniques, skills, and modern engineering and computing tools necessary for engineering practice
- a thorough grounding in chemistry and a working knowledge of advanced chemistry such as organic, inorganic, physical, analytical, materials, biochemistry, or environmental science, selected based on the student's interest
- a working knowledge, including safety and environmental aspects, of material and energy balances applied to chemical processes; thermodynamics of physical and chemical equilibria; heat, mass, and momentum transfer; chemical reaction engineering; continuos and stage-wise separation operations; process dynamics and control

## Facilities

The facilities located in the H. H. Dow Building include biochemical engineering, catalysis, chemical sensors, heat transfer, light scattering and spectroscopy, petroleum research, rheology, polymer physics, process dynamics, and surface science laboratories; and in the G. G. Brown Laboratories Building, large- and pilot-scale heat transfer, mass transfer, kinetics, and separations processes equipment.

## Dual Degree Opportunities

Students who are interested in more than one program offered by the College may want to work on two bachelor's degrees concurrently. The most common second degrees for Chemical Engineering students are Materials Science and Engineering, Mechanical Engineering, and Electrical Engineering, but dual degrees with other departments can be arranged in consultation with both program advisors.

## Sample Schedule
## B.S.E. Chemical Engineering

| | Credit Hours | Terms 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| **Subjects required by all programs** | | | | | | | | | |
| Mathematics 115+, 116+, 215, and 216+ | 16 | 4 | 4 | 4 | 4 | - | - | - | - |
| Engr 100, Introduction to Engineering | 4 | 4 | - | - | - | - | - | - | - |
| Engr 101, Introduction to Computers+ | 4 | - | 4 | - | - | - | - | - | - |
| Chemistry 130+ | 3 | 3 | - | - | - | - | - | - | - |
| Physics 140/141+; 240/241 | 10 | 5 | - | - | 5 | - | - | - | - |
| Humanities and Social Sciences (to include a course in economics) | 16 | - | 4 | - | - | 4 | - | 4 | 4 |
| **Advanced Science** | | | | | | | | | |
| [1]Biology/Life science elective | 3 | - | - | - | - | - | 3 | - | - |
| Chem 210,211, Struct and Reactv I and Lab+ | 5 | - | 5 | - | - | - | - | - | - |
| Chem 215,216, Struct and Reactv II and Lab+ | 5 | - | - | 5 | - | - | - | - | - |
| Chem 261, Chemical Principles+ | 1 | - | - | - | 1 | - | - | - | - |
| Chem 241/2 Analytical Chemistry | 4 | - | - | - | - | 4 | - | - | - |
| **Related Technical Subjects** | | | | | | | | | |
| Materials Elective (MSE 250) | 4 | - | - | - | - | - | - | 4 | - |
| [2]Technical Electives (to include at least 2 credits of Engineering) | 6 | - | - | - | - | - | - | 4 | 2 |
| **Program Subjects** | | | | | | | | | |
| ChemE 230, Thermodynamics I+ | 4 | - | - | 4 | - | - | - | - | - |
| ChemE 330, Thermodynamics II+ | 3 | - | - | - | 3 | - | - | - | - |
| ChemE 341, Fluid Mechanics+ | 4 | - | - | - | 4 | - | - | - | - |
| ChemE 342, Heat and Mass Transfer+ | 4 | - | - | - | - | 4 | - | - | - |
| ChemE 343, Separation Processes+ | 3 | - | - | - | - | 3 | - | - | - |
| ChemE 344, Reaction Engr and Design+ | 4 | - | - | - | - | - | 4 | - | - |
| ChemE 360, ChemE Lab I | 4 | - | - | - | - | - | 4 | - | - |
| ChemE 460, ChemE Lab II | 4 | - | - | - | - | - | - | - | 4 |
| ChemE 466, Process Control and Dynamics | 3 | - | - | - | - | - | - | 3 | - |
| ChemE 486, Chem Proc Sim and Design I | 4 | - | - | - | - | - | - | - | 4 |
| **Free Electives** | 10 | - | - | 3 | - | - | 4 | - | 3 |
| **Total** | 128 | 16 | 17 | 16 | 17 | 15 | 15 | 15 | 17 |

**Notes:**

[1]Biology/Life science elective currently fulfilled by Biol. 162 (5 cr.), with 2 credits going to free electives. Elective waived if bio-focused technical elective chosen. See department for list of eligible courses.

[2]Technical electives must include a minimum of 2 credits of Engineering Electives, and may include up to 4 credits of Advanced Science Electives. At least one course must be outside of Chemical Engineering. Engineering courses are to be at the 200 or higher level. Courses in AOSS are not considered engineering courses for this purpose. See Department for other exceptions and for a list of approved Advances Science Electives.

(+) Students must earn a "C-" or better in prerequisite courses indicated by the (+).

## Chemical Engineering Course Listings

Course descriptions are found also on the College of Engineering web site at http://courses.engin.umich.edu/

**ChemE 230. Thermodynamics I**
*Prerequisite: Eng 101, Chem 130, and Math 116. I (4 credits)*
An introduction to applications of the first law of thermodynamics. Steady and unsteady state material and energy balances, the equilibrium concept. Properties of fluids. Engineering systems.

**ChemE 290. Directed Study, Research, and Special Problems**
*Prerequisite: First or second year standing, and permission of instructor. II (to be arranged)*
Provides an opportunity for undergraduate students to work in chemical engineering research or in areas of special interest such as design problems. For each hour of credit, it is expected that the student will work three or four hours per week. Oral presentation and/or written report due at end of term.

**ChemE 330. Thermodynamics II**
*Prerequisite: ChemE 230. II (3 credits)*
Development of fundamental thermodynamic property relations and complete energy and entropy balances. Analysis of heat pumps and engines, and use of combined energy-entropy balances in flow devices. Calculation and application of total and partial properties in physical and chemical equilibria. Prediction and correlation of physical/chemical properties of various states and aggregates.

**ChemE 341. Fluid Mechanics**
*Prerequisite: Physics 140, preceded or accompanied by ChemE 230 and Math 216. II (4 credits)*
Fluid mechanics for chemical engineers. Mass, momentum, and energy balances on finite and differential systems. Laminar and turbulent flow in pipes, equipment, and porous media. Polymer processing and boundary layers. Potential, two-phase, and non-Newtonian flow.

**ChemE 342. Heat and Mass Transfer**
*Prerequisite: ChemE 230, ChemE 341, and Math 216. I (4 credits)*
Theories and applications of heat and mass transport phenomena, emphasizing their analogies and contrasts. Fourier's law. Steady and unsteady thermal conduction. Heat transfer from extended surfaces. Heat transfer coefficients. Heat exchangers. Condensation and boiling. Radiation, Kirchoff's law and view factors. Fick's law. Steady and unsteady diffusion. Mass transfer coefficients. Mass transfer equipment. Absorbers. Simultaneous heat and mass transfer. Mass transfer with reaction.

**ChemE 343. Separation Processes**
*Prerequisite: ChemE 230. I (3 credits)*
Introduction and survey of separations based on physical properties, phase equilibria, and rate processes. Emphasis on analysis and modeling of separation processes. Staged and countercurrent operations.

**ChemE 344. Reaction Engineering and Design**
*Prerequisite: ChemE 330, ChemE 342. II (4 credits)*
Fundamentals of chemical reaction engineering. Rate laws, kinetics, and mechanisms of homogeneous and heterogeneous reactions. Analysis of rate data, multiple reactions, heat effects, bioreactors. Design of industrial reactors.

**ChemE 360. Chemical Engineering Laboratory I**
*Prerequisite: ChemE 342. I, II. (4 credits)*
Experimentation in thermodynamics and heat, mass, and momentum transport on a bench scale. Measurement error estimation and analysis. Lecture, laboratory, conferences, and reports. Technical communications.

**ChemE 413 (MacroSE 413) (MSE 413). Polymeric Materials**
*Prerequisites: MSE 220 or 250. I (4 credits)*
The synthesis, characterization, microstructure, rheology, and properties of polymer materials. Polymers in solution and in the liquid, liquid-crystalline, crystalline, and glassy states. Engineering and design properties, including viscoelasticity, yielding, and fracture. Forming and processing methods. Recycling and environmental issues.

**ChemE 415 (MacroSE 415) (Mfg 415) (MSE 415). Applied Polymer Processing**
*Prerequisites: MSE 413 or equivalent. II (4 credits)*
Theory and practice of polymer processing. Non-Newtonian flow, extrusion, injection-molding, fiber, film, and rubber processing. Kinetics of and structural development during solidification. Physical characterization of microstructure and macroscopic properties. Component manufacturing and recycling issues, compounding and blending.

**ChemE 444. Applied Chemical Kinetics**
*Prerequisite: Chem 260 or 261, ChemE 344. I (3 credits)*
Fundamentals of chemical and engineering kinetics from a molecular perspective. Relationship between kinetics and mechanisms. Kinetics of elementary steps in gas, liquid, and supercritical fluid reaction media. Gas-solid and surface reactions. Heterogeneous and homogeneous catalysis. Kinetics and mechanisms of chemical processes such as polymerization, combustion, and enzymatic reactions.

**ChemE 447 (Mfg 448). Waste Management in Chemical Engineering**
*Prerequisite: ChemE 342, ChemE 343. I (3 credits)*
Control of gaseous, liquid, and solid wastes. Regulations and management procedures. Waste minimization and resource recovery. Separations and reaction engineering approaches.

**ChemE 460. Chemical Engineering Laboratory II**
*ChemE 343 I, II (4 credits)*
Experimentation in rate and separation processes on a scale which tests process models. Introduction to the use of instrumental analysis and process control. Laboratory, conferences, and reports. Technology communications.

**ChemE 466. Process Dynamics and Control**
*Prerequisites: ChemE 343, ChemE 344. I (3 credits)*
Introduction and process control in chemical engineering. Application of Laplace transforms and frequency domain theory to the analysis of open-loop and closed-loop process dynamics. Stability analysis and gain/phase margins. Controller modes and settings. Applications to the control of level, flow, heat exchangers, reactors, and elementary multivariable systems.

**ChemE 470. Colloids and Interfaces**
*Prerequisite: ChemE 343, ChemE 344. I (3 credits)*
This is a first course in colloid and interface science. The repulsive forces and attractive forces at interfaces are described along with the dynamics of the interfaces. Topics include the stability of macroemulsions, the formulation and properties of microemulsions, and surface metal-support interactions of catalysts.

**ChemE 472. Polymer Science and Engineering**
*Prerequisite: Preceded or accompanied by ChemE 344. II (4 credits)*
Polymer reaction engineering, characterization and processing for chemical engineers. Polymerization mechanisms, kinetics and industrial equipment. Thermodynamics of polymer solutions, morphology, crystallization and mechanical properties. Polymer processing equipment and technology. Adhesives, diffusion in polymers, reactive polymeric resins and biological applications of macromolecules.

**ChemE 486. Chemical Process Simulation and Design I**
*Prerequisite: preceded or accompanied by ChemE 342, ChemE 343. I (4 credits)*
Economic evaluation of chemical processes. Strategies for decision-making, trouble-shooting faults, potential problem analysis, environmental compliance,

plant safety and failure analysis. The selection and specification of engineering materials for use in industries employing chemical engineers.

**ChemE 487. Chemical Process Simulation and Design II**

*Prerequisite: ChemE 486, preceded or accompanied by ChemE 344, ChemE 466. I, II (4 credits)*

Process synthesis and design. Process simulation with computer assistance. Process and corporate economics. Design project with oral and technical reports. Technical communications.

**ChemE 490. Advanced Directed Study, Research and Special Problems**

*Prerequisite: ChemE 230 & ChemE 341 or ChemE 290 or equivalent. I, II, III, IIIa, IIIb (to be arranged)*

Provides an opportunity for undergraduate students to work in chemical engineering research or in areas of special interest such as design problems. For each hour of credit, it is expected that the student will work three or four hours per week. Oral presentation and/or written report due at end of term. Not open to graduate students.

**ChemE 496. Special Topics in Chemical Engineering**

*Prerequisite: permission of instructor. I, II, III, IIIa, IIIb (2-4 credits)*

Selected topics pertinent to chemical engineering.

**ChemE 507. Mathematical Modeling in Chemical Engineering**

*Prerequisite: ChemE 344, Eng 303. I (3 credits)*

Formulation of deterministic models from conservation laws, population balances; transport and reaction rates. Formulation of boundary and initial conditions. Dimensional analysis, analytical and numerical methods.

**ChemE 508. Applied Numerical Methods I**

*Prerequisite: Eng 101. (3 credits)*

Numerical approximation, integration, and differentiation. Single and simultaneous linear and nonlinear equations. Initial-value methods for ordinary differential equations. Finite-difference methods for parabolic and elliptic partial differential equations. Implementation of numerical methods on the digital computer, with applications to fluid flow, heat transfer, reactor engineering, and related areas.

**ChemE 509. Statistical Analysis of Engineering Experiments**

*(3 credits)*

The use of statistical methods in analyzing and interpreting experimental data and in planning experimental programs. Probability, distributions, parameter estimation, test of hypotheses, control charts, regression and an introduction to analysis of variance.

**ChemE 510. Mathematical Methods in Chemical Engineering**

*Prerequisite: graduate standing, differential equations. II (3 credits)*

Linear algebra, ordinary and partial differential equations, integral equations with chemical engineering applications. Analytical techniques and preliminaries for numerical methods, including: spectral analysis, orthogonal polynomials, Green's functions, separation of variables, existence and uniqueness of solutions.

**ChemE 511 (MacroSE 511) (MSE 511). Rheology of Polymeric Materials**

*Prerequisite: a course in fluid mechanics or permission of instructor. (3 credits)*

An introduction to the relationships between the chemical structure of polymer chains and the rheological behavior. The course will make frequent reference to synthesis, processing, characterization, and use of polymers for high technology applications.

**ChemE 512 (MacroSE 512) (MSE 512). Physical Polymers**

*Prerequisite: senior or graduate standing in engineering or physical science. (3 credits)*

Structure and properties of polymers as related to their composition, annealing and mechanical treatments. Topics include creep, stress-relaxation, dynamic mechanical properties, viscoelasticity, transitions, fracture, impact response, dielectric properties, permeation, and morphology.

**ChemE 517 (MFG 517). Biochemical Science and Technology**

*Prerequisite: ChemE 344, Bio 311 or equivalent; permission of instructor. II (3 credits)*

Concepts necessary in the adaptation of biological and biochemical principles to industrial processing in biotechnology and pharmaceutical industries. Topics include rational screening, functional genomics, cell cultivation, oxygen transfer, etc. Lectures, problems, and library study will be used.

**ChemE 518 (BiomedE 518). Engineering Fundamentals in Biological Systems**

*Prerequisite: ChemE 517 or Bio 311 or permission of instructor. II alternate years (3 credits)*

Application of fundamental chemical engineering principles (mass, heat and momentum transport, kinetics) to the study of biological systems. Focus will be on current bioengineering research in the department.

**ChemE 519 (Pharm 519). Pharmaceutical Engineering**

*Prerequisite: Senior or graduate standing, permission by instructor. I (3 credits)*

Concepts necessary in the adaptation of engineering principles to pharmaceutical and life sciences-related industries. Topics include process engineering in drug discovery, high throughput characterization and optimization of new chemical entities, solid-state engineering and intelligent pharmaceutical manufacturing systems. Lectures, problems, Internet and library study will be used to develop the ideas presented.

**ChemE 527. Fluid Flow**

*Prerequisite: ChemE 341. (3 credits)*

Applications of fluid dynamics to chemical engineering systems. Theory and practice of laminar and turbulent flow of Newtonian and non-Newtonian fluids in conduits and other equipment. Multi-phase flow. Introduction to the dynamics of suspended particles, drops, bubbles, foams, and froth. Selected topics relevant to chemical and other engineering disciplines.

**ChemE 528. Chemical Reactor Engineering**

*Prerequisite: ChemE 344. (3 credits)*

Analysis of kinetic, thermal, diffusive, and flow factors on reactor performance. Topics include batch, plug flow, backmix reactors, empirical rate expressions, residence time analysis, catalytic reactions, stability, and optimization.

**ChemE 538. Statistical and Irreversible Thermodynamics**

*Prerequisite: ChemE 330. (3 credits)*

The laws of probability and statistics are applied to microscopic matter to yield properties of macroscopic systems. Relations between classical and statistical thermodynamics are developed. Coupling of irreversible processes is treated through the entropy balance and microscopic reversibility.

**ChemE 542. Intermediate Transport Phenomena**

*Prerequisite: graduate standing. (3 credits)*

Foundations of transport phenomena. Heat and mass transfer with chemical reaction in three dimensions, selective motion. Unsteady energy and mass balances in three dimensions. Distributions in more than one variable. Boundary layer theory. Estimation of interfacial transport coefficients. Dispersive flows: Taylor Dispersion. Application to equipment design.

**ChemE 543. Advanced Separation Processes**

*Prerequisite: ChemE 343. II (3 credits)*

Forces for adsorption, equilibrium adsorption isotherms, sorbent materials, pore size distribution, heterogeneity, predicting mixture adsorption, rate processes in adsorption/adsorbers, adsorber dynamics, cyclic adsorption processes, temperature and pressure swing adsorbtion, membrane separation processes, polymer membranes, dialysis electrolysis, pervaporation, reverse osmosis, research projects.

**ChemE 548. Electrochemical Engineering**
*Prerequisite: ChemE 344. (3 credits)*
Analysis of electrochemical systems from a theoretical and practical point of view. Topics include the application of electrochemical thermodynamics and kinetics to batteries, fuel cells, electroplating, electrosynthesis, and corrosion.

**ChemE 566 (Mfg 566). Process Control in the Chemical Industries**
*Prerequisite: ChemE 343, ChemE 460. II (3 credits)*
Techniques of regulation applied to equipment and processes in the chemical and petrochemical industries. Linear and nonlinear control theory, largely in the spectral domain. Controller types, transducers, final control elements, interacting systems, and applications.

**ChemE 580 (Eng 580). Teaching Engineering**
*Prerequisite: graduate standing. II alternate years (3 credits)*
Aimed at doctoral students from all engineering disciplines interested in teaching. Topics include educational philosophies, educational objectives, learning styles, collaborative and active learning, creativity, testing and grading, ABET requirements, gender and racial issues. Participants prepare materials for a course of their choice, including course objectives, syllabus, homework, exams, mini-lecture.

**ChemE 583 (BiomedE 583) (MSE 583). Biocompatibility of Materials**
*Prerequisite: undergraduate course in biology and/or physiology; undergraduate course in biochemistry, organic chemistry, or molecular biology. II (2 credits)*
This course describes the interactions between tissue and materials and the biologic/pathologic processes involved. In addition, specifications which govern biocompatibility testing, various strengths and weaknesses of a number of approaches to testing, and future directions are discussed.

**ChemE 584 (BiomedE 584) (Biomaterials 584). Tissue Engineering**
*Prerequisite: Bio 311, ChemE 517, or equivalent biology course; senior standing. I (3 credits)*
Fundamental engineering and biological principles underlying field of tissue engineering are studied, along with specific examples and strategies to engineer specific tissues for clinical use (e.g., skin). Student design teams propose new approaches to tissue engineering challenges.

**ChemE 595. Chemical Engineering Research Survey**
*(1 credit)*
Research activities and opportunities in Chemical Engineering program. Lectures by University of Michigan faculty and guest lecturers. Topics are drawn from current research interests of the faculty.

**ChemE 596 (Pharm 596). Pharmaceutical Engineering Seminar.**
*Prerequisite: graduate standing. I, II (1 credit)*
This seminar will feature invited speakers from pharmaceutical and life sciences-related industries, and academic institutions.

**ChemE 607. Mathematical Methods in Chemical Engineering**
*Prerequisite: Chem 507. (3 credits)*
Matrices and their application to reaction and separation processes. Linear operator theory and application to transport phenomena. Non-linear systems, stability, bifurcation. Perturbation methods and chaotic systems.

**ChemE 616 (BiomedE 616). Analysis of Chemical Signalling**
*Prerequisite: Math 216, Biochemistry 415. II (3 credits)*
Quantitative analysis of chemical signalling systems, including receptor/ligand binding and trafficking, signal transduction and second messenger production, and cellular responses such as adhesion and migration.

**ChemE 617 (Mfg 617). Advanced Biochemical Technology**
*Prerequisite: ChemE 517 or permission of instructor. II alternate years (3 credits)*
Practical and theoretical aspects of various unit operations required to separate and purify cells, proteins, and other biological compounds. Topics covered include various types of chromatography, liquid/liquid extractions, solid/liquid separations, membrane processing and field-enhanced separations. This course will focus on new and non-traditional separation methods.

**ChemE 628. Industrial Catalysis**
*Prerequisite: ChemE 528. (3 credits)*
Theoretical and experimental aspects of heterogeneous catalysis and surface science. Design, preparation, and characterization of catalysts. Kinetics of heterogeneous catalytic reactions, thermal and diffusional effects in catalytic reactors. Case studies of important industrial catalytic processes.

**ChemE 629 (Physics 629). Complex Fluids**
*Prerequisite: ChemE 527. II alternate years (3 credits)*
Structure, dynamics, and flow properties of polymers, colloids, liquid crystals, and other substances with both liquid and solid-like characteristics.

**ChemE 695. Research Problems in Chemical Engineering**
*(to be arranged)*
Laboratory and conferences. Provides an opportunity for individual or group work in a particular field or on a problem of special interest to the student. The program of workis arranged at the beginning of each term by mutual agreement between the student and a member of the faculty. Any problem in the field of chemical engineering may be selected. The student writes a final report on his project.

**ChemE 696. Selected Topics in Chemical Engineering**
*(to be arranged)*

**ChemE 697. Problems in Chemical Engineering**
*(to be arranged)*

**ChemE 698. Directed Study in Chemical Engineering**
*(to be arranged)*

**ChemE 751 (Chem 751) (MacroSE 751) (MSE 751) (Physics 751). Special Topics in Macromolecular Science**
*Prerequisite: permission of instructor. (2 credits)*
Advanced topics of current interest will be stressed. The specific topics will vary with the instructor.

**ChemE 895. Seminar in Chemical Engineering**
*(to be arranged)*

**ChemE 990. Dissertation/Pre-Candidate**
*I, II, III, IIIa, IIIb (1-8 credits)*
Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**ChemE 995. Dissertation/Candidate**
*Prerequisite: Graduate School authorization for admission as a doctoral candidate. I, II, III, IIIa, IIIb (4 or 8 credits)*
Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

## Chemical Engineering Faculty

Ronald G. Larson, Ph.D., P.E., *G.G. Brown Professor of Chemical Engineering and Chair*

### Professors

H. Scott Fogler, Ph.D., P.E., *Vennema Professor of Chemical Engineering*
John L. Gland, Ph.D.
Erdogan Gulari, Ph.D.; *also Macromolecular Science and Engineering*
Costas Kravaris, Ph.D.
Phillip E. Savage, Ph.D., P.E.
Johannes W. Schwank, Ph.D.
Levi T. Thompson, Jr., Ph.D.
Henry Y. Wang, M.S., Ph.D.
Ralph T. Yang, Ph.D.
Albert F. Yee, Ph.D.; *also Materials Science and Engineering*
Robert Ziff, Ph.D.; *also Macromolecular Science and Engineering*

### Professors Emeritus

Dale E. Briggs, Ph.D., P.E.
Brice Carnahan, Ph.D., P.E.
Rane L. Curl, Sc.D.
Francis M. Donahue, Ph.D.
Robert H. Kadlec, Ph.D., P.E.
John E. Powers, Ph.D.
Maurice J. Sinnott, Sc.D.; *also Metallurgical Engineering*
Mehmet Rasin Tek, Ph.D., P.E.
James Oscroft Wilkes, Ph.D.
George Brymer Williams, Ph.D., P.E.
Gregory S. Y. Yeh, Ph.D.
Edwin Harold Young, M.S.E., P.E.; *also Metallurgical Engineering*

### Associate Professors

Stacy G. Bike, Ph.D.; *also Macromolecular Science and Engineering*
Mark Burns, Ph.D., P.E.
Sharon C. Glotzer, Ph.D., *also Materials Science and Engineering*
Jennifer J. Linderman, Ph.D.
David James Mooney, Ph.D.; *also Biomedical Engineering and Dentistry*

### Assistant Professors

Ofer Blum, Ph.D.
Robert A. Lionberger, Ph.D.
Michael J. Solomon, Ph.D., *Dow Corning Assistant Professor*

### Lecturer

Susan M. Montgomery, Ph.D., P.E.

## Chemical Engineering Contact Information

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*Professor Garrett H. Evans*
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Civil engineers have always had the unique opportunity to touch the everyday lives of those around them. They design, plan, and construct the buildings in which we live and work; the roads, highways, and bridges upon which we travel; the transit and transportation systems we use and much more. As the world population grows and society becomes more technologically complex, the issues facing civil and environmental engineers will be even more important and the challenges more exciting. Civil and environmental engineers will be involved in environmental and public health issues as they examine the disposal of newly generated wastes and the handling of contaminated sites. New technologies for the control of water and air quality, and computer models to predict the movement and dispersion of wastes in ground and surface waters, will be developed. Advances in the construction industry will allow civil engineers to design and build new facilities more efficiently. As new materials are developed, innovations in all constructed facilities, from buildings to space stations will be possible. Computer technology, including machine learning, will also play a larger role. In all of these areas, civil and environmental engineers are given the rare opportunity to improve the environment and to have a direct impact on society's life style.

This program is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

## Our Mission, Goals, Objectives and Outcomes for Undergraduate Education

### *Mission*

To be a leader in the education of civil engineers in the application of engineering principles to infrastructure and environmental problems with emphasis on: infrastructure design, construction, rehabilitation, monitoring, and management; remediation technologies and pollution prevention; watershed management; and mitigation of natural hazards and risk assessment.

### *Goals*

• To recruit, educate, and support excellent, diverse students and prepare them to be leaders in the design and construction of civil and environmental systems.
• To have the leading program in civil and environmental engineering; one that provides a dedication to life-long learning, and engineering education that effectively prepares the student to adapt to a changing profession.

### *Objectives*

• To provide students with a solid foundation in civil and environmental engineering while preparing them for a broad range of career opportunities. The program's primary emphasis is on the scientific, engineering, and design aspects of infrastructure and environmental systems.
• To provide opportunities for teamwork, open ended problem solving and critical thinking.
• To provide skills for effective communication of technical/professional information in written, oral, visual and graphical form.
• To provide opportunities for awareness of moral, ethical, legal and professional obligations to protect human health, human welfare, and the environment.

### *Outcomes*

The outcomes we desire are that graduates of the University of Michigan Civil Engineering Program demonstrate:
• An ability to apply knowledge of mathematics, science, and engineering within civil engineering
• An ability to design and conduct experiments, and to critically analyze and interpret data
• An ability to design a system, component or process to meet desired needs
• An ability to function in multi-disciplinary teams.
• An ability to identify, formulate and sovle engineering problems
• An understanding of professional and ethical responsibility
• An ability for effective oral, graphic and written communication
• An understanding of the impact of engineering

solutions in a global and societal context.
• A recognition of the need for, and an ability to engage in life-long learning
• A knowledge of contemporary issues that affect civil engineering
• An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.
• A proficiency in a minimum of four major civil engineering areas
• An understanding of professional practice issues and the importance of licensure

## Areas of Concentration

The following are areas of concentration within Civil Engineering at Michigan.

### Construction Engineering and Management

Planning, estimating, scheduling, and managing the construction of engineered facilities using modern construction methods, materials, and equipment. Business and legal principles of construction contracting.

### Environmental Engineering

Municipal and industrial water distribution and waste collection, water quality and water pollution control, the improvement and regulation of natural waters for municipal, industrial, and recreational use; water resources development and management, the analysis and design of water resource systems; environmental design for control of solid wastes and air and water pollution, management of engineering problems in the urban environment.

### Geotechnical Engineering

The evaluation of soil properties and environmental conditions in foundations of earth-supported structures; mass stability in excavations and subsurface construction; use of soil characteristics and properties and soil classification in design and construction of highways, railways, airports, and other surface facilities.

### Hydraulic and Hydrological Engineering

The application of the fundamental principles of hydraulics and hydrology to the optimum development of surface water and ground-water resources; the study of flood prediction and flood control, flow and contaminant transport in surface and ground waters, transients in pipelines and channels, coastal engineering, and design of structures to interface with the water environment.

### Materials and Highway Engineering

The analysis, engineering, and testing of civil engineering materials pertaining to infrastructure renewal and high-performance structures, including the study of infrastructure rehabilitation (including bridge and pavement technology), advanced emerging materials (including cement-based composites, polymers, and ceramics), micromechanics of composite materials, durability of materials, and innovative materials and structures.

### Structural Engineering

The theory, analysis, design, and construction of structures such as bridges, buildings, chimneys, tanks, and towers, involving the use of steel, reinforced concrete, aluminum, timber, and other materials; studies of inelastic behavior of materials and structures; studies of dynamic forces and their effects on structures.

## Facilities

The Civil and Environmental Engineering departmental offices are in the George Granger Brown Building. The G. G. Brown Building on the North Campus houses the construction engineering and management laboratory, the structural research laboratory, the hydraulic engineering laboratory, the soil mechanics laboratory, and the civil engineering materials laboratory.

The Environmental and Water Resources Engineering Building, a wing of the G. G. Brown Building, contains laboratories for environmental and water resources engineering. Equipment is available for physical and biological studies, analytical determinations, and data analyses in environmental science as well as in water-quality engineering.

# Sample Schedule
# B.S.E. Civil Engineering

| | Credit Hours | Terms 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| **Subjects required by all programs (52 hrs.)** | | | | | | | | | |
| Mathematics 115, 116, 215, and 216 | 16 | 4 | 4 | 4 | 4 | - | - | - | - |
| Engr 100, Intro to Engr | 4 | 4 | - | - | - | - | - | - | - |
| Engr 101, Intro to Computers | 4 | - | 4 | - | - | - | - | - | - |
| [1]Chemistry 125 and 130 or Chemistry 210 and 211 | (5) 4 | 4 | - | - | - | - | - | - | - |
| [2]Physics 140 with Lab 141; 240 with Lab 241 | (10) 8 | - | 4 | 4 | - | - | - | - | - |
| Humanities and Social Sciences *(includes one 4-hour economics course)* | 16 | 4 | 4 | - | - | - | 4 | - | 4 |
| **Advanced Mathematics (8 hrs.)** | | | | | | | | | |
| IOE 265, Engr Probility and Statistics | 4 | - | - | - | 4 | - | - | - | - |
| CEE 303, Computational Methods | 4 | - | - | - | - | - | 4 | - | - |
| **[3]Technical Core Subjects (20 hrs.)** | | | | | | | | | |
| ME 230, Thermal Science or Chem E 230, Thermodynamics I | 4 | - | - | 4 | - | - | - | - | - |
| CEE 211, Statics and Dynamics | 4 | - | - | 4 | - | - | - | - | - |
| CEE 212, Solid and Structural Mechanics | 4 | - | - | - | 4 | - | - | - | - |
| CEE 260, Environmental Principles | 4 | - | - | - | 4 | - | - | - | - |
| CEE 325, Fluid Mechanics | 4 | - | - | - | - | 4 | - | - | - |
| **Program Subjects (20 hrs.)** | | | | | | | | | |
| CEE 445, Engineering Properties of Soils | 4 | - | - | - | - | 4 | - | - | - |
| CEE 412, Structural Engineering | 4 | - | - | - | - | 4 | - | - | - |
| CEE 351, Civil Engineering Materials | 4 | - | - | - | - | - | 4 | - | - |
| CEE 360, Environmental Process Engineering | 4 | - | - | - | - | - | 4 | - | - |
| CEE 421, Hydrology and Hydraulics | 4 | - | - | - | - | - | - | 4 | - |
| CEE 431, Construction Contracting | 3 | - | - | - | - | - | - | 3 | - |
| CEE 402, Professional Issues & Design | 4 | - | - | - | - | - | - | - | 4 |
| **[4]Technical Electives (9 hrs.)** | 9 | - | - | - | - | - | - | 6 | 3 |
| [5]Construction — CEE 432, CEE 536, CEE 537 (any two) | | | | | | | | | |
| [5]Hydraulics/Hydrology — CEE 428, CEE 526 | | | | | | | | | |
| [5]Enviromental — CEE 460 and (CEE 581 or CEE 582) | | | | | | | | | |
| [5]Materials — CEE 547, CEE 554 | | | | | | | | | |
| [5]Geotechnical — CEE 545, CEE 546 | | | | | | | | | |
| [5]Structural — CEE 413, CEE415 | | | | | | | | | |
| **Unrestricted Electives (12 hrs.)** | 12 | - | - | - | - | - | 4 | 3 | 5 |
| **Total** | 128 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |

Candidates for the Bachelor of Science degree in Engineering (Civil Engineering)—B.S.E. (C.E.)—must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

**Notes: (See additional "Notes" on the next page.)**

[1]Chemistry: 125, 130 or 210, 211 will count for 5 total credits, 1 of which will be applied according to individual program directives.

[2]Physics: 140, 141; 240, 241 will count for 10 total credits, 2 of which will be applied according to individual program directives.

[3]CEE will accept equivalent courses offered by other departments in the College of Engineering.

[4]In the senior year, students choose a concentration area and take two technical electives in this concentration. The remaining technical elective must be taken from outside of the chosen concentration.

[5]The following CEE courses are 3 credit hours: all technical electives and 431.

## Civil and Environmental Engineering Course Listings

Course descriptions are found also on the College of Engineering web site at http://courses.engin.umich.edu/

### CEE 211. Statics and Dynamics
*Prerequisites: Physics 140. I (4 credits)*

Statics: review of vector mathematics; moment and force resultants; static equilibrium in two & three dimensions; centroids; center of gravity; distributed loadings. Dynamics: review of concepts of velocity and acceleration; dynamics of particles and rigid bodies; concepts of work, energy, momentum; introduction to vibrations.

### CEE 212. Solid and Structural Mechanics
*Prerequisites: CEE 211 or equivalent. II (4 credits)*

Fundamental principles of solid and structural mechanics and their application in engineering disciplines. Covered: concepts of stress and strain, stress and strain transformations, axial, torsion, bending and combined loading, elastic deformations, energy concepts, and strength design principles. Four lectures per week.

### CEE 260. Environmental Principles
*Prerequisites: Chem 130, Math 116. II (4 credits)*

Basic principles which govern the use of chemicals, their fate and transport in the environment, and their removal from waste streams. Toxicology, perception of risk, government regulation, and ethics as they pertain to the design of treatment processes for the removal of environmental contaminants. Pollution prevention.

### CEE 303 (Eng 303). Computational Methods for Engineers and Scientists
*Prerequisite: Eng. 101, Math 216. II (4 credits)*

Applications of numerical methods to infrastructure and environmental problems. Development of mathematical models and computer programs using a compiled language (FORTRAN). Formulation and solution of initial and boundary-value problems with emphasis on structural analysis, fluid flow, and transport of contaminants. Lecture, recitation and computation.

### CEE 325. Fluid Mechanics
*Prerequisite: CEE 211 and ME 230 or ChemE 230. I (4 credits)*

Principles of mechanics applied to real and ideal fluids. Fluid properties and statics; continuity, energy, and momentum equations by control volume analysis; differential equations of motion for laminar and turbulent flow; dimensional analysis and similitude; boundary layers, drag, and lift; incompressible flow in pipes; fluid measurement and turbomachinery. Lectures and laboratory.

### CEE 332. Engineering Surveying, Mapping and GIS Applications
*Prerequisite: Math 116, Eng 101. I, IIIa (4 credits)*

Engineering surveying measurements of terrain including contouring and layout of infrastructural works. Survey measurement theory and practice, and measurement errors. Design of measurements and field operations including use of GPS. Maps, types, mapping methods representations in digital data bases, GIS analysis and applications, use of computers.

### CEE 351. Civil Engineering Materials
*Prerequisites: CEE 212 or equivalent. II (4 credits)*

Discussion of basic mechanical and physical properties of a variety of important civil and environmental engineering materials such as concrete, steel, plastic, asphalt, wood and fiber composites. Evaluation of constituents and design of mixtures and composites, load-time deformation characteristics, response to typical service environments. Lecture and laboratory.

### CEE 360. Environmental Process Engineering
*Prerequisite: CEE 260; CEE 325. II (4 credits)*

An introduction to the analysis, characterization, and modeling of environmental processes; physical, chemical, and biological processes and reactor configurations commonly used for water quality control; applications to the development and design of specific water and wastewater treatment operations; discussion of economic and legislative constraints and requirements.

**CEE 400. Construction Law and Related Legal Issues**
*Prerequisites: senior standing. I, II (3 credits)*
Survey of areas of the law that impact the design and construction process with a concentration on the fields of contracts, equity, torts, product liability, agency, mechanics liens, workers' compensation and property rights. Class discussion is emphasized.

**CEE 402. Professional Issues and Design**
*Prerequisite: senior standing. II (4 credits)*
Multidisciplinary team design experience including consideration of codes, regulations, alternate solutions, economic factors, sustainability, constructibility, reliability, and aesthetics in the solution of a civil or environmental engineering problem. Professionalism and ethics in the practice of engineering.

**CEE 412. Structural Engineering**
*Prerequisite: CEE 212 or equivalent. I (4 credits)*
Introduction to the field of structural engineering. Discussion of structural analysis techniques and concepts such as virtual work, flexibility method, stiffness method, and influence lines. Exposure to commonly used structural analysis computer program(s). Discussion of basic design concepts and principles. Lecture and laboratory.

**CEE 413. Design of Metal Structures**
*Prerequisites: CEE 412. I (3 credits)*
Design of metal members and connections, and their use in buildings and bridges. Application of relevant design specifications with emphasis on structural steel. Lectures, problems, and laboratory.

**CEE 415. Design of Reinforced Concrete Structures**
*Prerequisites: CEE 412. II (3 credits)*
Design of reinforced concrete members and slabs, and their use in buildings and bridges. Application of relevant design specifications. Lectures, problems, and laboratory.

**CEE 421. Hydrology and Floodplain Hydraulics**
*Prerequisites: CEE 303, CEE 325. I (4 credits)*
Fundamentals of surface-water hydrology, flow in open channels, and flood hazard mitigation. Rainfall-runoff relations. Unit hydrograph method. Uniform and nonuniform flow in open channels. Measurement and control of river flow. Flood waves in rivers, floodplains, and reservoirs. Design of storage basins, storm channels, and culverts. Lecture, laboratory and computation.

**CEE 428. Introduction to Groundwater Hydrology**
*Prerequisites: junior standing. I (3 credits)*
Importance and occurrence of ground-water; chemical and physical properties of the groundwater environment; basic principles of ground-water flow; measurement of parameters; pump test design and analysis; transport of contaminants; use of computer models for the simulation of flow and transport problems.

**CEE 430. Special Problems in Construction Engineering**
*Prerequisites: permission of instructor. I, II, IIIa, IIIb (1-3 credits)*
Individual student may choose his or her special problem from a wide range of construction engineering and management areas.

**CEE 431. Construction Contracting**
*Prerequisites: junior standing. I, II (3 credits)*
Construction contracting for contractors, architects, owners. (1) Organization and administration; industry structure; construction contracts, bonds, insurance. (2) Planning, estimating, and control; quantity takeoff and pricing; labor and equipment estimates; estimating excavation and concrete; proposal preparation; scheduling; accounting and cost control. Students use contract documents to prepare detailed estimate.

**CEE 432. Construction Engineering**
*Prerequisites: junior standing. II (3 credits)*
Major construction equipment and concrete construction. Selection of scrapers, dozers, cranes, etc., based on applications, methods, and production requirements. Power gen-eration, transmission, and output capacity of equipment engines. Calculation of transport cycle times. Concreting methods include mixing, delivery, and placement. Design of forms for concrete walls and supported slabs.

**CEE 445. Engineering Properties of Soil**
*Prerequisite: CEE 212. I (4 credits)*
Soil classification and index properties; soil structures and moisture, seepage, compressibility and consolidation; stress and settlement analysis; shear strength; applications to foundations, retaining structures, slopes and landfills. Lectures, problems, laboratory, report writing.

**CEE 446. Engineering Geology**
*Prerequisites: CEE 445 or permission of instructor. II (3 credits)*
Composition and properties of rocks and soil, geologic processes, geologic structures and engineering consequences, natural and artificial underground openings, terrain analysis and site investigation, civil engineering facility siting, seismic zonation for ground motions and soil liquefaction potential, geotechnical aspects of municipal and hazardous waste disposal.

**CEE 460. Design of Environmental Engineering Systems**
*Prerequisite: CEE 360. I (3 credits)*
Design and theoretical understanding of environmental processes; biological, physical, and chemical processes, and reactor configurations commonly used for water quality control; applications to the design of specific water and wastewaster treatment operations; discussion of pollution prevention and green engineering options.

**CEE 470. Transportation Engineering**
*Prerequisites: junior standing. I (3 credits)*
Planning, location, design, and operation of transportation facilities. Introduction to engineering economics.

**CEE 490. Independent Study in Civil and Environmental Engineering**
*Prerequisites: permission of instructor. I, II, IIIa, IIIb (1-3 credits)*
Individual or group experimental or theoretical research in any area of Civil and Environmental Engineering. The program of work is arranged at the beginning of each term by mutual agreement between the student and a faculty member. Written and oral reports may be required.

**CEE 501. Legal Aspects of Engineering**
*Prerequisites: CEE 400 or a course in contract law. I (3 credits)*
Provides insight into various areas of civil litigation. Includes personal and property loss, professional liability, product liability, land use, and the role of the engineer as an expert witness.

**CEE 510 (NA 512). Finite Element Methods in Solid and Structural Mechanics**
*Prerequisites: graduate standing. II (3 credits)*
Basic equations of three-dimensional elasticity. Derivation of relevant variational principles. Finite element approximation. Convergence requirements. Isoparametric elements in two and three dimensions. Implementational considerations. Locking phenomena. Problems involving non-linear material behavior.

**CEE 511. Dynamics of Structures**
*Prerequisite: CEE 512 or equivalent (may be taken simultaneously). I (3 credits)*
Dynamic equilibrium of structures. Response of a single degree of freedom system to dynamic excitation: free vibration, harmonic loads, pulses and earth-

quakes. Response spectra. Response of multi-degree-of-freedom systems. Seismic behavior of buildings and the basis for seismic building codes.

**CEE 512. Theory of Structures**
*Prerequisite: CEE 412 or equivalent. I (3 credits)*
Presentation of the direct stiffness method of analysis for two-dimensional and three-dimensional structures. Overview of analysis techniques for arch and cable-supported structures. Brief introduction to the theory of plates and shells. Lecture.

**CEE 513. Plastic Analysis and Design of Frames**
*Prerequisite: CEE 413. II (3 credits)*
Plastic analysis and design of steel framed structures. Stepwise incremental load and mechanism methods. Behavior beyond elastic range; failure mechanisms. Use of computer programs and AISC specifications. Application to earthquake resistant design.

**CEE 514. Prestressed Concrete**
*Prerequisite: CEE 415. II (3 credits)*
Fundamental principles of prestressing; prestressing materials; prestress losses; allowable stress and ultimate strength design methods; analysis and design of beams for flexure, shear, and deflection; composite construction; bridges; slab systems; partial prestressings; FRP tendons.

**CEE 515. Advanced Design of Reinforced Concrete Structures**
*Prerequisite: CEE 415. I (3 credits)*
Analysis and design of concrete structural systems including two-way floor systems, slender columns, members subjected to torsion, structural walls and connections. Applications of computer-aided design programs. Use of design code provisions. Design projects.

**CEE 516. Bridge Structures**
*Prerequisites: CEE 413, CEE 415. I (3 credits)*
Advanced concepts and modern trends in design of bridges. Rehabilitation, repair, and retrofit of existing bridges. Use of relevant codes. Study of alternative structural forms and materials for efficiency and economy. Design problems and reports.

**CEE 517. Reliability of Structures**
*Prerequisites: CEE 412. II (3 credits)*
Fundamental concepts related to structural reliability, safety measures, load models, resistance models, system reliability, optimum safety levels, and optimization of design codes.

**CEE 518. Fiber Reinforced Cement Composites**
*Prerequisite: CEE 415 or CEE 553. I (3 credits)*
Fiber-reinforcement of cement-based matrices; continuous and discontinuous fibers and meshes. Fiber-reinforced concrete and Ferro-cement. Laminated cementitious composites. Behavior and mechanical properties. Mechanics of fiber reinforcement. Constitutive models. High-strength, high-performance fiber composites. Hybrid and smart composites. Lectures, projects and laboratory.

**CEE 520. Deterministic and Stochastic Models in Hydrology**
*Prerequisites: CEE 420, CEE 421. II (3 credits)*
Mathematical description of the Hydrologic cycle. Computation of overland flow. Flood routing through reservoirs and rivers. Unit Hydrograph theory. Linear and nonlinear models for small watershed analysis. Application of time series and spectral analysis to hydrologic data. Streamflow stimulation by autoregressive and moving average models.

**CEE 521. Flow in Open Channels**
*Prerequisite: CEE 421. I alternate even years (3 credits)*
Conservation laws for transient flow in open channels; shallow-water approximation; the method of characteristics; simple waves and hydraulic jumps; nonreflective boundary conditions; dam-break analysis; overland flow; prediction and mitigation of flood waves.

**CEE 523 (Aero 523) (ME 523). Computational Fluid Dynamics I**
*Prerequisites: Aero 520 or ME 520. I (3 credits)*
Physical and mathematical foundations of computational fluid mechanics with emphasis on applications. Solution methods for model equations and the Euler and the Navier-Stokes equations. The finite volume formulation of the equations. Classification of partial differential equations and solution techniques. Truncation errors, stability, conservation and monotonicity. Computer projects and homework.

**CEE 524. Environmental Turbulence**
*Prerequisites: CEE 325 or equivalent. II alternate years (3 credits)*
Introduction to the topic of turbulence with special emphasis on physical processes; characterization of fundamental turbulent flows such as shear layers, wakes, jets, plumes, and thermals; effect of stratification on turbulence; forcing and control of turbulence by acceleration and pulsation.

**CEE 525. Turbulent Mixing in Buoyant Flows**
*Prerequisites: CEE 325 or equivalent. I alternate years (3 credits)*
Analysis of submerged turbulent buoyant jets; scaling relations; consideration of ambient effects including density stratification, ambient currents, and limited depth; numerical models for buoyant jet mixing; hydraulics of two-layer stratified flow and control on mixing processes.

**CEE 526. Design of Hydraulic Systems**
*Prerequisite: CEE 325 or equivalent. II (3 credits)*
Hydraulic design of piping systems including pumps and networks; pump system design including variable speed operation, cavitation, and wet wall design; waterhammer and other transient phenomena; control valves and flow metering considerations; hydraulic control structures.

**CEE 527. Coastal Hydraulics**
*Prerequisite: CEE 325 or equivalent. I alternate even years (3 credits)*
General description of wave systems including spectral representation; solutions to oscillatory wave equation; wave breaking; harbor resonance; wave shoaling, refraction, and diffraction; wave forecasting; selection of design wave conditions; forces on coastal structures; shoreline erosion processes.

**CEE 528. Flow and Transport in Porous Media**
*Prerequisite: CEE 428 or equivalent. II (3 credits)*
Basic principles governing flow and transport in porous media; development of mathematical models at pore and continuum levels; single and multiphase flow; solute transport and dispersion theory; parameter estimation; application to saturated and unsaturated groundwater flow, flow in fractured media, petroleum reservoirs, saltwater intrusion and miscible and immiscible subsurface contamination.

**CEE 529. Hydraulic Transients I**
*Prerequisite: CEE 421. I (3 credits)*
Incompressible unsteady flow through conduits; numerical, algebraic and graphical analysis of waterhammer; solution of transient problems by the method of characteristics; digital computer applications to pump failures, complex piping systems; valve stroking, and liquid column separation.

**CEE 530. Construction Professional Practice Seminar**
*Prerequisite: permission of instructor; mandatory satisfactory/unsatisfactory. I, II (1-3 credits)*
Construction industry speakers, field trips, team projects. Student teams investigate construction technologies and work with construction industry clients as volunteer consultants to address industry, organization, and project problems. Teams prepare and present written and oral reports to seminar and clients.

**CEE 531. Construction Cost Engineering**
*Prerequisite: graduate standing and preceded or accompanied by CEE 431. I (3 credits)*
Cost engineering for construction organizations, projects, and operations. Con-

struction financing; break-even, profit, and cash flow analyses; capital budgeting. Equipment cost and procurement decisions. Construction financial accounting, cost accounting, cost control systems, databases. Cost indices, parametric estimates, unit price proposals, measuring work and settling claims.

**CEE 532. Construction Management and Project Engineering**
*Prerequisite: preceded or accompanied by CEE 431. II (3 credits)*
Project, company organization. Manpower planning, procurement; union, non-union construction. Job site layout. Material equipment procurement. Construction operation planning, supervision, measurement, analysis, improvement, automation, robotics. Dimensions of performance: safety, quality, quality of work life, productivity, innovation. Examples, cases from construction.

**CEE 533. Advanced Construction Systems**
*Prerequisite: preceded or accompanied by CEE 431. II (3 credits)*
Human-machine interactions. Automation and robotics. Ergonomics, job analysis, and job design. Work physiology, environmental factors. Occupational health and safety with focus on underlying causes and prevention of illnesses and injuries rather than on regulation. Risk, safety, and loss management.

**CEE 535. Excavation and Tunneling**
*Prerequisite: CEE 445. II (3 credits)*
Selection of methods of attack for excavation of tunnels and deep vertical-sided open-ings. Tunneling procedures based on behavioral characteristics of soil and rock. Study of tunnel boring machines, shielded and drill-and-blast operations, linings. Soil liner interaction. Deep excavation procedures related to support of excavation systems, methods of installation and dewatering.

**CEE 536 (Mfg 536). Critical Path Methods**
*Prerequisite: senior or graduate standing. I, IIIa (3 credits)*
Basic critical path planning and scheduling with arrow and precedence networks; project control; basic overlapping networks; introduction to resource leveling and least cost scheduling; fundamental PERT systems.

**CEE 537. Construction of Buildings**
*Prerequisite: CEE 315. I (3 credits)*
Material selection, construction details, manufacture, fabrication, and erection of building structures using steel, light wood, timber, cast-in-place concrete, precast concrete, and masonry; and of building materials for roof, floor, and wall surfaces. Field trips to fabrication plants and construction sites.

**CEE 538. Concrete Construction**
*Prerequisite: CEE 351, CEE 315. I (3 credits)*
Selection of concrete, batch design, additives, and batch plant. Structural design, construction of concrete formwork for buildings, civil works. Transporting, placing, and finishing equipment and methods. Plant and on-site pre-casting and prestressing methods and field erection. Sprayed, vacuum, and preplaced aggregate concrete applications. Industrialized concrete systems. Concrete grouting, repair.

**CEE 540. Biotechnical Slope Stabilization**
*Prerequisite: senior or graduate standing in Engineering or Natural Resources. I alternate years (3 credits)*
Introduction to soil bioengineering and biotechnical methods for protecting slopes against erosion and mass wasting. Role of herbaceous and woody vegetation in slope stability. Selection, handling, establishment of live plant materials. Reinforced grass systems, using hard and soft armor. Case studies of biotechnical stabilization of cut and fill slopes, streambanks, landfill covers.

**CEE 541. Soil Sampling and Testing**
*Prerequisite: preceded or accompanied by CEE 445. I (3 credits)*
Field and laboratory practice in sampling and testing of soils for engineering purposes. Field sampling and testing; standard split-spoon sampler, Dutch Cone penetrometer, field vane, Iowa borehole shear device. Lab tests; direct shear, unconfined compression, triaxial compression, consolidation. Laboratory and lecture.

**CEE 542. Soil and Site Improvement**
*Prerequisite: CEE 445. I (3 credits)*
Analysis of geotechnical problems affecting site use including weak, compressible soil; water-logged conditions; high shrink-swell potential; erodibility. Stabilization techniques including compaction, earth reinforcement, drainage and erosion control, admixture stabilization, grouting, precompression, thermal and electrokinetic stabilization. Geotechnical aspects of disposal fills, e.g., tailings, fly ash, sanitary landfills, and hazardous waste.

**CEE 543. Geosynthetics**
*Prerequisite: CEE 445. I (3 credits)*
Physical, mechanical, chemical, biological, and endurance properties of geosynthetics (including geotextiles, geogrids, geonets, geomembranes, geopipes and geocomposites). Standard testing methods for geosynthetics. Application and design procedures for geosynthetics in Civil and Environmental Engineering: separation, reinforcement, stabilization, filtration, drainage and containment of solids and liquids.

**CEE 544. Rock Mechanics**
*Prerequisite: ME 211. I (3 credits)*
Engineering properties and classification of rocks. Strength and deformability of intact and jointed rock; in situ stresses; lab and field test methods. Stereonets and structural geology. Rock slopes; stability and reinforcement. Foundations on rock.

**CEE 545. Foundation Engineering**
*Prerequisite: CEE 445. I (3 credits)*
Application of principles of soil mechanics to: determination of bearing capacity and settlement of spread footings, mats, single piles and pile groups; site investigation, evaluation of data from field and laboratory tests; estimation of stresses in soil masses; and lateral resistance of piles and pile groups.

**CEE 546. Stability of Earth Masses**
*Prerequisite: CEE 445. II (3 credits)*
Stability of hillsides and open cuts, geologic considerations; stability of man-made embankments including earth dams and structural fills, compaction and placement of soil in earth embankments, problems of seepage and rapid draw-down, earthquake effects, slope stabilization techniques; lateral earth pressures and retaining walls, braced excavations.

**CEE 547. Soils Engineering and Pavement Systems**
*Prerequisite: CEE 445. I (3 credits)*
Soils engineering as applied to the design, construction and rehabilitation of pavement systems. The design, evaluation and rehabilitation of rigid, flexible and composite pavements.

**CEE 548. Foundations for Marine Structures**
*Prerequisite: CEE 445. I (3 credits)*
Effects of seepage and dewatering on design of waterfront structures. Soil retaining structures, cellular cofferdams, anchored bulk-heads. Compaction and consolidation of soil masses. Water wave forces on offshore and harbor structures. Soil-structure interaction for offshore towers, piers, wharves, sea walls, and jetties.

**CEE 549. Geotechnical Aspects of Landfill Design**
*Prerequisite: CEE 445. I (3 credits)*
Introduction to landfill design (compacted clay and synthetic liners). Landfill slope and foundation stability analyses. Leachate collection system design including use of HELP Model. Landfill cover and gas venting systems. Case studies in vertical landfill expansion. Construction quality assurance and quality control of soil components and geosynthetic liners.

**CEE 550. Quality Control of Construction Materials**
*Prerequisite: CEE 351. II (3 credits)*
Construction material specification and test procedures. Sampling methods, data collection and statistical data distributions. Quality control charts, development of quality assurance specifications and acceptance plans. Examples

using data from actual field construction and laboratory experiments collected by destructive and non-destructive methods.

### CEE 551. Rehabilitation of Constructed Facilities
*Prerequisite: CEE 351. II (3 credits)*

Infrastructure needs. Rehabilitation studies of buildings, underground construction, bridges, streets, and highways. Types of distress; numerical condition surveys for foundation, structural, and functional deterioration; design criteria; materials and techniques; predictive performance models; evaluating alternatives; databases; maintenance management.

### CEE 552. Bituminous and Cement Mixes for Construction
*Prerequisite: CEE 351. II (3 credits)*

Types and properties of bituminous, Portland, and other cements used in construction. Natural and synthetic aggregate characteristics and uses. Compositions and properties of different mixtures used for highways, airports, parking areas, reservoir linings and other constructed facilities. Laboratory experiments with selected compositions.

### CEE 553. Advanced Concrete Materials
*Prerequisite: CEE 351. I (3 credits)*

Concrete components, microstructure, and properties of Portland cement pastes. Early heat of hydration and thermal stress development in concrete. Strength, fatigue, failure mechanisms, creep, shrinkage, and durability of hardened concrete. Special concretes: lightweight, heavy-weight, high strength, and ultra high strength.

### CEE 554 (Mfg 551). Materials in Engineering Design
*Prerequisite: CEE 351 or permission of instructor. II (3 credits)*

Integrated study of material properties, processing, performance, structure, cost and mechanics, as related to engineering design and material selection. Topics include design process, material properties and selection; scaling; materials database, processing and design, and optimization. Examples will be drawn from cement and ceramics, metals, polymers and composites.

### CEE 560. Digital Mapping and Geographical Information Systems
*Prerequisite: Math 215. II (3 credits)*

Maps as multiple representations and abstractions of reality and visualization. Digital representations. Databases/models. Principles and techniques of mapping, Geo-graphical Information Systems analysis and modeling. Integration of multi-source data, map updating. Errors in maps and Geographical Information Systems products. Applications in Civil/Environmental Engineering and Interdisciplinary Studies, e.g. global change studies and Intelligent Vehicle Highway Systems.

### CEE 570 (Nat. Res. 569). Introduction to Geostatistics
*Prerequisite: IOE 265 (statistics and probability) or equivalent. I (3 credits)*

Sampling design and data representativity. Univariate and bivariate data analysis: continuous and categorical environmental attributes. Description and modeling of spatial variability. Deterministic vs. stochastic models. Spatial interpolation of environmental attributes. Soil and water pollution data will be analyzed using geostatistical software.

### CEE 580. Physicochemical Processes in Environmental Engineering
*Prerequisite: CEE 460. II (3 credits)*

Physicochemical separated and transformation processes in natural and engineered environmental systems; process modeling; design of operations involving state and phase transformation; chemical oxidation, reduction, sorption, stripping, and exchange processes, membrane separations, particle aggregation and coagulation, sedimentation and filtration.

### CEE 581. Aquatic Chemistry
*Prerequisite: Chem 125. I, II (3 credits)*

Chemical principles applicable to the analysis of the chemical composition of natural waters and engineered water systems; chemistry of water purification technology and water pollution control; chemical processes which control the movement and fate of trace contaminants in aquatic environments including precipitation-dissolution, oxidation-reduction, adsorption-desorption, and complexation.

### CEE 582. Environmental Microbiology
*Prerequisite: Chem 130. I (3 credits)*

Discussion of basic microbial metabolic processes, thermodynamics of growth and energy generation, and genetic and metabolic diversity. Emphasis is placed on the application of these concepts to biogeochemical cycling, subsurface microbiology, wastewater microbiology, pollutant degradation, and microbial ecology.

### CEE 583. Surfaces and Interfaces in Aquatic Systems
*Prerequisite: CEE 581 or permission of instructor. II (3 credits)*

Introduction to the principles of surface and interfacial aquatic chemistry, surface complexation theory, and interfacial phenomena. Topics covered include capillarity, wetability, surface tension, contact angle, and surface active agents; surface-chemical aspects of adsorption, ion-exchange, and electrical double layer theory. Discussion of the effects of surfaces and interfaces on transformation reactions of aquatic pollutants.

### CEE 584 (EIH 667). Hazardous Waste Processes
*II (3 credits)*

The study of thermal, chemical and other systems and processes used in the detoxification of hazardous wastes, other than radioactive wastes.

### CEE 585. Solid Waste Management
*I (3 credits)*

The study of methods for managing the solid wastes generated by urban communities, evaluating alternatives and design of disposal facilities. Methods for minimizing adverse effects on the human health and environment are included.

### CEE 586. (Nat. Res. 557) Industrial Ecology
*Prerequisite: senior standing. II (3-4 credits)*

Analysis of material and energy flows in industrial systems to enhance eco-efficiency and sustainability. Methods: life cycle assessment quantifies energy, waste, emissions (greenhouse gases) for materials production, manufacturing, product use, recovery/disposition. Life cycle design integrate environmental, performance, economic, and regulatory objectives. Multi-objective analysis, engineering design analysis, cross-functional teamwork, large sea modeling skills.

### CEE 587 (Nat. Res. 558). Water Resource Policy
*Prerequisite: senior or graduate standing. I (3 credits)*

Consideration of policy processes associated with the development and utilization of water resources. Special attention is given to the history and development of policy related to water quality. Multi-objective planning is presented. Consideration of institutional problems associated with the implementation of water policy in the federal, state, regional, and local arenas.

### CEE 589 (Nat. Res. 595). Risk and Benefit Analysis in Environmental Engineering
*Prerequisite: senior or graduate standing. II (3 credits)*

Introduction to techniques of risk-benefit analysis as applied to water resources and environmental engineering. Techniques of multi-objective water resource planning. The engineering political interfaces; consideration of political bargaining and decision-making.

### CEE 590. Stream, Lake, and Estuary Analysis
*Prerequisite: CEE 460 or permission of instructor. II (3 credits)*

Development of mass balance equations for the characteristics and spatial and temporal distributions of contaminants in natural aquatic systems. Role of biochemical kinetics and mass transfer processes on oxygen resources in streams, lakes, and estuaries. Demonstration of case studies and applied problems.

**CEE 592. Biological Processes in Environmental Engineering**
*Prerequisite: CEE 460. II (3 credits)*
Theoretical principles, qualitative and quantitative description of suspended growth and biofilm processes, as applicable to wastewater treatment and the bioremediation of soils, sediments and groundwater. Bioremediation processes discussed include bioventing and biosparging, in situ intrinsic and enhanced bioremediation of chlorinated and nonchlorinated compounds.

**CEE 593. Environmental Soil Physics**
*Prerequisite: CEE 428 or CEE 445. II (3 credits)*
Principles of soil physics with emphasis on environmental problems. Topics include characteristics of solid, liquid and gaseous components of soil; capillarity, air entrapment and the static distribution of water in the unsaturated zone; infiltration, exfiltration and the redistribution of water. Extension of principles to movement of organic liquids in subsurface.

**CEE 594. Environmental Soil Chemistry**
*Prerequisite: CEE 581. II (3 credits)*
Introduction to the principles of soil chemistry. Topics covered include chemical composition of soils, chemical structure of minerals and soil organic matter, soil colloidal phenomena, sorption, ion-exchange, surface complexation theory, reactivity of soil constituents with inorganic and organic environmental contaminants. Emphasis on the relationship between chemical structure and reactivity.

**CEE 595. Field Methods in Hydrogeochemistry**
*Prerequisite: CEE 428. III (3 credits)*
Intensive field laboratory and lecture sessions providing hands-on experience in sampling and analysis of groundwater and aquifer materials for hydrogeologic and geochemical purposes. The course emphasizes field experimental design, execution and evaluation at actual sites of ground-water/soil contamination.

**CEE 599 (EIH 699). Hazardous Wastes: Regulation, Remediation, and Worker Protection**
*Prerequisite: graduate standing and EIH 503 or EIH 508 or EIH 541 or EIH 650 or EIH 667 or permission of instructor. (3 credits)*
Integration of information on current regulatory climate and governmental guidelines with case studies in hazardous wastes/substances. Case studies provide examples of hazardous waste and remedial actions, with emphasis on site worker exposure and protection, and community exposures to chemical and radiological agents. Lectures, problem-solving sessions, and guest speakers.

**CEE 611. Earthquake Engineering**
*Prerequisite: CEE 512, CEE 513, or equivalent. II alternate years (3 credits)*
Introduction to rational earthquake-resistant design. Topics: engineering characterization of earthquakes; inelastic dynamic analysis; performance-based earthquake-resistant design; structural system design considerations; modeling and analysis of buildings; and advanced seismic design topics. Lectures and independent projects.

**CEE 613. Metal Structural Members**
*Prerequisite: CEE 413. I alternate years (3 credits)*
Elastic and inelastic behavior of beams and columns. Torsion of open and box members. Combined bending and torsion. Buckling of beams and beam-columns. Frame buckling. Behavior of steel and aluminum structural members in studies with reference to their code design procedures.

**CEE 614. Advanced Prestressed Concrete**
*Prerequisite: CEE 514. I alternate years (3 credits)*
Prestressing in statically indeterminate structures: prestressed concrete slabs; analysis and design of partially prestressed concrete beams; nonlinear analysis; optimum design; members prestressed with unbonded tendons; external prestressing; prestressed tensile members; prestressing with FRPs. Special research and/or application related topics.

**CEE 615. Reinforced Concrete Members**
*Prerequisite: CEE 415. I alternate years (3 credits)*
Inelastic behavior of reinforced concrete beams, columns, and connections. Combined bending, shear, and torsion in beams. Use of strut and tie models. Behavior under load reversals, and development of appropriate hysteresis models.

**CEE 617 (Aero 615) (ME 649). Random Vibrations**
*Prerequisite: Math 425 or equivalent, CEE 513 or ME 541, (AM 541) or Aero 543 or equivalent. II alternate years (3 credits)*
Introduction to concepts of random vibration with applications in civil, mechanical, and aerospace engineering. Topics include: characterization of random processes and random fields, calculus of random processes, applications of random vibrations to linear dynamical systems, brief discussion on applications to nonlinear dynamical systems.

**CEE 622. Special Problems in Hydraulic Engineering or Hydrology**
*Prerequisite: permission of instructor. I, II (to be arranged)*
Assigned work on an individual basis. Problems of an advanced nature may be selected from a wide variety of topics.

**CEE 624. Free Surface Flow**
*Prerequisite: CEE 521. II (3 credits)*
Transient, incompressible flow in three space dimensions. Reynolds averaging and large eddy simulation of turbulent flows. Kinematic and dynamic conditions at air-water interfaces. Numerical solution by finite element and finite volume methods. Algorithms for locating a free surface. Applications to river, lake and estuary models.

**CEE 625 (Nat. Res. 624). Geostatistical Modeling of Uncertainty**
*Prerequisite: CEE 570. II (3 credits)*
Risk assessment: parametric and non-parametric approaches. Optimal estimates. Decision making in the face of uncertainty. Classification of categorical attributes. Stochastic spatial simulation: continuous and categorical environmental attributes. Propagation of uncertainty. Soil and water pollution data will be analyzed using geostatistical software.

**CEE 628. Numerical Modeling of Subsurface Flow**
*Prerequisite: CEE 528 or CEE 593 and Math 471. I (3 credits)*
Application of numerical solution methods, including finite differences, finite elements, boundary elements, and method of characteristics to various subsurface flow problems: saturated isothermal flow, solute transport, multiphase flow, geothermal reservoirs, use and modification of existing models in addition to new code development.

**CEE 630. Directed Studies in Construction Engineering**
*Prerequisite: graduate standing. I, II, IIIa, IIIb (1-3 credits)*
Selected reading in specific construction areas.

**CEE 631. Construction Decisions Under Uncertainty**
*Prerequisite: CEE 405 or a course in probability or statistics such as Stat 310 or Stat 311 or SMS 301. II (3 credits)*
Construction project and organization decisions for the uncertain future. Selection of construction method, equipment, contract, markup, and financing alternatives having the highest expected values. Uses decision theory, competitive bid analysis, probabilistic modeling and simulation, and multiple regression analysis in managing construction.

**CEE 633. Construction Management Information Systems**
*Prerequisite: CEE 531, preceded or accompanied by CEE 536. II (3 credits)*
Design of computerized construction management information systems (MIS). Students perform microcomputer database and spreadsheet programming to develop estimating, planning and scheduling, financial and cost accounting, and project control subsystems having common, integrated data structures.

Students implement subsystems as an integrated MIS which they apply to construction problems and case studies.

**CEE 645. Theoretical Soil Mechanics**
*Prerequisite: permission of instructor. (3 credits)*
Stress conditions for failure of soils; earth pressures and retaining walls; arching in soils; theories for elastic and plastic deformations of soil masses; theory of bearing capacity; theories for stresses in semi-infinite and layered elastic solids; theory of elastic subgrade reaction.

**CEE 646. Geophysical Techniques in Environmental Geotechnology**
*Prerequisite: CEE 445. II (3 credits)*
Introduction to geophysical techniques currently available for use in environmental geotechnology. Principles on which methods are based. Site characterization, pore fluid identification, buried object location by these non-intrusive, non-destructive tests. AI programming for selection of appropriate methods. Case studies in use of geophysical methods.

**CEE 648. Dynamics of Soils and Foundations**
*Prerequisite: CEE 445. II (3 credits)*
Transient and steady state vibrations of foundations; phase plane analysis of foundations with one and two degrees of freedom; dynamic properties of soils; vibration transmission through soils.

**CEE 649. Civil Engineering Vibrations Laboratory**
*Prerequisite: CEE 611, preceded or accompanied by CEE 648. II (2 credits)*
Field and laboratory determination of dynamic material properties; measurement of vibration of structures and foundations; introduction to electronics for dynamic measurements; introduction to holographic interferometry.

**CEE 650. Fracture and Micromechanics of Fibrous Composites**
*Prerequisite: permission of instructor. I (3 credits)*
Fracture mechanics fundamentals and micromechanics of cement, ceramic- and polmer-based fibrous composites. Topics include elastic crack mechanics, energy principles, interface mechanics; shear lag models; residual stress; non-alignment problems; first crack strength, steady state cracking and reliability; multiple cracking, bridging fracture energy; and R-curve behavior. Lectures and project.

**CEE 651. Directed Studies in Civil Engineering Materials**
*Prerequisite: graduate standing. I, II, IIIa, IIIb (1-3 credits)*
Individual studies in specific civil engineering materials areas.

**CEE 682. Special Problems in Environmental Engineering**
*Prerequisite: permission of instructor. I, II, IIIa, IIIb (to be arranged)*
Special problems designed to develop perspective and depth of comprehension in selected areas of sanitary, environmental or water resources engineering.

**CEE 687 (EIH 617). Special Problems in Solid Waste Engineering**
*Prerequisite: CEE 585 and permission of instructor; mandatory satisfactory/unsatisfactory. I, II, IIIa, IIIb (to be arranged)*
Application of principles presented in CEE 585 to engineering and environmental health problems in the collection and disposal of solid wastes; comprehensive analysis and report assigned on individual student basis.

**CEE 692. Biological and Chemical Degradation of Pollutants**
*Prerequisite: CEE 582 or permission of instructor. I (3 credits)*
Biological and chemical mechanisms and pathways of organic pollutant degradation under environmental conditions. Biological: substitution, elimination, redox reactions; enzyme participation. Chemical: substitution, elimination reactions, linear free-energy, applications. Pollutants include: aliphatic and aromatic compounds, both with and without halogen substituents.

**CEE 693. Environmental Molecular Biology**
*Prerequisite: CEE 592 or permission of instructor. I alternate years (3 credits)*
Principles and techniques of molecular biology with an emphasis on genetic analysis of enzymatic systems capable of pollutant degradation: Genetic systems and gene probing in unusual prokaryotes: Use of molecular biological techniques for the enumeration and characterization of natural microbial communities: Biochemistry and kinetics of enzymatic systems. Lectures and laboratory.

**CEE 810. Structural Engineering Seminar**
*I, II (to be arranged)*
Preparation and presentation of reports covering assigned topics.

**CEE 830. Construction Engineering and Management Seminar**
*I, II (to be arranged)*
Assigned reading and student reports on problems selected from the field of construction engineering and management.

**CEE 880. Seminar in Environmental and Water Resources Engineering**
*Prerequisite: none. I, II (to be arranged)*
Presentation and discussion of selected topics relating to environmental and water resources engineering. Student participation and guest lecturers.

**CEE 910. Structural Engineering Research**
*(to be arranged)*
Assigned work in structural engineering as approved by the professor of structural engineering. A wide range of subject matter is available, including laboratory and library studies.

**CEE 921. Hydraulic and Hydrological Engineering Research**
*Prerequisite: permission of instructor. I, II (to be arranged)*
Assigned work in hydraulic and hydrological research; a wide range of matter and method permissible.

**CEE 930. Construction Engineering Research**
*(to be arranged)*
Selected work from a wide range of construction engineering areas including planning, equipment, methods, estimating and costs.

**CEE 946. Soil Mechanics Research**
*(to be arranged)*
Advanced problems in soil mechanics, foundations or underground construction, selected to provide the student with knowledge of recent application and development in engineering design and construction practice. Assigned problems must be carried to a stage of completion sufficient for a written report which will normally be required for credit.

**CEE 950. Structural Materials Research**
*Prerequisite: permission of instructor. I, II (to be arranged)*
Topics dealing with mechanics and engineering of structural materials. Assigned reading and student reports.

**CEE 980. Research in Environmental Engineering**
*Prerequisite: permission of instructor. (to be arranged)*
A research study of some problems relating to water resource development and water supply, waste treatment and pollution control, or sanitation and environmental health; a wide range of both subject matter and method is available, including field investigations, laboratory experimentation, library and public record searches, and engineering design work.

**CEE 990. Dissertation/Pre-Candidate**
*I, II, IIIa, IIIb I, II (2-8 credits); IIIa, IIIb (1-4 credits)*
Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

## Civil and Environmental Engineering Faculty

Richard D. Woods, Ph.D., P.E., *Chair and Professor*

### Professors

Linda M. Abriola, Ph.D.
Michael J. Barcelona, Ph.D.
Jonathan W. Bulkley, Ph.D., P.E.; *also Natural Resources and Environment*
Robert I. Carr, Ph.D., P.E.
Subhash C. Goel, Ph.D., P.E.
Robert D. Hanson, Ph.D., P.E.
Roman D. Hryciw, Ph.D.
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Victor C. Li, Ph.D.
Radoslaw L. Michalowski, Ph.D.
Antoine E. Naaman, Ph.D.
Andrzej S. Nowak, Ph.D.
Walter Jacob Weber, Jr., Ph.D., P.E., *The Gordon M. Fair and Earnest Boyce Distinguished University Professor of Environmental Sciences and Engineering*
James Kenneth Wight, Ph.D., P.E.
Steven J. Wright, Ph.D., P.E.

### Adjunct Professors

Garrett H. Evans, M.S.E.(C.E.), P.E.
Charles J. Hurbis, B.S.E. (I.E.), J.D.

### Professors Emeritus

Glen Virgil Berg, Ph.D., P.E.
Ernest Frederick Brater, Ph.D., P.E., *Hydraulic Engineering*
Raymond P. Canale, Ph.D., P.E.
Donald E. Cleveland, Ph.D., P.E.
Donald Nathan Cortright, M.S.E., P.E.
Eugene Andrus Glysson, Ph.D., P.E.
Donald H. Gray, Ph.D.
Robert Blynn Harris, M.S.C.E., P.E.
Movses Jeremy Kaldjian, Ph.D., *also Naval Architecture and Marine Engineering*
Wadi Saliba Rumman, Ph.D.
Victor Lyle Streeter, Sc.D., P.E.
Egons Tons, Ph.D., P.E.
E. Benjamin Wylie, Ph.D., P.E.

### Associate Professors

Peter Adriaens, Ph.D.
Avery H. Demond, Ph.D., P.E.
Will Hansen, Ph.D.
Kim F. Hayes, Ph.D.
Photios G. Ioannou, Ph.D.
Terese M. Olson, Ph.D.

### Associate Professor Emeritus

John M. Armstrong, Ph.D.

### Assistant Professors

Kevin R. Collins, Ph.D.
Aline J. Cotel, Ph.D.
Pierre Goovaerts, Ph.D.
Gustavo Parra-Montesinos, Ph.D.
Jeremy D. Semrau, Ph.D.

### Lecturers

Rajendra K. Aggarwala, M.S.
John G. Everett, Ph.D., P.E.

### Associate Research Scientist

Richard C. Nolen-Hoeksema, Ph.D.

### Assistant Research Scientist

Andrei L. Barkovskii, Ph.D.
Jiasong Fang, Ph.D.
Maria M. Szerszen, Ph.D.

### Research Investigator

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## Civil and Environmental Engineering Contact Information

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Modern electrical engineering continues to be a broad and diverse field. The closely related area of computer science and engineering has arrived as a profession and rivals all engineering disciplines in its impact on society. The expanding roles of electrical engineers, computer engineers, and computer scientists in today's society reflect the variety and scope of these exciting professions. In recognition of the distinct qualifications required of engineers and scientists entering these fields, the Electrical Engineering and Computer Science department offers three undergraduate programs: the electrical engineering program leads to a Bachelor of Science in Engineering (Electrical Engineering)—B.S.E. (E.E.); the computer engineering program leads to a Bachelor of Science in Engineering (Computer Engineering)—B.S.E. (C.E.); the computer science program in the College of Engineerng leads to a B.S.E. (Computer Science)—B.S.E. (C.S.); and the Computer Science program in the College of LSA leads to a Bachelor of Arts or Bachelor of Science degree in Computer Science (please consult the LS&A *Bulletin* for information about completing a computer science degree in LSA).

Throughout each program, students work with modern laboratory equipment and computer systems and are exposed to the most recent analytical techniques and technological developments in their field. Students have many opportunities to associate with outstanding faculty, most of whom are actively engaged in research and/or professional consulting. Such interaction serves to acquaint students with the opportunities and rewards available to practicing electrical or computer engineers and scientists. Our students are encouraged to seek an advanced degree if further specialization and a higher degree of competence in a particular area is desired. The advanced degrees available are listed in the graduate section of Electrical Engineering and Computer Science on pages 218-221.

# Our Mission, Goals, Objectives and Outcomes for Undergraduate Education

## Computer Science

### *Mission*

To provide each student with a solid foundation in the science, engineering, and societal aspects of computing that prepares the student for a career that can advance the creation and application of computing technologies for the benefit of society.

### *Goal*

To educate students with core knowledge of the software, hardware, and theory of computing; to give each student in-depth knowledge in one or more computing areas; and to develop leaders in this field.

### *Objectives*

- To educate and train students in the principles and methods of computer science and engineering.
- To graduate students in a timely manner, who are well-equipped for positions in industry or continuing their education in graduate school.
- To develop the necessary skills for the design and implementation of computer systems and applications.
- To train students how to perform and validate experiments, including the collection of data and testing of theories.
- To develop skills for designing systems by working in teams, including effective oral and written communications.
- To instill an understanding of professional responsibilities, including ethics, and the need for life-long learning.

### *Outcomes*

The outcomes we desire are that our graduates demonstrate:

- An ability to apply knowledge of mathematics, science, and engineering.
- An ability to design and conduct experiments, as well as to analyze and interpret data.
- An ability to design, implement, test, and evaluate a computer system, component, or algorithm to meet desired needs.
- An ability to function on multi-disciplinary teams.
- An ability to identify, formulate, and solve computer science and engineering problems.
- An understanding of professional and ethical responsibility.
- An ability to communicate effectively.
- The broad education necessary to understand the impact of computer science and engineering solutions in a global and societal context.
- A recognition of the need for an ability to engage in life-long learning.
- A knowledge of contemporary issues.
- An ability to use the techniques, skills, and modern tools necessary for computer science and engineering practice.
- A knowledge of probability and statistics, including applications appropriate to computer science and engineering.
- A knowledge of mathematics through differential and integral calculus, basic sciences, and engineering sciences necessary to analyze and design complex computing systems, as appropriate to program objectives.
- A knowledge of advanced mathematics, typically including differential equations, linear algebra, and discrete mathematics.

## Computer Engineering

### *Mission*

To provide a solid technical foundation that prepares students for a career that can adapt to rapidly changing technology in computer engineering.

### *Goal*

To educate students with a broad and in-depth knowledge of computing systems, and to develop leaders in this field.

### *Objectives*

- To educate and train students in the principles and methods of computer engineering.
- To graduate students, in a timely manner, who are well-equipped for positions in industry or continuing their education in graduate school.
- To develop the necessary skills for both the design and implementation of computer systems, including general-purpose microprocessors, embedded computers, and networks of stationary or mobile computers, and associated applications.
- To train students how to perform and validate experiments, including the collection of data and testing of theories.
- To develop skills for designing systems by working in teams, including effective oral and written communications.
- To instill an understanding of professional responsibilities, including ethics, and the need for life-long learning.

### *Outcomes*

The outcomes we desire are that our graduates demonstrate:

- An ability to apply knowledge of mathematics, science, and engineering.
- An ability to design and conduct experiments, as well as to analyze and interpret data.
- An ability to design, implement, test, and evaluate a computer system, component, or algorithm to meet desired needs.
- An ability to function on multi-disciplinary teams.
- An ability to identify, formulate, and solve engineering problems.
- An understanding of professional and ethical responsibility.
- The broad education necessary to understand the impact of computer engineering solutions in a global and societal context.
- A recognition of the need for an ability to engage in life-long learning.
- A knowledge of contemporary issues.

• An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.
• A knowledge of probability and statistics, including applications appropriate to computer science and engineering.
• A knowledge of mathematics through differential and integral calculus, basic sciences, and engineering sciences necessary to analyze and design complex systems containing hardware and software components, as appropriate to program objectives.
•A knowledge of advanced mathematics, typically including differential equations, linear algebra, and discrete mathematics.

## Electrical Engineering

### *Mission*
To provide an outstanding education for engineers in electrical engineering and to develop future leaders.

### *Goal*
To provide students with the education for a rewarding and successful career.

### *Objectives*
• To educate and train students in the principles and methods of electrical engineering, including the mathematics and science required to analyze and solve problems;
• To graduate in a timely manner students for positions in industry and in graduate schools;
• To train students in the use of current laboratory equipment to perform experiments for gathering data and testing theories;
• To develop skills pertinent to design, including the ability to formulate problems, work in teams, and communicate effectively both orally and in writing;
• To instill an understanding of professional responsibilities, including ethics and the need for life-long learning.

### *Outcomes*
The outcomes that we desire are that our graduates demonstrate:
• An ability to apply knowledge of mathematics, science, and engineering;
• An ability to design and conduct experiments, as well as to analyze and interpret data;
• An ability to design a system, component, or process to meet desired needs;
• An ability to function on multi-disciplinary teams;
• An ability to identify, formulate, and solve engineering problems;
• An understanding of professional and ethical responsibility;
• An ability to communicate effectively;
• The broad education necessary to understand the impact of electrical engineering solutions in a global and societal context;
• A recognition of the need for an ability to engage in life-long learning;
• A knowledge of contemporary issues;
• An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice;
• Knowledge of probability and statistics, including applications appropriate to electrical engineering;
• Knowledge of mathematics through differential and integral calculus, basic sciences, and engineering sciences necessary to analyze and design complex devices and systems, containing hardware and software components, as appropriate to program objectives;
•A knowledge of advanced mathematics, typically including differential equations, linear algebra, complex variables, and discrete mathematics.

### Facilities
The departmental facilities include modern instructional and research laboratories in the areas of communications and signal processing, bioelectrical science, control systems, electro-magnetics, solid-state electronics, optical science, vehicular electronics, advanced computer architecture, computer vision and cognitive science, artificial intelligence, robotics, and software systems. Our instructional laboratory facilities provide student access to many types of digital computers, logic design modules, and modern instrumentation for the design of discrete analog and digital circuits and systems.

In addition, there are specialized facilities for communications, signal and image processing, integrated circuit and solid-state device fabrication, electro-magnetics and optics, VLSI design, distributed systems, computer vision, and artificial intelligence.

## Computer Science

Computer scientists are experts on the subject of computation, both in terms of the theory of what fundamental capabilities and limitations of computation are, as well as how computation can be practically realized and applied. A computer scientist understands how to design and analyze algorithms that apply computation effectively, how to store and retireve information effciently, how computers work to deliver computation, and how to develop software systems that solve complex problems. Specialists within computer science might have expertise in developing software applications, in designing computer hardware, or in analyzing algorithms, among many other current possibilities, and even more emerging specialities!

The *new* computer science (CS) program at the University of Michigan is available to students in both the Colleges of Engineering and of Literature, Science, and the Arts. The program requires students to have a solid foundation in computer software, hardware, and theory, but also gives a student ample opportunity to take advanced electives in areas of computer science such as databases, architecture, networks, artificial intelligence, and graphics, or in emerging interdisciplinary areas such as electronic commerce, web information systems, and computer game design.

## Computer Engineering

The program in Computer Engineering provides each student with a broad and well-integrated background in the concepts and methodologies that are needed for the analysis, design, and utilization of information processing systems. Although such systems are often popularly called "computers," they involve a far wider range of disciplines than merely computation, and the Computer Engineering Program is correspondingly broad. A set of required technical courses (along with the college-wide requirements) gives the essential material in electronic circuits and systems, digital logic, discrete mathematics, computer programming, data structures, and other topics. Following completion of this work, the student can select courses in a wide range of subject areas. These include operating systems, programming languages and compilers, database systems, software engineering, computer graphics, computer architecture, computer-aided design and VLSI, fault-tolerant computation, artificial intelligence, robotics, control engineering, and computer networking, among others. A broad selection from several areas is recommended for most undergraduate students. Specialization in particular areas is more typical of graduate programs of study.

This program is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

## Electrical Engineering

This program is designed to provide students with a fundamental background in the basic theoretical concepts and technological principles that constitute the foundations of modern electrical engineering and, at the same time, the opportunity to emphasize subject areas in which they have a particular interest. The curriculum requirements are flexible enough to allow students to design their academic program to achieve a variety of objectives, with the assistance and approval of a program advisor. Students may emphasize applied and experimental aspects of electrical engineering or concentrate on subjects requiring analytical or theoretical treatment.

Students are expected to pursue a basic coherent course of study. Programs, e.g. music, are also possible. Electives should be carefully planned in consultation with advisors so that the complete bachelor's program includes at least the equivalent of one term of engineering design.

This program is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

## Requirements

Candidates for the Bachelor of Science in Engineering degree (Computer Science)—B.S.E. (C.S.), the Bachelor of Science in Engineering (Computer Engineering)—B.S.E. (E.), and Bachelor of Science in Engineering (Electrical Engineering)—B.S.E. (E.E.) must complete the respective program which follows. These sample schedules are examples of programs leading to graduation in eight terms. Candidates for the Bachelor of Science or Bachelor of Arts degree in Computer Science through the College of Literature, Science, and the Arts should consult the LS&A Bulletin for degree requirements.

Up to 4 credit hours of independent study (EECS 499) may be used toward the EE degree.

## Sample Schedule B.S.E. Computer Science

| | Credit Hours | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| **Subjects required by all programs (55 hrs.)** | | | | | | | | | |
| Mathematics 115, 116, 215, and 216 | 16 | 4 | 4 | 4 | 4 | - | - | - | - |
| Intro to Composition or Engr 100 | 4 | - | 4 | - | - | - | - | - | - |
| Engr 101 | 4 | 4 | - | - | - | - | - | - | - |
| [1]Chemistry 125/130 or Chemistry 210/211 | 5 | 5 | - | - | - | - | - | - | - |
| Physics 140 with Lab 141; 240 with Lab 241 | 10 | - | 5 | 5 | - | - | - | - | - |
| Humanities and Social Sciences | 16 | 4 | 4 | - | - | 4 | - | 4 | - |
| **Program Subjects (28 hrs.)** | | | | | | | | | |
| EECS 203, Discrete Structures | 4 | - | - | 4 | - | - | - | - | - |
| EECS 280, Programming & Elem. Data Structures | 4 | - | - | 4 | - | - | - | - | - |
| EECS 281, Data Structures & Algorithms | 4 | - | - | - | 4 | - | - | - | - |
| EECS 370, Computer Organization | 4 | - | - | - | - | 4 | - | - | - |
| [2]EECS 401 or Math 425 or Stat 412 or IOE 265 | 3 | - | - | - | 3 | - | - | - | - |
| EECS 376, Foundations of Computer Science | 4 | - | - | - | - | - | 4 | - | - |
| Tech Com 281 | 1 | - | - | - | 1 | - | - | - | - |
| Tech Com 496/ EECS 496 | 4 | - | - | - | - | - | - | 4 | - |
| **Technical Electives (26 hrs.)** | | | | | | | | | |
| [3]Advanced CS Technical Electives | 10 | - | - | - | - | - | 4 | 4 | 2 |
| [4]Approved Technical Electives | 8 | - | - | - | - | - | - | - | 8 |
| [5]Flexible Technical Electives | 8 | - | - | - | - | 4 | 4 | - | - |
| **[6]Non-Computer Technical Electives (4 hrs.)** | 4 | - | - | - | - | - | - | 4 | - |
| **Free Electives (15 hrs.)** | 15 | - | - | - | 4 | 3 | 4 | - | 4 |
| **Total** | 128 | 17 | 17 | 17 | 16 | 15 | 16 | 16 | 14 |

**Notes:**

[1]Chemistry: Students who qualify are encouraged to take Chem. 210 (4 hrs.) & Chem. 211 (1 hr.) as a replacement for Chem. 130 (3 hrs.) & Chem. 125 (2 hrs.).

[2]Probability/Statistics Course: IOE 265 is a 4 credit course, if this course is elected the extra credit is counted toward free electives.

[3]Advanced CS Technical Electives: courses at the 400-level or higher in EECS that revolve around computing. A minimum of 2 credits must be part of the Major Design Experience requirement.

[4]Approved Technical Electives: see the Undergraduate Advising Office for a list of approved electives. Courses meeting the requirements of the Advanced CS Technical Electives may also be used to fulfill this requirement.

[5]Flexible Technical Electives: courses that satisfy the Approved Technical Electives category, CS courses at the 300-level or above, or other approved courses (see Undergraduate Advising Office for current list), typically, courses at the 200-level or higher that are required by a program/concentration in Engineering, Math or Science or additional CS courses at the 300-level or above.

[6]Non-Computer Technical Electives: a 200-level course required by another program in Engineering or any 300-level course in Engineering that does not revolve around computing.

No more that 4 hours of EECS 499, Directed Study, may be taken to fulfill the technical elective requirement.

Advanced CS Technical Electives: CS courses at the 400-level or higher. A CS course is any course that is cross listed between EECS (in Engineering) and CMPTRSC (in LSA). A minimum of 2 credits must be part of the Major Design Experience.

## Sample Schedule B.S.E. Computer Engineering

| | Credit Hours | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| **Subjects required by all programs (55 hrs.)** | | | | | | | | | |
| Mathematics 115, 116, 215, and 216 | 16 | 4 | 4 | 4 | 4 | - | - | - | - |
| Introductory Composition or Engr 100 | 4 | 4 | - | - | - | - | - | - | - |
| Engr 101 | 4 | - | 4 | - | - | - | - | - | - |
| [1]Chemistry 125/130 or Chemistry 210/211 | 5 | 5 | - | - | - | - | - | - | - |
| Physics 140 with Lab 141; 240 with Lab 241 | 10 | - | 5 | 5 | - | - | - | - | - |
| Humanities and Social Sciences | 16 | 4 | 4 | - | 4 | 4 | - | - | - |
| **Program Subjects (32 hrs.)** | | | | | | | | | |
| EECS 203, Discrete Structures | 4 | - | - | - | - | - | 4 | - | - |
| EECS 206, Signals and Systems | 4 | - | - | - | 4 | - | - | - | - |
| EECS 215, Circuits | 4 | - | - | - | 4 | - | - | - | - |
| EECS 270, Intro to Logic Design | 4 | - | - | 4 | - | - | - | - | - |
| EECS 280, Programming & Intro Data Structures | 4 | - | - | 4 | - | - | - | - | - |
| EECS 370, Intro to Computer Organization | 4 | - | - | - | - | - | 4 | - | - |
| EECS 401, Math 425 or Stat 412 | 3 | - | - | - | - | 3 | - | - | - |
| [2]Tech Com 215 or 281 | 1 | - | - | - | 1 | - | - | - | - |
| [3]Tech Com 496 | 2 | - | - | - | - | - | - | - | 2 |
| [4]EECS 496 | 2 | - | - | - | - | - | - | - | 2 |
| **Technical Electives (22 hrs.)** | | | | | | | | | |
| [5]Flexible Technical Electives | 4 | - | - | - | - | 4 | - | - | - |
| [6]Core Electives | 8 | - | - | - | - | - | 4 | 4 | - |
| [7]Upper Level Electives | 10 | - | - | - | - | - | - | 4 | 6 |
| **Non-Program Technical Electives (3 hrs.)** | 3 | - | - | - | - | - | - | 3 | - |
| **Free Electives (16 hrs.)** | 16 | - | - | - | - | 4 | 4 | 4 | 4 |
| **Total** | 128 | 17 | 17 | 17 | 17 | 15 | 16 | 15 | 14 |

**Notes:**

[1]Chemistry: Students who qualify are encouraged to take Chem. 210 (4 hrs.) & Chem 211 (1 hr.) as a replacement for Chem. 130 (3 hrs.) & Chem. 125 (2 hrs.).

[2]Tech Com 215 or 281: must be elected concurrently or after EECS 215 or concurrently with EECS 281.

[3]Tech Com 496/EECS 496: must be elected concurrently with a Major Design Experience course.

[4]Flexible Technical Elective: 4 credits of EECS coursework at the 200-level or above, excluding non-major courses.

[5]Core Electives: 8 credits from the following list: 281, 306, 312, 373.

[6]Upper Level Electives: 10 credits from the following list: 427*, 452*, 470*, 473*, 478, 482*, 483*, 489*, 499*. Must include at least one Major Design Experience course taken concurrently with EECS 496 and Tech Com 496 (MDE courses are indicated with an *).

[7]Non-Program Technical Electives: a 200-level course required by another program in Engineering or any 300-level course in Engineering.

No more than 4 hours of EECS 499, Directed Study, may be taken to fulfill the technical elective requirement.

## Sample Schedule
## B.S.E. Electrical Engineering

| | Credit Hours | Terms 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| **Subjects required by all programs (58 hrs.)** | | | | | | | | | |
| [1]Mathematics 115, 116, 216, and 215 | 16 | 4 | 4 | 4 | 4 | - | - | - | - |
| Introductory Composition or Engr 100 | 4 | 4 | - | - | - | - | - | - | - |
| Engr 101 | 4 | - | 4 | - | - | - | - | - | - |
| Chemistry 125/130 or Chemistry 210/211 | 5 | 5 | - | - | - | - | - | - | - |
| Physics 140 with Lab 141; Physics 240 (or 260) with Lab 241 | 10 | - | 5 | 5 | - | - | - | - | - |
| Humanities and Social Sciences | 16 | 4 | 4 | 4 | 4 | - | - | - | - |
| **Program Subjects (24 hrs.)** | | | | | | | | | |
| EECS 206, Signals and Systems | 4 | - | - | 4 | - | - | - | - | - |
| EECS 215, Circuits | 4 | - | - | - | 4 | - | - | - | - |
| EECS 230, Electromagnetics I | 4 | - | - | - | - | 4 | - | - | - |
| EECS 280, Prog and Elem Data Structures | 4 | - | - | - | 4 | - | - | - | - |
| EECS 320, Intro to Semiconductor Device Theory | 4 | - | - | - | - | 4 | - | - | - |
| EECS 401, Probabilistic Methods in Engineering | 4 | - | - | - | - | - | 4 | - | - |
| Tech Com 215, | 1 | - | - | - | 1 | - | - | - | - |
| Tech Com 496 | 2 | - | - | - | - | - | - | - | 2 |
| **Technical Electives (34 hrs.)** | | | | | | | | | |
| [2]Core Electives | 8 | - | - | - | - | 4 | 4 | - | - |
| [3]EECS Upper-Level Electives | 8 | - | - | - | - | - | - | 8 | - |
| [4]Major Design Experience | 4 | - | - | - | - | - | - | - | 4 |
| [5]Engineering Breadth Elective | 3 | - | - | - | - | 3 | - | - | - |
| [6]Flexible Technical Electives | 11 | - | - | - | - | - | 4 | 3 | 4 |
| **Free Electives (12 hrs.)** | 12 | - | - | - | - | - | 4 | 4 | 4 |
| **Total** | 128 | 17 | 17 | 17 | 17 | 15 | 16 | 15 | 14 |

**Notes:**

[1]EE students should take MATH 216 before MATH 215 since MATH 216 is a prerequisite for EECS 215.

[2]Core Electives: At least 8 credits from at least two categories: Systems (306), Circuits (311, 312), Electromagnetics/optics (330) or Computers (270, 370). (8 hours minimum)

[3]EECS Upper-Level Courses: Any 300-level or higher EECS course, must include at least one course at the 400-level or higher. (8 hours minimum)

[4]Major Design Experience: Pre-approved courses: EECS 411, 425, 427, 430, 438, 452, 470; other courses may be acceptable with prior approval of a Program Advisor. (4 hours minimum)

[5]Engineering Breadth Elective: One 300-level or higher Engineering course of 3 or more credits, offered *outside* the EECS department or an approved CS course. Selected 200-level courses are also acceptable. A list of approved courses is available in the EECS Advising Office. (3 hours minimum)

[6]Flexible Technical Electives: The remaining 11 hours of the technical elective requirement may be fulfilled by taking selected courses in EECS, other engineering departments, biology, business, chemistry, economics, math, or physics. A list of approved courses is available in the EECS Advising Office. All other courses must be approved by an EE program advisor.

Up to 4 credit hours of independent study (EECS 499) may be used toward the EE degree.

## Graduate Study Opportunities

A special CUGS (Concurrent Undergraduate-Graduate Status) program is available to students with at least a 3.60 grade point average (G.P.A.). See the Chief Program Advisor for details.

Students with at least a 3.4 G.P.A. in their technical course work and as an overall G.P.A. at the time of graduation can be admitted to EECS Masters Degree programs. See any Program Advisor for details.

## Electrical Engineering and Computer Science Course Listings

Course descriptions are found also on the College of Engineering web site at http://courses.engin.umich.edu/

**EECS 181 (CS 181). Introduction to Computer Systems**
*Prerequisite: none. I, II (4 credits)*
Fundamental computer skills needed to increase productivity. Use of software packages and applications including word processors, web browsers, spreadsheets, database systems. Creating a web home page. History of computing, ethics and legal issues. Introduction to basic hardware components. Intended for non CE/CS/EE majors whose goal is computer literacy.

**EECS 183 (CS 183). Elementary Programming Concepts**
*Prerequisite: none. (Credit for only one: EECS 183, Eng 101, Eng 103, or Eng 104.) I, II, IIIa (4 credits)*
Fundamental concepts and skills of programming in a high-level language. Flow of control: selection, iteration, subprograms. Data structures: strings, arrays, records, lists, tables. Algorithms using selection and iteration (decision making, finding maxima/minima, searching, sorting, simulation, etc.) Good program design, structure and style are emphasized. Testing and debugging. Not intended for Engineering students (who should take ENGR 101), nor for CS students in LSA who qualify to enter CMPTRSC 280.

**EECS 203 (CS 203). Discrete Structures**
*Prerequisite: Math 115. I, II (4 credits)*
Fundamental concepts of algebra; partially ordered sets, lattices, Boolean algebras, semigroups, rings, polynomial rings. Graphical representation of algebraic systems; graphs, directed graphs. Application of these concepts to various areas of computer engineering.

**EECS 206. Signals and Systems I**
*Prerequisite: Eng 101, Math 116. Can not receive credit for EECS 212/316 and 206. I, II (4 credits)*
Introduction to theory and practice of signals and systems engineering in continuous and discrete time. Hands-on experience with representative engineering tasks in laboratory sessions involving audio, images, and other signals. Time-domain concepts: energy, power, periodicity, filtering, linear system, convolution, correlation, detection, modulation, sampling, quantization, histogram. Frequency-domain concepts: sinusiods, exponentials, Fourier series, Fourier transform, frequency response. Ditigal processing of analog signals.

**EECS 211. Electrical Engineering II**
*Prerequisite: preceded by EECS 210, preceded or accompanied by Math 216, EECS 230 and EECS 270. I (4 credits)*
Introductory electrical engineering topics, continued: basic circuit analysis; elementary transistor and diode circuits. Equivalent transformations of electric circuits. Transient analysis of circuits. Introduction to diode and transistor

circuits. Amplifiers, limiters, filters and logic circuits. Laboratory experience with electrical signals and circuits.

**EECS 212. Signals and Systems**
*Prerequisite: EECS 210 and Math 216. I, II (4 credits)*
Basic linear system theory concepts and their use in analyzing signals and linear systems. Topics include: superposition; convolution and impulse response; Fourier series and transforms; Laplace transforms; transfer functions; Applications include: filtering; amplitude modulation; Nyquist sampling theorem; feedback control systems. Computational aspects of the material are illustrated through MATLAB exercises. Cannot recieve credit for EECS 212 and 316.

**EECS 215. Introduction to Circuits**
*Prerequisite: Math 116, PHYS 240 (or 260) Corequisute: Math 216, EECS 206. Can not receive credit for EECS 210 and 215. I, II, IIIa (4 credits)*
Introduction to electrical circuits. Kirchhoff's voltage and current laws; Ohm's law; voltage and current sources; Thevenin and Norton equivalent circuits; energy and power. Time-domain and frequency-domain analysis of RLC circuits. Operational amplifier circuits. Basic passive and active electronic filters. Laboratory experience with electrical signals and circuits.

**EECS 230. Electromagnetics I**
*Prerequisite: Math 215, PHYS 240 (or 260) and EECS 215. I (4 credits)*
Electric charge and current. Traveling waves and phasors. Transmission lines; sinusoidal analysis and transient response. Vector calculus. Electrostatics. Magnetostatics. Laboratory segment includes experiments with transmission lines, the use of computer-simulation exercises, and classroom demonstrations.

**EECS 250 (Nav Sci 202). Electronic Sensing Systems**
*Prerequisite: preceded or accompanied by EECS 230 or Physics 240. II (3 credits)*
Introduction to properties and behavior of electromagnetic energy as it pertains to naval applications of communication, radar, and electro-optics. Additional topics include sound navigation and ranging (SONAR) tracking and guidance systems, and computer controlled systems. Several laboratory demonstrations will illustrate applications of the theories and concepts learned in the classroom.

**EECS 270 (CS 270). Introduction to Logic Design**
*Prerequisite: EECS 183 or Eng 101 or equivalent. I, II, IIIa (4 credits)*
Binary and non-binary systems, Boolean algebra digital design techniques, logic gates, logic minimization, standard combinational circuits, sequential circuits, flip-flops, synthesis of synchronous sequential circuits, PLAs, ROMs, RAMs, arithmetic circuits, computer-aided design. Laboratory includes hardware design and CAD experiments.

**EECS 280 (CS 280). Programming and Introductory Data Structures**
*Prerequisite: Math 115 and prior programming experience. I, II (4 credits)*
Techniques and algorithm development and effective programming, top-down analysis, structured programming, testing, and program correctness. Program language syntax and static and runtime semantics. Scope, procedure instantiation, recursion, abstract data types, and parameter passing methods. Structured data types, pointers, linked data structures, stacks, queues, arrays, records, and trees.

**EECS 281 (CS 281). Data Structures and Algorithms**
*Prerequisite: EECS 203 and 280. I, II (4 credits)*
Introduction to algorithm analysis and O-notation; Fundamental data structures including lists, stacks, queues, priority queues, hash tables, binary trees, search trees, balanced trees and graphs; searching and sorting algorithms; basic graph algorithms; introduction to greedy algorithms and divide and conquer strategy. Several programming assignments.

**EECS 283 (CS 283). Programming for Science and Engineering**
*Prerequisite: EECS 183 or Eng 101 or equivalent. II (4 credits)*
Programming concepts with numeric applications for mathematics, the sciences, and engineering. Object-oriented programming, abstract data types, and standard class libraries with numeric and non-numeric applications. Elementary data structures, linked lists, and dynamic allocation. Searching and sorting methods. Not intended for CS majors.

**EECS 284 (CS 284). Introduction to a Programming Language or System**
*Prerequisite: some programming knowledge. I, II (1 credit)*
A minicourse covering a complex computer system or programming language. Specific languages or systems to be offered will be announced in advance.

**EECS 285 (CS 285). A Programming Language or Computer System**
*Prerequisite: some programming experience. I, II (2 credits)*
A course covering a complex computer system or programming language. Programming problems will be assigned. Specific languages or systems to be offered will be announced in advanced.

**EECS 306. Signals and Systems II**
*Prerequisite: EECS 206, 215 and Math 216. Can not receive credit for EECS 212/316 and 306. I, II (4 credits)*
Theory and practice of signals and systems engineering in continuous and discrete time. Hands-on experience in laboratory sessions with communications, control and signal processing. Continous-time linear systems: convolution, Fourier and Laplace transforms, transfer functions, poles and zeros, stability, sampling, introductions to communications and feedback control. Discrete-time linear systems: Z transform, filters, Fourier transform, signal processing. State space models of systems using finite-state machines.

**EECS 311. Electronics Circuits**
*Prerequisite: EECS 211 and EECS 230. I, II (4 credits)*
Circuit models for bipolar junction and field-effect transistors; nonlinear elements; small-signal and piecewise analysis of nonlinear circuits; analysis and design of basic single-stage transistor amplifiers: gain, biasing, and frequency response; digital logic circuits; memory circuits (RAM, ROM). Design projects. Lecture and laboratory.

**EECS 312. Digital Integrated Circuits**
*Prerequisite: EECS 215 and 320. II (4 credits)*
Design and analysis of static CMOS inverters and complex combinational logic gates. Dynamic logic families, pass-transistor logic, ratioed logic families. Sequential elements (latches, flip-flops). Bipolar-based logic; ECL, BiCMOS. Memories; SRAM, DRAM, EEPROM, PLA. I/O circuits and interconnect effects. Design project(s). Lecture, recitation and software labs.

**EECS 314. Circuit Analysis and Electronics**
*Prerequisite: Math 216, Physics 240; Not open to EE,CE, and engineering science students. A student can receive credit for only one: EECS 210, 215, 314. I, II, IIIa (4 credits)*
A survey of electrical and electronic circuits for students not in EE or CE. Formulation of circuit equations; equivalent circuits; frequency response ideas; steady-state and transient response; introduction to amplifiers; operational amplifiers; survey of electronic devices and circuits. Use of computer simulations for analysis of more advanced circuits.

**EECS 320. Introduction to Semiconductor Devices**
*Prerequisite: PHYS 240 or 260. I (4 credits)*
Introduction to semiconductors in terms of atomic bonding and electron energy bands. Equilibrium statistics of electrons and holes. Carrier dynamics; continu-

ity, drift, and diffusion currents; generation and recombination processes. Introduction to: PN junctions, metal-semiconductor junctions, bipolar junction transistors, junction and MOSFETs.

**EECS 330. Electromagnetics II**
*Prerequisite: EECS 230. I, II (4 credits)*
Time-varying electromagnetic fields and Maxwell's equations. Plane-wave propagation, reflection, and transmission. Geometric optics. Radiation and antennas. System applications of electromagnetic waves. Laboratory segment consists of experiments involving microwave and optical measurements and the design of practical systems.

**EECS 334. Principles of Optics**
*Prerequisite: EECS 330 or Physics 240. A student can receive credit for only one: EECS 334 or Physics 402. II (4 credits)*
Basic principles of optics: light sources and propagation of light; geometrical optics, lenses and imaging; ray tracing and lens aberrations; interference of light waves, coherent and incoherent light beams; Fresnel and Fraunhofer diffraction. Overview of modern optics with laboratory demonstrations.

**EECS 353. Introduction to Communications Systems**
*Prerequisite: EECS 212 or 316. II (4 credits)*
Mathematical analysis of signals and signal processing used in analog and digital communication systems; sampling; quantization; pulse transmission; intersymbol interference; Nyquist criterion; partial response signals; eye diagrams; equalization; mixing; analog modulation and demodulation; receiver architectures; phase-locked loops; signal-to-noise ratio analysis; digital modulation and demodulation; spread specturm communications.

**EECS 361. Automotive Electronic Systems**
*Prerequisite: EECS 212 or 316 or ME 360. II even years (3 credits)*
Theory and practice of electronic systems on automobiles. Detailed qualitative, quantitative, and performance analyses are made of automotive electronic systems including: digital engine/drivetrain control, instrumentation, vehicle multiplexing, diagnostics, suspension, steering, antilock braking/traction control, communication and safety subsystems.

**EECS 370 (CS 370). Introduction to Computer Organization**
*Prerequisite: EECS 280 or 283. I, II (4 credits)*
Basic concepts of computer organization and hardware. Instructions executed by a processor and how to use these instructions in simple assembly-language programs. Stored-program concept. Datapath and control for multiple implementations of a processor. Performance evaluation, pipelining, caches, virtual memory, input/output.

**EECS 373 (CS 373). Design of Microprocessor Based Systems**
*Prerequisite: EECS 270 and 370 and junior standing. I, II (4 credits)*
Principles of hardware and software microcomputer interfacing; digital logic design and implementation. Experiments with specially designed laboratory facilities. Introduction to digital development equipment and logic analyzers. Assembly language programming. Lecture and laboratory.

**EECS 376 (CS 376). Foundations of Computer Science**
*Prerequisite: EECS 203 or 280 or equivalent. I, II (4 credits)*
An introduction to computation theory: finite automata, regular languages, pushdown automata, context-free languages, Turing machines, recursive languages and functions, and computational complexity.

**EECS 398 (CS 398). Special Topics**
*Prerequisite: permission of instructor. (1-4 credits)*
Topics of current interest selected by the faculty. Lecture, seminar, or laboratory.

**EECS 401. Probabilistic Methods in Engineering**
*Prerequisite: EECS 206, 212 or 316 and junior standing. I, II (4 credits)*
Basic concepts of probability theory. Random variables: discrete, continuous, and conditional probability distributions; averages; independence. Introduction to discrete and continuous random processes: wide sense stationarity, correlation, spectral density.

**EECS 411. Microwave Circuits I**
*Prerequisite: EECS 330. I (4 credits)*
Transmission-line theory, microstrip and coplanar lines, S-parameters, signal-flow graphs, matching networks, directional couplers, low-pass and band-pass filters, diode detectors. Design, fabrication, and measurements (1-10GHz) of microwave-integrated circuits using CAD tools and network analyzers.

**EECS 413. Monolithic Amplifier Circuits**
*Prerequisite: EECS 311, EECS 320. I (4 credits)*
Analysis and design of BJT and MOS multi-transistor amplifiers. Feedback theory and application to feedback amplifiers. Stability considerations, pole-zero cancellation, root locus techniques in feedback amplifiers. Detailed analysis and design of BJT and MOS integrated operational amplifiers. Lectures and laboratory.

**EECS 415 (ME 424). Engineering Acoustics**
*Prerequisite: Math 216 and EECS 230 or Physics 240. II (3 credits)*
Vibrating systems; acoustic wave equation; plane and spherical waves in fluid media; reflection and transmission at interfaces; propagation in lossy media; radiation and reception of acoustic waves; pipes, cavities, and waveguides; resonators and filters; noise; selected topics in physiological, environmental and architectural acoustics.

**EECS 417 (BiomedE 417). Electrical Biophysics**
*Prerequisite: EECS 211 or EECS 314, preceded or accompanied by EECS 316. I (4 credits)*
Electrical biophysics of nerve and muscle; electrical conduction in excitable tissue; quantitative models for nerve and muscle, including the Hodgkin Huxley equations; biopotential mapping, cardiac electrophysiology, and functional electrical stimulation; group projects. Lecture and recitation.

**EECS 420. Introduction to Quantum Electronics**
*Prerequisite: EECS 320 and EECS 330 or equivalent. I (4 credits)*
Introduction to quantum mechanics of electrons and photons. Electrons in crystals. Metals, semiconductors and insulators. Effective mass, holes, valence and conduction band. Quantum wells, wires and dots. Tunneling effects and applications. Introduction to scattering theory. Charge transport, mobilities in semiconductors. Optical absorption and gain in semiconductors. Physical phenomena discussed in this course will be related to important microelectronic devices.

**EECS 421. Properties of Transistors**
*Prerequisite: EECS 230, EECS 320. I (3 credits)*
DC, small and large signal AC, switching and power-limiting characteristics, and derivation of equivalent circuit models of: PN junctions, metal-semiconductor and metal-insulator semiconductor diodes, bipolar junction transistors, junction and insulated-gate field-effect transistors, and thyristors.

**EECS 423. Solid-State Device Laboratory**
*Prerequisite: EECS 320. I (4 credits)*
Semiconductor material and device fabrication and evaluation: diodes, bipolar and field-effect transistors, passive components. Semiconductor processing techniques: oxidation, diffusion, deposition, etching, photolithography. Lecture and laboratory. Projects to design and simulate device fabrication sequence.

**EECS 425. Integrated Circuits Laboratory**
*Prerequisite: EECS 320, EECS 427. II (3 credits)*
Integrated circuit fabrication; mask design, photographic reduction; photoresist application, exposure, development, and etching; oxidation; diffusion; metal film deposition by evaporation and sputtering; die bonding, wire bonding, and encapsulation; testing of completed integrated circuits.

**EECS 427. VLSI Design I**
*Prerequisite: EECS 270 and EECS 311. I, II (4 credits)*

Design techniques for rapid implementations of very large-scale integrated (VLSI) circuits, MOS technology and logic. Structured design. Design rules, layout procedures. Design aids: layout, design rule checking, logic, and circuit simulation. Timing. Testability. Architectures for VLSI. Projects to develop and lay out circuits.

**EECS 429. Semiconductor Optoelectronic Devices**
*Prerequisite: EECS 320. II (4 credits)*
Materials for optoelectronics, optical processes in semiconductors, absorption and radiation, transition rates and carrier lifetime. Principles of LEDs, lasers, photodetectors, modulators and solar cells. Optoelectronic integrated circuits. Designs, demonstrations and projects related to optoelectronic device phenomena.

**EECS 430. Radiowave Propagation and Link Design**
*Prerequisite: EECS 330 and senior standing. II (4 credits)*
Fundamentals of electromagnetic wave propagation in the ionosphere, the troposphere, and near the Earth. Student teams will develop practical radio link designs and demonstrate critical technologies. Simple antennas, noise, diffraction, refraction, absorption, multi-path interference, and scattering are studied.

**EECS 432 (BioE 432). Fundamentals of Ultrasonics with Medical Applications.**
*Prerequisites: EECS 230. II (3 credits)*
Basic principles; waves, propagation, impedance, reflection, transmission, attenuation, power levels. Generation of ultrasonic waves; transducers, focusing, Fraunhofer and Fresnel zones. Instrumentation; display methods, Doppler techniques, signal processing. Medical applications will be emphasized.

**EECS 434. Principles of Photonics**
*Prerequisite: EECS 330 or EECS 334 or permission of instructor. I (4 credits)*
Introduction to photonics, opto-electronics, lasers and fiber-optics. Topics include mirrors, interferometers,modulators and propagation in waveguides and fibers. The second half treats photons in semiconductors, including semiconductor lasers, detectors and noise effects. System applications include fiber lightwave systems, ultra-high-peak power lasers, and display technologies.

**EECS 435. Fourier Optics**
*Prerequisite: EECS 212 or 316, preceded or accompanied by EECS 334. II odd years (3 credits)*
Basic physical optics treated from the viewpoint of Fourier analysis. Fourier-transform relations in optical systems. Theory of image formation and Fourier transformation by lenses. Frequency response of diffraction-limited and aberrated imaging systems. Coherent and incoherent light. Comparison of imagery with coherent and with incoherent light. Resolution limitations. Optical information processing, including spatial matched filtering.

**EECS 438. Advanced Lasers and Optics Laboratory**
*Prerequisite: EECS 334 or EECS 434. II (4 credits)*
Construction and design of lasers; gaussian beams; nonlinear optics; fiber optics; detectors; dispersion; Fourier optics; spectroscopy. Project requires the design and set-up of a practical optical system.

**EECS 442 (CS 442). Computer Vision**
*Prerequisite: EECS 281. I (4 credits)*
Computational methods for the recovery, representation, and application of visual information. Topics from image formation, binary images, digital geometry, similarity and dissimilarity detection, matching, curve and surface fitting, constraint propagation relaxation labeling, stereo, shading texture, object representation and recognition, dynamic scene analysis, and knowledge based techniques. Hardware, software techniques.

**EECS 450 (NR 543). Imaging Radar as a Remote Sensor**
*Prerequisite: NR 541 or permission of instructor. II (3 credits)*
Descriptive treatment of imaging radar systems, theoretical and operational performance and limitations, reflection from terrestrial and vegetal surfaces, interpretation of imagery; application to topics of student's interest (e.g., geology, oceanography, forestry). Special topics include holographic radar, passive microwave systems, synthetic aperture radar, and imaging sonar.

**EECS 451. Digital Signal Processing and Analysis**
*Prerequisite: EECS 212, 306 or 316. I, II, IIIa (4 credits)*
Introduction to digital signal processing of continuous and discrete signals. The family of Fourier Transforms including the Discrete Fourier Transform (DFT). Development of the Fast Fourier Transform (FFT). Signal sampling and reconstruction. Design and analysis of digital filters. Correlation and spectral estimation. Laboratory experiences exercise and illustrate the concepts presented.

**EECS 452. Digital Signal Processing Design Laboratory**
*Prerequisite: preceded or accompanied by EECS 451. I, II (4 credits)*
Architectural features of single-chip DSP processors are introduced in lecture. Laboratory exercises using two different state-of-the-art fixed-point processors include sampling, A/D and D/A conversion, digital wave form generators, real-time FIR and IIR filter implementations. The central component of this course is a 12-week team project in real-time DSP Design (including software and hardware development).

**EECS 455. Digital Communication Signals and Systems**
*Prerequisite: EECS 212 or 316, EECS 401. I (3 credits)*
Digital transmission techniques in data communications, with application to computer and space communications; design and detection of digital signals for low error rate; forward and feedback transmission techniques; matched filters; modems, block and convolutional coding; Viterbi decoding.

**EECS 458 (BiomedE 458). Biomedical Instrumentation and Design**
*Prerequisite: EECS 215, 314 or consent of instructor. II (4 credits)*
Measurement and analysis of biopotentials and biomedical transducer characteristics; electrical safety; applications of FETs, integrated circuits, operational amplifiers for signal processing and computer interfacing; signal analysis and display on the laboratory minicomputer. Lectures and laboratory.

**EECS 459 Advanced Electronic Instrumentation**
*Prerequisite: EECS 360 or EECS 359 or EECS 453 or EECS 458. II, odd years (3 credits)*
Systematic design of optimum measuring instruments which give maximum confidence in results. Analog and digital signal processing, transducer modeling. A/D and D/A conversion, survey of modern instrumentation components.

**EECS 460. Control Systems Analysis and Design**
*Prerequisite: EECS 212 or 316. I (3 credits)*
Basic techniques for analysis and design of controllers applicable in any industry (e.g. automotive, aerospace, semiconductor, bioengineering, power, etc.) are discussed. Both time- and frequency-domain methods are covered. Root locus, Nyquist stability criterion, and Bode plot-based techniques are used as tools for analysis and design.

**EECS 470 (CS 470). Computer Architecture**
*Prerequisite: EECS 370. I, II (4 credits)*
Basic concepts of computer architecture and organization. Computer evolution. Design methodology. Performance evaluation. Elementary queueing models. CPU architecture. Introduction sets. ALU design. Hardware and micro-programmed control. Nanoprogramming. Memory hierarchies. Virtual memory. Cache design. Input-output architectures. Interrupts and DMA. I/O processors. Parallel processing. Pipelined processors. Multiprocessors.

**EECS 473 (CS 473). Advanced Digital System Design**
*Prerequisite: EECS 373 or permission of instructor. II (3 credits)*
This course introduces advanced digital system design concepts, such as timing analysis, reliability, and testability. These concepts are then applied to a

semester-long design project of the student's choice. The result of this project will be a highly testable, highly reliable digital system.

**EECS 477 (CS 477). Introduction to Algorithms**
*Prerequisite: EECS 281. I (4 credits)*
Fundamental techniques for designing efficient algorithms and basic mathematical methods for analyzing their performance. Paradigms for algorithm design: divide-and-conquer, greedy methods, graph search techniques, dynamic programming. Design of efficient data structures and analysis of the running time and space requirements of algorithms in the worst and average cases.

**EECS 478 (CS 478). Logic Circuit Synthesis and Optimization**
*Prerequisite: EECS 203, EECS 270, and senior or graduate standing. I, II (4 credits)*
Advanced design of logic circuits. Technology constraints. Theoretical foundations. Computer-aided design algorithms. Two-level and multilevel optimization of combinational circuits. Optimization of finite-state machines. High-level synthesis techniques: modeling, scheduling, and binding. Verification and testing.

**EECS 481 (CS 481). Software Engineering**
*Prerequisite: EECS 281. I, II (4 credits)*
Pragmatic aspects of the production of software systems, dealing with structuring principles, design methodologies and informal analysis. Emphasis is given to development of large, complex software systems. A term project is usually required.

**EECS 482 (CS 482). Introduction to Operating Systems**
*Prerequisite: EECS 281, EECS 370. I, II (4 credits)*
Operating system design and implementation: multi-tasking; concurrency and synchronization; inter-process communication; deadlock; scheduling; resource allocation; memory and storage management; input-output; file systems; protection and security. Students write several substantial programs dealing with concurrency and synchronization in a multi-task environment, with file systems, and with memory management.

**EECS 483 (CS 483). Compiler Construction**
*Prerequisite: EECS 281, EECS 376. I, II (4 credits)*
Introduction to compiling techniques including parsing algorithms, semantic processing and optimization. Students implement a compiler for a substantial programming language using a compiler generating system.

**EECS 484 (CS 484). Database Management Systems**
*Prerequisite: EECS 281. I, II (4 credits)*
Concepts and methods for the design, creation, query and management of large enterprise databases. Functions and characteristics of the leading database management systems. Query languages such as SQL, forms, embedded SQL, and application development tools. Database design, integrity, normalization, access methods, query optimization, transaction management and concurrency control and recovery.

**EECS 485 (CS 485). Web Database and Information Systems**
*Prerequisites: EECS 484 or permission of instructor. II (4 credits)*
Design and use of databases in the Web context; data models, database design, replication issues, client/server systems, information retrieval, web server design; substantial project involving the development of a database-backed web site.

**EECS 486 (CS 486). Object-Oriented Software Development**
*Prerequisite: EECS 281. II (4 credits)*
Object-based programming concepts such as data and program abstraction, encapsulation, polymorphism, single and multiple inheritance, and reusable objects. Techniques for object-oriented system decomposition and class design. Study and use of class libraries and application frameworks. Programming projects in an object-oriented language currently standard in industry.

**EECS 487 (CS 487). Interactive Computer Graphics**
*Prerequisite: EECS 281 and senior standing. I, II (4 credits)*
Computer graphics hardware, line drawing, rasterization, anti-aliasing, graphical user interface (GUI), affine geometry, projective geometry, geometric transformation, polygons, curves, splines, solid models, lighting and shading, image rendering, ray tracing, radiosity, hidden surface removal, texture mapping, animation, virtual reality, and scientific visualization.

**EECS 489 (CS 489). Computer Networks**
*Prerequisite: EECS 482. I, II (4 credits)*
Protocols and architectures of computer networks. Topics include client-server computing, socket programming, naming and addressing, media access protocols, routing and transport protocols, flow and congestion control, and other application-specific protocols. Emphasis is placed on understanding protocol design principles. Programming problems to explore design choices and actual implementation issues assigned.

**EECS 492 (CS 492). Introduction to Artificial Intelligence**
*Prerequisite: EECS 281. I, II (4 credits)*
Fundamental concepts of AI, organized around the task of building computational agents. Core topics include search, logic, representation and reasoning, automated planning, decision making under uncertainty, and machine learning.

**EECS 493 (CS 493). User Interface Development**
*Prerequisite: EECS 281. I (4 credits)*
Concepts and techniques for designing computer system user interfaces to be easy to learn and use, with an introduction to their implementation. Task analysis, design of functionality, display and interaction design, and usability evaluation. Interface programming using an object-oriented application framework. Fluency in a standard object-oriented programming language is assumed.

**EECS 494 (CS 494). Computer Game Design and Development**
*Prerequisite: EECS 281. I (4 credits)*
Concepts and methods for the design and development of computer games. Topics include: history of games, 2D graphics and animation, sprites, 3D animation, binary space partition trees, software engineering, game design, interactive fiction, user interfaces, artificial intelligence, game SDK's, networking, multi-player games, game development environments, commercialization of software.

**EECS 496 (CS 496). Capstone Design Course in Computing**
*Prerequisite: none. I, II (2 credits)*
Capstone design course for seniors in computer science or computer engineering. Design principles for multidisciplinary team projects, team strategies, entrepreneurial skills, ethics, social and environmental awareness. Each student must take (simultaneously) Tech Com 496 (2 cr.) and one of the approved 400-level team project courses in computing (2-4 cr.).

**EECS 497 (CS 497). EECS Major Design Projects**
*Prerequisite: senior standing and successful completion of at least two-thirds of the credit hours required for the program subjects. A student may select this course more than once ONLY with the explicit approval of the Chief Program Advisor. I, II (4 credits)*
Professional problem-solving methods developed through intensive group studies. Normally one significant design project is chosen for entire class requiring multiple EECS disciplines and teams. Use of analytic, computer, design, and experimental techniques where applicable are used. Projects are often interdisciplinary allowing non-EECS seniors to also take the course (consult with instructor).

**EECS 498 (CS 498). Special Topics**
*Prerequisite: permission of instructor. (1-4 credits)*
Topics of current interest selected by the faculty. Lecture, seminar or laboratory.

**EECS 499 (CS 499). Directed Study**
*Prerequisite: senior standing in EECS. I, II, III (1-4 credits)*
Individual study of selected topics in Electrical Engineering and Computer Science. May include experimental investigation or library research. Primarily for undergraduates.

**EECS 500. Tutorial Lecture Series in System Science**
*Prerequisite: graduate standing; mandatory satisfactory/ unsatisfactory. I, II (1 credit)*
Students are introduced to the frontiers of System Science research. Sections 01, 02, and 03 are devoted, respectively, to Communications, Control, and Signal Processing. The tutorials are delivered by leaders of the respective research fields, invited from academia and industry. The presentations are self-contained and accessible to all graduate students in System Science.

**EECS 501 (Aero 552). Probability and Random Processes**
*Prerequisite: EECS 401 or graduate standing. I, II (4 credits)*
Introduction to probability and random processes. Topics include probability axioms, sigma algebras, random vectors, expectation, probability distributions and densities, Poisson and Wiener processes, stationary processes, autocorrelation, spectral density, effects of filtering, linear least-squares estimation, and convergence of random sequences.

**EECS 502. Stochastic Processes**
*Prerequisite: EECS 501. II odd years (3 credits)*
Correlations and spectra. Quadratic mean calculus, including stochastic integrals and representations, wide-sense stationary processes (filtering, white noise, sampling, time averages, moving averages, autoregression). Renewal and regenerative processes, Markov chains, random walk and run, branching processing, Markov jump processes, uniformization, reversibility, and queueing applications.

**EECS 503. Introduction to Numerical Electromagnetics**
*Prerequisite: EECS 330. I (3 credits)*
Introduction to numerical methods in electromagnetics including finite difference, finite element and integral equation methods for static, harmonic and time dependent fields; use of commercial software for analysis and design purposes; applications to open and shielded transmission lines, antennas, cavity resonances and scattering.

**EECS 506 (CS 506). Computing System Evaluation**
*Prerequisite: EECS 183 or EECS 280, and EECS 370, EECS 501. II odd years (3 credits)*
Theory and application of analytic methods for evaluating the performance and reliability of computing systems. Measures of performance, reliability, and performability. Reliability evaluation: classification and representation of faults, stochastic process models, coherent systems. Performance evaluation: Markovian queueing models, networks of queues. Unified performance-reliability evaluation.

**EECS 509 (IOE 517). Traffic Modeling**
*Prerequisite: IOE 316, Stat 310, or EECS 401. I alternate years (3 credits)*
Traffic Models and their analysis in the context of ITS (Intelligent Transportation Systems). Those aspects of traffic theory relevant to ITS are presented including traffic flow and signalized intersections, with particular emphasis on the optimization via route guidance and signal control of large scale traffic networks.

**EECS 510. Intelligent Transportation Systems Research Topics**
*Prerequisite: two ITS-Certificate courses (may be taken concurrently). II (2 credits)*
Topics include driver-highway interactions (traffic modeling, analysis and simulation), driver-vehicle interactions (human factors), vehicle-highway interactions (computer/communications systems architecture), collision prevention, ITS technologies (in-vehicle electronic sensors, etc.), socioeconomic aspects (user acceptance and liability), and system integration (comprehensive modeling and competitive strategy).

**EECS 512. Amorphous and Micro stayalline Semiconductor Thin Film Devices**
*Prerequisite: EECS 421 and/or permission of instructor. I (3 credits)*
Introduction and fundamentals of physical, optical and electrical properties of amorphous and microcrystalline semiconductor based devices: MIM structures, Schottky diodes, p-i-n junctions, heterojunctions, MIS structures, thin-film transistors, solar cells, threshold and memory switching devices and large area x-ray radiation detectors.

**EECS 513. Flat Panel Displays**
*Prerequisite: EECS 423, EECS 512 and/or permission of instructor. II (3 credits)*
Introduction and fundamentals to the passive, active, reflective and emissive flat panel display technologies. This course will discuss the physics, operating principles, properties and technology of the flat panel displays.

**EECS 516 (Bio E 516). Medical Imaging Systems**
*Prerequisite: EECS 451. I (3 credits)*
Principles of modern medical imaging systems. For each modality the basic physics is described, leading to a systems model of the imager. Fundamental similarities between the imaging equations of different modalities will be stressed. Modalities covered include radiography, x-ray computed tomography (CT), NMR imaging (MRI) and real-time ultra-sound.

**EECS 517 (NERS 578). Physical Processes in Plasmas**
*Prerequisite: EECS 330. II even years (3 credits)*
Plasma physics applied to electrical gas discharges used for material processing. Gas kinetics; atomic collisions; transport coefficients; drift and diffusion; sheaths; Boltzmann distribution function calculation; plasma simulation; plasma diagnostics by particle probes, spectroscopy, and electromagnetic waves; analysis of commonly used plasma tools for materials processing.

**EECS 518 (AOSS 595). Magnetosphere and Solar Wind**
*Prerequisite: graduate standing. I, even years (3 credits)*
General principles of magnetohydrodynamics; theory of the expanding atmospheres; properties of solar wind, interaction of solar wind with the magnetosphere of the Earth and other planets; bow shock and magnetotail, trapped particles, auroras.

**EECS 519 (NERS 575). Plasma Generation and Diagnostics Laboratory**
*Prerequisite: preceded or accompanied by a course covering electromagnetism. II (3 credits)*
Laboratory techniques for plasma ionization and diagnosis relevant to plasma processing, propulsion, vacuum electronics, and fusion. Plasma generation includes: high voltage-DC, radio frequency, and electron beam sustained discharges. Diagnostics include: Langmuir probes, microwave cavity perturbation, microwave interferometry, laser schlieren, and optical emission spectroscopy. Plasma parameters measured are: electron/ion density and electron temperature.

**EECS 520. Electronic and Optical Properties of Semiconductors**
*Prerequisite: EECS 420 or EECS 540. II (4 credits)*
The course discusses in detail the theory behind important semiconductor-based experiments such as Hall effect and Hall mobility measurement; velocity-field measurement; photoluminescence; gain; pump-probe studies; pressure and strain-dependent studies. Theory will cover: Bandstructure in quantum wells; effect of strain on bandstructure; transport theory; Monte Carlo methods for high field transport; excitons, optical absorption, luminescence and gain.

**EECS 521. High-Speed Transistors**
*Prerequisite: EECS 421 or EECS 422. II (3 credits)*
Detailed theory of high-speed digital and high-frequency analog transistors. Carrier injection and control mechanisms. Limits to miniaturization of conven-

tional transistor concepts. Novel submicron transistors including MESFET, heterojunction and quasi-ballistic transistor concepts.

**EECS 522. Analog Integrated Circuits**
*Prerequisite: EECS 413. II (4 credits)*
Review of integrated circuit fabrication technologies and BJT and MOS transistor models. Detailed analysis and design of analog integrated circuits, including power amplifiers, voltage references, voltage regulators, rectifiers, oscillators, multipliers, mixers, phase detectors, and phase-locked loops. Design projects. Lectures and discussion.

**EECS 523. Digital Integrated Technology**
*Prerequisite: EECS 311 and EECS 320 and EECS 423 or 425. I (4 credits)*
Device technologies for LSI circuits. Approaches to logic implementation, including gate arrays, master-slices, PLAs. Non-volatile semiconductor memory structures, including ROM, PROM, EPROM, and EAROM. Static and dynamic random access memory and microcomputers. Relationship of terminal performance to the design, layout, and fabrication techniques used. Circuit layout and computer simulation.

**EECS 524. Field-Effect-Transistors and Microwave Monolithic Integrated Circuits Technology**
*Prerequisite: graduate standing and EECS 421, and either EECS 525 or EECS 528. II even years (3 credits)*
Physical and electrical properties of III-V materials, epitaxy and ion-implantation, GaAs and InP based devices (MESFETs, HEMTs varactors) and Microwave Monolithic Integrated Circuits (MMICs). Cleaning, Photolithography, metal and dielectric deposition, wet and dry etching. Device isolation, ohmic and Schottky contacts, dielectrics, passive component technology, interconnects, via holes, dicing and mounting. Study of the above processes by DC characterization.

**EECS 525. Advanced Solid State Microwave Circuits**
*Prerequisite: EECS 411, EECS 421 or EECS 521. I (3 credits)*
General properties and design of linear and nonlinear solid state microwave circuits including: amplifier gain blocks, low-noise, broadband and power amplifiers, oscillators, mixer and multiplier circuits, packaging, system implementation for wireless communication.

**EECS 526. High-Performance Dynamic Device Models and Circuits**
*Prerequisite: EECS 413, or both EECS 311 and EECS 320. II (4 credits)*
Models for devices (BJTs, FETs, and integrated circuits), with primary emphasis on large-signal dynamic charge-control models. Mathematics and physics fundamentals for measurement concepts and methods. Mathematical and computer analysis and design of high-speed dynamic circuits. Dynamic circuit functional blocks, level detection/comparison circuits; sweep/ramp, multivibrator, and logic gate circuits.

**EECS 527. Layout Synthesis and Optimization**
*Prerequisite: EECS 478. II (3 credits)*
Theory of circuit layout partitioning and placement algorithms. Routing algorithms, parallel design automation on shared memory and distributed memory multi-processors, simulated annealing and other optimization techniques and their applications in CAD, layout transformation and compaction, fault-repair algorithms for RAMs and PLAs hardware synthesis from behavioral modeling, artificial intelligence-based CAD.

**EECS 528. Principles of Microelectronics Process Technology**
*Prerequisite: EECS 421, EECS 423. II (3 credits)*
Theoretical analysis of the chemistry and physics of process technologies used in micro-electronics fabrication. Topics include: semiconductor growth, material characterization, lithography tools, photo-resist models, thin film deposition, chemical etching, plasma etching, electrical contact formation, microstructure processing, and process modeling.

**EECS 529. Semiconductor Lasers and LEDs**
*Prerequisite: EECS 429. I (3 credits)*
Optical processes in semiconductors, spontaneous emission, absorption gain, stimulated emission. Principles of light-emitting diodes, including transient effects, spectral and spatial radiation fields. Principles of semiconducting lasers; gain-current relationships, radiation fields, optical confinement and transient effects.

**EECS 530 (Appl Phys 530). Electromagnetic Theory I**
*Prerequisite: EECS 330 or Physics 438. I (3 credits)*
Maxwell's equations, constitutive relations and boundary conditions. Potentials and the representation of electromagnetic fields. Uniqueness, duality, equivalence, reciprocity and Babinet's theorems. Plane, cylindrical, and spherical waves. Waveguides and elementary antennas. The limiting case of electro- and magneto-statics.

**EECS 531. Antenna Theory and Design**
*Prerequisite: EECS 330. II (3 credits)*
Theory of transmitting and receiving antennas. Reciprocity. Wire antennas: dipoles, loops and traveling-wave antennas. Analysis and synthesis of linear arrays. Phased arrays. Input impedance and method of moments. Mutual impedance. Aperture antennas: slot, Babinet's principle. Microstrip antennas. Horns, reflector and lens antennas.

**EECS 532. Microwave Remote Sensing I: Radiometry**
*Prerequisite: EECS 330, graduate standing. I odd years (3 credits)*
Radiative transfer theory: blackbody radiation; microwave radiometry; atmospheric propagation and emission; radiometer receivers; surface and volume scattering and emission; applications to meteorology, oceanography, and hydrology.

**EECS 533. Microwave Measurements Laboratory**
*Prerequisite: EECS 330, graduate standing. II (3 credits)*
Advanced topics in microwave measurements: power spectrum and noise measurement, introduction to state-of-the-art microwave test equipment, methods for measuring the dielectric constant of materials, polarimetric radar cross section measurements, near field antenna pattern measurements, electromagnetic emission measurement (EM compatibility). Followed by a project that will include design, analysis, and construction of a microwave subsystem.

**EECS 534. Design and Characterization of Microwave Devices and Monolithic Circuits**
*Prerequisite: graduate standing, EECS 421 or EECS 525. I odd years (4 credits)*
Theory and design of passive and active microwave components and monolithic integrated circuits including: microstrip, lumped inductors and capacitors, GaAs FETs, varactor and mixer diodes, monolithic phase shifters, attenuators, amplifiers and oscillators. Experimental characterization of the above components using network analyzer, spectrum analyzer, power and noise meters. Lecture and laboratory.

**EECS 535. Optical Information Processing**
*Prerequisite: EECS 334. I even years (3 credits)*
Theory of image formation with holography; applications of holography; white light interferometry; techniques for optical digital computing; special topics of current research interest.

**EECS 536. Classical Statistical Optics**
*Prerequisite: EECS 334 or EECS 434, and EECS 401 or Math 425. I odd years (3 credits)*
Applications of random variables to optics; statistical properties of light waves. Coherence theory, spatial and temporal. Information retrieval; imaging through inhomogeneous media; noise processes in imaging and interferometric systems.

**EECS 537 (Appl Phys 537). Classical Optics**
*Prerequisite: EECS 330 and EECS 334. I (3 credits)*

Theory of electromagnetic, physical, and geometrical optics. Classical theory of dispersion. Linear response, Kramers-Kronig relations, and pulse propagation. Light scattering. Geometrical optics and propagation in inhomogeneous media. Dielectric waveguides. Interferometry and theory of coherence. Diffraction, Fresnel and Fraunhofer. Gaussian beams and ABCD law.

### EECS 538 (Appl Phys 550) (Physics 650). Optical Waves in Crystals

*Prerequisite: EECS 434. I (3 credits)*

Propagation of laser beams: Gaussian wave optics and the ABCD law. Manipulation of light by electrical, acoustical waves; crystal properties and the dielectric tensor; electro-optic, acousto-optic effects and devices. Introduction to nonlinear optics; harmonic generation, optical rectification, four-wave mixing, self-focusing, and self-phase modulation.

### EECS 539 (Appl Phys 551) (Physics 651). Lasers

*Prerequisite: EECS 537 and EECS 538. II (3 credits)*

Complete study of laser operation: the atom-field interaction; homogeneous and inhomogeneous broadening mechanisms; atomic rate equations; gain and saturation; laser oscillation; laser resonators, modes, and cavity equations; cavity modes; laser dynamics, Q-switching adn modelocking. Special topics such as femto-seconds lasers and ultrahigh power lasers.

### EECS 540 (Appl Phys 540). Applied Quantum Mechanics I

*Prerequisite: permission of instructor. I (3 credits)*

Introduction to nonrelativistic quantum mechanics. Summary of classical mechanics, postulates of quantum mechanics and operator formalism, stationary state problems (including quantum wells, harmonic oscillator, angular momentum theory and spin, atoms and molecules, band theory in solids), time evolution, approximation methods for time independent and time dependent interactions including electromagnetic interactions, scattering.

### EECS 541 (Appl Phys 541). Applied Quantum Mechanics II

*Prerequisite: EECS 540. II (3 credits)*

Continuation of nonrelativistic quantum mechanics. Advanced angular momentum theory, second quantization, non-relativistic quantum electrodynamics, advanced scattering theory, density matrix formalism, reservoir theory.

### EECS 542 (CS 542). Vision Processing

*Prerequisite: EECS 442. I odd years (3 credits)*

Details of image formation theory, including the consideration of dynamic image sequences. The theoretical frameworks for edge detection, feature extraction, and surface description are presented. The relationship between image formation and object features is examined in detail. Programming required.

### EECS 543 (CS 543). Knowledge-Based Systems

*Prerequisite: EECS 281 and graduate standing or permission of instructor. I (3 credits)*

Techniques and principles for developing application software based on explicit representation and manipulation of domain knowledge, as applied to computer vision, robotic control, design and manufacturing, diagnostics, autonomous systems, etc. Topics include: identifying and representing knowledge, integrating knowledge-based behavior into complex systems, reasoning, and handling uncertainty and unpredictability.

### EECS 545 (CS 545). Machine Learning

*Prerequisite: EECS 492. II odd years (3 credits)*

Survey of recent research on learning in artificial intelligence systems. Topics include learning based on examples, instructions, analogy, discovery, experimentation, observation, problem-solving and explanation. The cognitive aspects of learning will also be studied.

### EECS 546 (Appl Phys 546). Ultrafast Optics

*Prerequisite: EECS 537. II (3 credits)*

Propagation of ultrashort optical pulses in linear and nonlinear media, and through dispersive optical elements. Laser mode-locking and ultrashort pulse generation. Chirped-pulse amplification. Experimental techniques for high time resolution. Ultrafast Optoelectronics. Survey of ultrafast high field interactions.

### EECS 547 (SI 652). Electronic Commerce

*Prerequisites: EECS 281 or SI 502 or permission of instructor. II (3 credits)*

Introduction to the design and analysis of automated commerce systems, from both a technological and social perspective. Infrastructure supporting search for commerce oppportunities, negotiating terms of trade, and executing transactions. Issues of security, privacy, incentives, and strategy.

### EECS 548 (BiomedE 548). Advanced Bioinstrumentation and Computation

*Prerequisite: EECS 458, EECS 451. I (3 credits)*

Application of computer hardware and software to acquisition, pattern recognition, analysis, and diagnosis of physiological signals. These include, but are not restricted to, the electrocardiogram, the electroencephalogram, the electromyogram, and blood pressure measurement. This course will teach skills required for computer-based analysis of clinical signals, and computer modelling of physiological systems. Lecture and laboratory.

### EECS 550. Information Theory

*Prerequisite: EECS 501. I (3 credits)*

The concepts of source, channel, rate of transmission of information. Entropy and mutual information. The noiseless coding theorem. Noisy channels; the coding theorem for finite state zero memory channels. Channel capacity. Error bounds. Parity check codes. Source encoding.

### EECS 551. Wavelets and Time-Frequency Distribution

*Prerequisite: EECS 451. I (3 credits)*

Review of DTFT and digital filtering. Multirate filtering. Filter banks and sub-band decomposition of signals. Multiresolution subspaces. Wavelet scaling and basis functions and their design: Haar, Littlewood-Paley, Daubechies, Battle-Lemarie. Denoising and compression applications. Spectrogram, Wigner-Ville, Cohen's class of time-frequency distributions and their applications.

### EECS 552 (Appl Phys 552). Fiber Optical Communications

*Prerequisite: EECS 434 or EECS 538 or permission of instructor. II odd years (3 credits)*

Principles of fiber optical communications and networks. Point-to-point systems and shared medium networks. Fiber propagation including attenuation, dispersion and nonlinearities. Topics covered include erbium-doped amplifiers, Bragg and long period gratings, fiber transmission based on solitons and non-return-to-zero, and time- and wavelength-division-multiplexed networks.

### EECS 554. Introduction to Digital Communication and Coding

*Prerequisite: EECS 212 or 316, EECS 401. I (3 credits)*

Digital transmission of information across discrete and analog channels. Sampling; quantization; noiseless source codes for data compression: Huffman's algorithm and entropy; block and convolutional channel codes for error correction; channel capacity; digital modulation methods: PSK, MSK, FSK, QAM; matched filter receivers. Performance analysis: power, bandwidth, data rate, and error probability.

### EECS 555. Digital Communication Theory

*Prerequisite: EECS 501, EECS 554. II (3 credits)*

Theory of digital modulation and coding. Optimum receivers in Gaussian noise. Signal space and decision theory. Signal design. Bandwidth and dimensionality. Fundamental limits in coding and modulation. Capacity and cutoff rate. Block, convolutional and trellis coding. Continuous phase modulation. Filtered channels and intersymbol interference. Equalization. Spread-spectrum. Fading channels. Current topics.

### EECS 556. Image Processing

*Prerequisite: EECS 451, EECS 501. II (3 credits)*

Theory and application of digital image processing. Random field models of images. Sampling, quantization, image compression, enhancement, restoration, segmentation, shape description, reconstruction of pictures from their projections, pattern recognition. Applications include biomedical images, time-varying imagery, robotics, and optics.

**EECS 557. Communication Networks**

*Prerequisite: graduate standing, preceded by EECS 401 or accompanied by EECS 501. I (3 credits)*

System architectures. Data link control: error correction, protocol analysis, framing. Message delay: Markov processes, queuing, delays in statistical multiplexing, multiple users with reservations, limited service, priorities. Network delay: Kleinrock independence, reversibility, traffic flows, throughput analysis, Jackson networks. Multiple access networks: ALOHA and splitting protocols, carrier sensing, multi-access reservations.

**EECS 558. Stochastic Control**

*Prerequisite: EECS 501, EECS 560. I odd years (3 credits)*

Analysis and optimization of controlled stochastic systems. Models: linear and nonlinear stochastic controlled systems, controlled Markov chains. Optimization of systems described by Markov processes; dynamic programming under perfect and imperfect information, finite and infinite horizons. System identification: off-line, recursive. Stochastic adaptive control: Markov chains, self-tuning regulators, bandit problems.

**EECS 559. Advanced Signal Processing**

*Prerequisite: EECS 451, EECS 501. II (3 credits)*

Estimators of second order properties of random processes: nonparametric and model-based techniques of spectral estimation, characterization of output statistics for nonlinear systems, time-frequency representations. Performance evaluation using asymptotic techniques and Monte Carlo simulation. Applications include speech processing, signal extrapolation, multidimensional spectral estimation, and beamforming.

**EECS 560 (Aero 550) (ME 564). Linear Systems Theory**

*Prerequisite: graduate standing. I (4 credits)*

Linear spaces and linear operators. Bases, subspaces, eigenvalues and eigenvectors, canonical forms. Linear differential and difference equations. Mathematical representations: state equations, transfer functions, impulse response, matrix fraction and polynomial descriptions. System-theoretic concepts: causality, controllability, observability, realizations, canonical decomposition, stability.

**EECS 561 (Aero 571) (ME 561). Design of Digital Control Systems**

*Prerequisite: EECS 460 or Aero 471 or ME 461. I (4 credits)*

Sampling and data reconstruction. Z-transforms and state variable descriptions of discrete-time systems. Modeling and identification. Analysis and design using root locus, frequency response, and state space techniques. Linear quadratic optimal control and state estimation. Quantization and other nonlinearities. Computer simulations and laboratory implementation of real-time control systems.

**EECS 562 (Aero 551). Nonlinear Systems and Control**

*Prerequisite: graduate standing. II (3 credits)*

Introduction to the analysis and design of nonlinear systems and nonlinear control systems. Stability analysis using Liapunov, input-output and asymptotic methods. Design of stabilizing controllers using a variety of methods: linearization, absolute stability theory, vibrational control, sliding modes and feedback linearization.

**EECS 564. Estimation, Filtering, and Detection**

*Prerequisite: EECS 501. II (3 credits)*

Principles of estimation, linear filtering and detection. Estimation: linear and nonlinear minimum mean squared error estimation, and other strategies. Linear filtering: Wiener and Kalman filtering. Detection: simple, composite, binary and multiple hypotheses. Neyman-Pearson and Bayesian approaches.

**EECS 565 (Aero 580). Linear Feedback Control Systems**

*Prerequisite: EECS 460 or Aero 471 or ME 461 and EECS 560 (Aero 550). II (3 credits)*

Control design concepts for linear multivariable systems. Review of single variable systems and extensions to multivariable systems. Purpose of feedback. Sensitivity, robustness, and design tradeoffs. Design formulations using both frequency domain and state space descriptions. Pole placement/observer design. Linear quadratic Gaussian based design methods. Design problems unique to multivariable systems.

**EECS 566 (IOE 583) (Mfg 583). Scientific Basis for Reconfigurable Manufacturing**

*Prerequisite: Graduate standing or permission of instructor. II alternate years (3 credits)*

Principles of reconfigurable manufacturing systems (RMS). Students will be introduced to fundamental theories applicable to RMS synthesis and analysis. Concepts of customization, integratability, modularity, diagnosability, and convertability. Reconfiguration design theory, life-cycle economics, open-architecture principles, controller configuration, system reliability, multi-sensor monitoring, and stream of variations. Term projects.

**EECS 567 (Mfg 567) (ME 567). Introduction to Robotics: Theory and Practice**

*Prerequisite: EECS 281. II (3 credits)*

Introduction to robots considered as electro-mechanical computational systems performing work on the physical world. Data structures representing kinematics and dynamics of rigid body motions and forces and controllers for achieving them. Emphasis on building and programming real robotic systems and on representing the work they are to perform.

**EECS 568 (Mfg 570). Process Control for Microelectronics Manufacturing**

*Prerequisite: graduate standing or permission of instructor. I (3 credits)*

Selected processing steps in microelectronics manufacturing, design of experiments, process and substrate sensors, statistical process control, run-to-run control, real-time control, failure diagnostics, computer implementation of control systems.

**EECS 570 (CS 570). Parallel Computer Architecture**

*Prerequisite: EECS 470. I or II (3 credits)*

Pipelining and operation overlapping, SIMD and MIMD architectures, numeric and non-numeric applications, VLSI, WSI architectures for parallel computing, performance evaluation. Case studies and term projects.

**EECS 571 (CS 571). Principles of Real-Time Computing**

*Prerequisite: EECS 470, EECS 482 or permission of instructor. I (3 credits)*

Principles of real-time computing based on high performance, ultra reliability and environmental interface. Architectures, algorithms, operating systems and applications that deal with time as the most important resource. Real-time scheduling, communications and performance evaluation.

**EECS 573 (CS 573). Microarchitecture**

*Prerequisite: EECS 470 or permission of instructor. II alternate years (3 credits)*

Graduate-level introduction to the foundations of high performance microprocessor implementation. Problems involving instruction supply, data supply, and instruction processing. Compile-time vs. run-time tradeoffs. Aggressive branch prediction. Wide-issue processors, in-order vs. out-of-order execution, instruction retirement. Case studies taken from current microprocessors.

**EECS 574 (CS 574). Theoretical Computer Science I**

*Prerequisite: EECS 376. I (4 credits)*

Fundamentals of the theory of computation and complexity theory. Computability, undecidability, and logic. Relations between complexity classes, NP-completeness, P-completeness, and randomized computation. Applications in selected areas such as cryptography, logic programming, theorem proving, approximation of optimization problems, or parallel computing.

**EECS 575 (CS 575). Theoretical Computer Science II**
*Prerequisite: EECS 574. II (4 credits)*
Advanced computational complexity, intractability, classical probability and information theory, algorithmic information theory, and special topics such as computational algebra, concurrency, semantics, and verification.

**EECS 577 (CS 577). Reliable Computing Systems**
*Prerequisite: EECS 478, EECS 280. I (3 credits)*
An introduction to models and methods used in the analysis and design of reliable hardware systems, software systems and computing systems. Aspects of reliability considered include fault tolerance, fault detection and diagnosis, reconfiguration, design verification and testing, and reliability evaluation.

**EECS 578 (CS 578). Computer-Aided Design Verification of Digital Systems**
*Prerequisite: EECS 478. II (3 credits)*
Design specification vs. implementation. Design errors. Functional and temporal modeling of digital systems. Simulation vs. symbolic verification techniques. Functional verification of combinational and sequential circuits. Topological and functional path delays; path sensitization. Timing verification of combinational and sequential circuits. Clock schedule optimization.

**EECS 579 (CS 579). Digital System Testing**
*Prerequisite: graduate standing. I (3 credits)*
Overview of fault-tolerant computing. Fault sources and models. Testing process. Combinational circuit testing. D-Algorithm and PODEM. Sequential circuit testing. Checking experiments. RAM and microprocessor testing. Fault simulation. Design for testability. Testability measures. Self-testing circuits and systems.

**EECS 580 (CS 580). Formal Specification and Verification of Computer Systems**
*Prerequisite: EECS 203 or equivalent, and either EECS 470, 473, 481, 482, 483 or 484. I alternate years (4 credits)*
Learn to formally specify and validate real-life software and hardware systems of various kinds: sequential, parallel synchronous, distributed (and if time permits, real-time). A survey of major formal specification and verification approaches is presented.

**EECS 581 (CS 581). Software Engineering Tools**
*Prerequisite: EECS 481 or equivalent programming experience. II (3 credits)*
Fundamental areas of software engineering including life-cycle-paradigms, metrics,and tools. Information hiding architecture, modular languages, design methodologies, incremental programming, and very high level languages.

**EECS 582 (CS 582). Advanced Operating Systems**
*Prerequisite: EECS 482. II (4 credits)*
Course discusses advanced topics and research issues in operating systems. Topics will be drawn from a variety of operating systems areas such as distributed systems and languages, networking, security, and protection, real-time systems, modeling and analysis, etc.

**EECS 583 (CS 583). Programming Languages**
*Prerequisite: EECS 376 and 483. I (4 credits)*
Various programming languages are compared to understand general principles. To do this systematically and ignore inessential details, a formal specification method is introduced. Current programming paradigms are examined; their potentials and compatibility are assessed. For example, the question of why functional languages become imperative when they "go public" is discussed.

**EECS 584 (CS 584). Advanced Database Systems**
*Prerequisite: EECS 484. I (3 credits)*
Survey of advanced topics in database systems. Distributed databases, query procesing, transaction processing. Effects of data models: object-oriented and deductive databases; architectures: main-memory and parallel repositories; distributed organizations: client-server and heterogeneous systems. Basic data management for emerging areas: internet applications, OLAP, data mining. Case studies of existing systems. Group projects.

**EECS 585 (CS 585). Web Technologies**
*Prerequisites: EECS 482 or EECS 485 or permission of instructor. I alternate years (3 credits)*
Web-related client-server protocols and performance issues; web proxies; web coaching and prefetching; dynamic web content; server-side web applications support; scalable web servers; security topics such as user authentication, secure sockets layer and secure HTTP; electronic payment systems; web-based virtual communities; information discovery.

**EECS 586 (CS 586). Design and Analysis of Algorithms**
*Prerequisite: EECS 281. II (3 credits)*
Design of algorithms for nonnumeric problems involving sorting, searching, scheduling, graph theory, and geometry. Design techniques such as approximation, branch-and-bound, divide-and-conquer, dynamic programming, greed, and randomization applied to polynomial and NP-hard problems. Analysis of time and space utilization.

**EECS 587 (CS 587). Parallel Algorithms**
*Prerequisite: EECS 281 and graduate standing. I (3 credits)*
The design and analysis of efficient algorithms for parallel computers. Fundamental problem areas, such as sorting, matrix multiplication, and graph theory, are considered for a variety of parallel architectures. Simulations of one architecture by another.

**EECS 589 (CS 589). Advanced Computer Networks**
*Prerequisite: EECS 489. II (4 credits)*
Advanced topics and research issues in computer networks. Topics include routing protocols, multicast delivery, congestion control, quality of service support, network security, pricing and accounting, and wireless access and mobile networking. Emphasis is placed on performance trade-offs in protocol and architecture designs. Readings assigned from research publications. A course project allows in-depth exploration of topics of interest.

**EECS 591 (CS 591). Distributed Systems**
*Prerequisite: EECS 482 and graduate standing. I (4 credits)*
Principles and practice of distributed system design. Computations, consistency semantics, and failure models. Programming paradigms including group communication, RPC, distributed shared memory, and distributed objects. Operating system kernel support; distributed system services including replication, caching, file system management, naming, clock synchronization, and multicast communication. Case studies.

**EECS 592 (CS 592). Advanced Artificial Intelligence**
*Prerequisite: EECS 492 or permission of instructor. II (4 credits)*
Advanced topics in artificial intelligence. Issues in knowledge representation, knowledge-based systems, problem solving, planning and other topics will be discussed. Students will work on several projects.

**EECS 593 (CS 593). The Human as an Information Processing System**
*Prerequisite: graduate standing and permission of instructor. I, odd years (3 credits)*
Basic human information handling processes such as perception, learning cognitive map information, and problem solving are analyzed in an evolutionary context. Emphasis is largely theoretical. Includes the application to the human-computer interface of the principles that emerge.

**EECS 594 (CS 594). Introduction to Adaptive Systems**
*Prerequisite: EECS 203, Math 425 (Stat 425). II (3 credits)*
Programs and automata that "learn" by adapting to their environment; pro-

grams that utilize genetic algorithms for learning. Samuel's strategies, realistic neural networks, connectionist systems, classifier systems, and related models of cognition. Artificial intelligence systems, such as NETL and SOAR, are examined for their impact upon machine learning and cognitive science.

**EECS 595 (CS 595) (Ling 541). Natural Language Processing**
*Prerequisite: senior standing. I (3 credits)*
A survey of syntactic and semantic theories for natural language processing, including unification-based grammars, methods of parsing, and a wide range of semantic theories from artificial intelligence as well as from philosophy of language. Programming will be optional, though a project will normally be required.

**EECS 596. Master of Engineering Team Project**
*Prerequisite: enrollment in the Masters of Engineering program in EECS. I, II, IIIa, IIIb, and III (1-6 credits)*
To be elected by EECS students pursuing the Master of Engineering degree. Students are expected to work in project teams. May be taken more than once up to a total of 6 credit hours.

**EECS 597 (SI 760). Language and Information**
*Prerequisite: SI 503 or EECS 281 and graduate standing or permission of instructor. I (3 credits)*
A survey of techniques used in language studies and information processing. Students will learn how to explore and analyze textual data in the context of Web-based information retrieval systems. At the conclusion of the course, students will be able to work as information designers and analysts.

**EECS 598 (CS 598). Special Topics in Electrical Engineering and Computer Science**
*Prerequisite: permission of instructor or counselor. I, II, IIIa, IIIb, and III (1-4 credits)*
Topics of current interest in electrical engineering and computer science. Lectures, seminar, or laboratory. Can be taken more than once for credit.

**EECS 599. Directed Study**
*Prerequisite: prior arrangement with instructor; mandatory satisfactory/unsatisfactory. I, II, IIIa, IIIb and III (1-4 credits)*
Individual study of selected advanced topics in electrical engineering and computer science. May include experimental work or reading. Primarily for graduate students. To be graded on satisfactory/unsatisfactory basis ONLY.

**EECS 600 (Aero 651) (IOE 600). Function Space Methods in System Theory**
*Prerequisite: Math 419. I, II (3 credits)*
Introduction to the description and analysis of systems using function analytic methods. Metric spaces, normed linear spaces, Hilbert spaces, resolution spaces. Emphasis on using these concepts in systems problems.

**EECS 623. Integrated Sensors and Sensing Systems**
*Prerequisite: EECS 413, and either EECS 423, or EECS 425, or EECS 523. I (4 credits)*
Fundamental principles and design of integrated solid-state sensors and sensing systems. Micromachining and wafer bonding. Microstructures for the measurement of visible and infrared radiation, pressure, acceleration, temperature, gas purity, an ion concentrations. Merged process technologies for sensors and circuits. Data acquisitions circuits, microactuators and integrated microsystems.

**EECS 627. VLSI Design II**
*Prerequisite: EECS 427. I (4 credits)*
Advanced very large scale integrated (VLSI) circuit design. Design methodologies (architectural simulation, hardware description language design entry, silicon compilation, and verification), microarchitectures, interconnect, packaging, noise sources, circuit techniques, design for testability, design rules, VLSI technologies (silicon and GaAs), and yield. Projects in chip design.

**EECS 631. Electromagnetic Scattering**
*Prerequisite: EECS 530 and graduate standing. I even years (3 credits)*
Boundary conditions, field representations. Low and high frequency scattering. Scattering by half plane (Wiener-Hopf method) and wedge (Maliuzhinets method); edge diffraction. Scattering by a cylinder and sphere: Watson transformation, Airy and Fock functions, creeping waves. Geometrical and physical theories of diffraction.

**EECS 632. Microwave Remote Sensing II - Radar**
*Prerequisite: EECS 532. II even years (3 credits)*
Radar equation; noise statistics; resolution techniques; calibration; synthetic aperture radar; scatterometers; scattering models; surface and volume scattering; land and oceanographic applications.

**EECS 633. Numerical Methods in Electromagnetics**
*Prerequisite: EECS 530. I odd years (3 credits)*
Numerical techniques for antennas and scattering; integral representation: solutions of integral equations: method of moments, Galerkin's technique, conjugate gradient FFT; finite element methods for 2-D and 3-D simulations; hybrid finite element/boundary integral methods; applications: wire, patch and planar arrays; scattering composite structures.

**EECS 634 (Appl Phys 611) (Physics 611). Nonlinear Optics**
*Prerequisite: EECS 537 or EECS 538 or EECS 530. I (3 credits)*
Formalism of wave propagation in nonlinear media; susceptibility tensor; second harmonic generation and three-wave mixing; phase matching; third order nonlinearities and four-wave mixing processes; stimulated Raman and Brillouin scattering. Special topics: nonlinear optics in fibers, including solitons and self-phase modulation.

**EECS 638 (Appl Phys 609) (Physics 542). Quantum Theory of Light**
*Prerequisite: quantum mechanics electrodynamics and atom physics. II (3 credits)*
The atom-field interaction; density matrix; quantum theory of radiation including spontaneous emission; optical Bloch equations and theory of resonance fluorescence; coherent pulse propagation; dressed atoms and squeezed states; special topics in nonlinear optics.

**EECS 643 (Psych 643). Theory of Neural Computation**
*Prerequisite: graduate standing or permission of instructor. I, II (2-4 credits)*
This course will review computational models of human cognitive processes with four goals in mind: (1) to learn about the wide variety of approaches to cognitive modeling (e.g., self-organizing nets, multi-layer nets, and back-propogation, production systems, ACT*, EPIC, Soar . . .) and the advantages and disadvantages of each, (2) to study some of the most important cognitive models of specific domains (e.g., dual task performance, reasoning, explicit learning, working memory . . .), (3) to evaluate when cognitive modeling is an appropriate and useful research strategy, and (4) to give students an opportunity to gain hands-on experience in implementing their own cognitive models. Students will be expected to take turns in leading discussion of specific papers and to work in groups in implementing a computational model.

**EECS 644 (Psych 644). Computational Modeling of Cognition**
*Prerequisite: graduate standing or permission of instructor. I, II (2-4 credits)*
This course will examine computational models of human cognitive processes. Course goals include learning about important computational models of specific cognitive domains and evaluating the appropriateness and utility of different computational approaches to substantive problems in cognition.

**EECS 650. Channel Coding Theory**
*Prerequisite: EECS 501 and EECS 400. II alternate years (3 credits)*
The theory of channel coding for reliable communication and computer memo-

ries. Error correcting codes; linear, cyclic and convolutional codes; encoding and decoding algorithms; performance evaluation of codes on a variety of channels.

**EECS 651. Source Coding Theory**
*Prerequisite: EECS 501. II odd years (3 credits)*
Introduction to a variety of source coding techniques such as quantization, block quantization; and differential, predictive, transform and tree coding. Introduction to rate-distortion theory. Applications include speech and image coding.

**EECS 658. Fast Algorithms for Signal Processing**
*Prerequisite: EECS 451, EECS 501. I odd years (3 credits)*
Introduction to abstract algebra with applications to problems in signal processing. Fast algorithms for short convolutions and the discrete Fourier transform; number theoretic transforms; multi-dimensional transforms and convolutions; filter architectures.

**EECS 659. Adaptive Signal Processing**
*Prerequisite: EECS 559. I even years (3 credits)*
Theory and applications of adaptive filtering in systems and signal processing. Iterative methods of optimization and their convergence properties: transversal filters; LMS (gradient) algorithms. Adaptive Kalman filtering and least-squares algorithms. Specialized structures for implementation: e.g., least-squares lattice filters, systolic arrays. Applications to detection, noise cancelling, speech processing, and beam forming.

**EECS 661. Discrete Even Systems**
*Prerequisite: EECS 376 or EECS 560 or equivalent. I even years (3 credits)*
Modeling, analysis, and control of discrete event dynamical systems. Modeling formalisms considered include state machines, Petri nets, and recursive processes. Supervisory control theory; notions of controllable and observable languages. Analysis and control of Petri nets. Communicating sequential processes. Applications to database management, manufacturing, and communication protocols.

**EECS 662 (Aero 672) (ME 662). Advanced Nonlinear Control**
*Prerequisite: EECS 562 or ME 548. I (3 credits)*
Geometric and algebraic approaches to the analysis and design of nonlinear control systems. Nonlinear controllability and observability, feedback stabilization and linearization, asymptotic observers, tracking problems, trajectory generation, zero dynamics and inverse systems, singular perturbations, and vibrational control.

**EECS 670. Advanced Topics in Computer Architecture**
*Prerequisite: EECS 570, graduate standing, permission of instructor. I or II (3 credits)*
Advanced concepts and specialized areas in computer systems design are discussed and analyzed in depth. Topics chosen by instructor. Examples are database machines, highly reliable systems, computers for artificial intelligence, architectural support for operating system functional, high-level language architectures, object-oriented architecture, other special purpose architecture (vision, dataflow).

**EECS 682. Advanced System Programming**
*Prerequisite: EECS 482 or EECS 582. II (3 credits)*
This course introduces the student to the more difficult problems and techniques of system programming. Such areas as dynamic storage allocation and relocation, interaction between central and peripheral hardware units, etc., will be discussed. The main emphasis of the course is a group project and the handling of the problems that are involved in all aspects of system design and final implementation.

**EECS 684. Current Topics in Databases**
*Prerequisite: EECS 484. I (3 credits)*
Research issues in database systems chosen for in-depth study. Selected topics such as spatial, temporal, or real-time databases; data mining, data warehousing, or other emerging applications. Readings from recent research papers. Group projects.

**EECS 692. Current Topics in Artificial Intelligence**
*Prerequisites: EECS 592 or permission of instructor. I (3 credits)*
Research issues in artificial intelligence chose for in-depth study. Selected topics such as computational decision-making, knowledge representation, planning, design, multi-agent systems, cognitive architectures, AI in the arts, and rationality. Readings from recent research papers. Project and homework assignments.

**EECS 695 (Psych 640). Neural Models and Psychological Processes**
*Prerequisite: permission of instructor. II (3 credits)*
Consideration of adaptively and biologically oriented theories of human behavior. Emphasis on both the potential breadth of application and intuitive reasonableness of various models. There is a bias toward large theories and small simulations.

**EECS 698. Master's Thesis**
*Prerequisite: election of an EECS master's thesis option. I, II, IIIa, IIIb, and III (1-6 credits)*
To be elected by EE and EES students pursuing the master's thesis option. May be taken more than once up to a total of 6 credit hours. To be graded on a satisfactory/unsatisfactory basis ONLY.

**EECS 699. Research Work in Electrical Engineering and Computer Science**
*Prerequisite: graduate standing, permission of instructor; mandatory satisfactory/unsatisfactory. I, II, IIIa, IIIb, III (1-6 credits)*
Students working under the supervision of a faculty member plan and execute a research project. A formal report must be submitted. May be taken for credit more than once up to a total of 6 credit hours. To be graded satisfactory/unsatisfactory ONLY.

**EECS 700. Special Topics in System Theory**
*Prerequisite: permission of instructor (to be arranged)*

**EECS 720. Special Topics in Solid-State Devices, Integrated Circuits, and Physical Electronics**
*Prerequisite: permission of instructor. (1-4 credits)*
Special topics of current interest in solid-state devices, integrated circuits, microwave devices, quantum devices, noise, plasmas. This course may be taken for credit more than once.

**EECS 730. Special Topics in Electromagnetics**
*Prerequisite: permission of instructor. (1-4 credits) (to be arranged)*

**EECS 731 (AOSS 731). Space Terahertz Technology and Applications**
*Prerequisite: permission of instructor; mandatory satisfactory/unsatisfactory. I (1 credit)*
Study and discussion of various topics related to high frequency applications in space exploration. Topics will be chosen from the following areas: planetary atmospheres and remote sensing, antennas, active and passive circuits, space instrumentation.

**EECS 735 Special Topics in the Optical Sciences**
*Prerequisite: graduate standing, permission of instructor. (to be arranged) (1-4 credits)*
Key topics of current research interest in ultrafast phenomena, short wavelength lasers, atomic traps, integrated optics, nonlinear optics and spectroscopy. This course may be taken for credit more than once under different instructors.

**EECS 750. Special Topics in Communication and Information Theory**
*Prerequisite: permission of instructor. (to be arranged)*

**EECS 755. Special Topics in Signal Processing**
*Prerequisite: permission of instructor. (to be arranged) (1-4 credits)*

**EECS 760. Special Topics in Control Theory**
*Prerequisite: permission of instructor. (to be arranged)*

**EECS 765. Special Topics in Stochastic Systems and Control**
*Prerequisite: permission of instructor. (to be arranged) (3 credits)*
Advanced topics on stochastic systems such as stochastic calculus, nonlinear filtering, stochastic adaptive control, decentralized control, and queuing networks.

**EECS 770. Special Topics in Computer Systems**
*Prerequisite: permission of instructor. (to be arranged)*

**EECS 820. Seminar in Solid-State Electronics**
*Prerequisite: graduate standing, permission of instructor. I (1 credit)*
Advanced graduate seminar devoted to discussing current research topics in areas of solid-state electronics. Specific topics vary each time the course is offered. Course may be elected more than once.

**EECS 874. Seminar in Theory of Computing**
*Prerequisite: EECS 574. I, II (2 credits)*
Advanced graduate seminar devoted to new developments in theory of computing. Topics may include theory of programming languages, complexity, algorithms, AI, and applications of logic and mathematics to computer science.

**EECS 880. Software Research Seminar**
*Prerequisite: graduate standing in EECS or permission of instructor. I, II (1-3 credits)*
Seminar and current research in programming languages, operating systems, distributed computing, software engineering, databases, graphics, and other software topics. Each week a different speaker will describe his/her own research, or report on a recent published paper. Exact topics vary each term. Occasional speakers from other universities.

**EECS 892. Seminar in Artificial Intelligence**
*Prerequisite: EECS 592 or equivalent. I, II (2 credits)*
Advanced graduate seminar devoted to discussing current research papers in artificial intelligence. The specific topics vary each time the course is offered.

**EECS 990. Dissertation/Pre-Candidate**
*I, II, III (2-8 credits); IIIa, IIIb (1-4 credits)*
Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**EECS 995. Dissertation/Candidate**
*Prerequisite: Graduate School authorization for admission as a doctoral candidate. I, II, III (8 credits); IIIa, IIIb (4 credits)*
Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

## Electrical Engineering and Computer Science Faculty

Richard B. Brown, Ph.D., *Professor and Interim Chair, Electrical Engineering and Computer Science*
John E. Laird, Ph.D., *Professor and Associate Chair, Computer Science and Engineering Division*
Stephane Lafortune, Ph.D., *Professor and Associate Chair, Systems Science and Engineering Division*

### Professors

David J. Anderson, Ph.D.; *also Biomedical Engineering*
Daniel E. Atkins, Ph.D
Pallab K. Bhattacharya, Ph.D., *James R. Mellor Professor of Engineering*
Charles A. Cain, Ph.D.; *also Biomedical Engineering*
Stephen W. Director, Ph.D.; *also Robert J. Vlasic Dean of Engineering*
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Daniel G. Green, Ph.D.; *also Biomedical Engineering, Psychology, Opthamology*
Jessy W. Grizzle, Ph.D.
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Jerzy Kanicki, Ph.D.
Stephen Kaplan, Ph.D.; *also Psychology*
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### Adjunct Professors

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Lauren Peterson, Ph.D.
John Sayler, Ph.D.

### Professors Emeritus

Ben F. Barton, Ph.D.
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Basic physics is an integral part of every engineering curriculum. However, in many areas of engineering the sophistication of the field, coupled with the staggering rate of technological advance, has created a need for engineers with much stronger backgrounds in math and physics—people who can work in an engineering environment and who are capable of applying advanced physics concepts to bring innovations to the marketplace. For example, the development of the computer closely followed the invention of the transistor. Consider the number of other recently discovered physical phenomena (lasers, nuclear reactors, particle accelerators, etc.) that have been successfully brought to fruition by engineers.

Engineering Physics is particularly attractive to those students who may attend graduate school, even if they have not decided on a particular field. An advanced physics and mathematics background coupled with an engineering curriculum is excellent preparation for most graduate engineering programs and for a traditional physics or applied physics program.

Engineering Physics meets these needs by providing a thorough curriculum in basic and advanced engineering courses combined with sufficient physics and mathematics to be equivalent to a traditional degree in physics. A unique feature of the curriculum is the elective sequence of engineering courses that the student may select in a specialized field of engineering. This sequence of courses can be chosen by the student (with the advisor's agreement) in any field of interest, such as microprocessor design, plasma processing, electro-optics, radiological health, computational methods, or bioengineering, to name just a few. With 42 credit hours of electives in math, engineering and physics, the student has a high degree of flexibility and opportunity for exploring or specializing in fields of interest.

## Sample Schedule B.S.E. Engineering Physics

| | Credit Hours | Terms | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| **Subjects required by all programs (52 hrs.)** *(See pages 78-82 for alternatives.)* | | | | | | | | | |
| Mathematics 115, 116, 215, and 216 | 16 | 4 | 4 | 4 | 4 | - | - | - | - |
| Engr 100, Intro to Engr | 4 | 4 | - | - | - | - | - | - | - |
| Engr 101, Intro to Computers | 4 | - | 4 | - | - | - | - | - | - |
| [1]Chemistry 125 and 130 or Chemistry 210 and 211 | (5) 4 | 4 | - | - | - | - | - | - | - |
| [2]Physics 140 with Lab 141; 240 with Lab 241 | (10) 8 | - | 4 | 4 | - | - | - | - | - |
| Humanities and Social Sciences | 16 | 4 | 4 | 4 | 4 | - | - | - | - |
| **Advanced Mathematics (8 hrs.)** | | | | | | | | | |
| [3]Mathematics Electives | 8 | - | - | - | - | 4 | - | 4 | - |
| **Related Technical Subjects (20 hrs.)** | | | | | | | | | |
| MSE 250, Princ of Eng Materials | 4 | - | - | - | 4 | - | - | - | - |
| CEE 211, Statics and Dynamics | 4 | - | - | 4 | - | - | - | - | - |
| ME 230, Thermal Sciences I | 4 | - | - | - | - | - | 4 | - | - |
| ME 330, Thermal Sciences II | 4 | - | - | - | - | - | - | 4 | - |
| EECS 314, Cct Analy and Electr or EECS 210, Intro to Electrical Engr | 4 | - | - | - | - | 4 | - | - | - |
| **Physics Technical Subjects (16 hrs.)** | | | | | | | | | |
| [4]NERS 311, Ele Nucl Eng and Rad Sci I or Physics 340, Waves, Heat and Light | 4 | - | - | - | - | 4 | - | - | - |
| Physics 401, Int Mech | 3 | - | - | - | - | - | 3 | - | - |
| Physics 405, Int Elect and Mag | 4 | - | - | - | - | - | - | 4 | - |
| Physics 406, Stat and Thermal Phys | 3 | - | - | - | - | - | - | - | 3 |
| Physics Lab Elective or Directed Study with Research Lab Component | 2 | - | - | - | - | - | - | - | 2 |
| **Technical Electives (20 hrs.)** | | | | | | | | | |
| [5]Engineering Electives | 16 | - | - | - | - | 4 | 4 | 4 | 4 |
| Laboratory Elective (400-level) | 4 | - | - | - | - | - | - | - | 4 |
| [6]**Unrestricted Electives (12 hrs.)** | 12 | - | - | - | 4 | - | 4 | - | 4 |
| **Total** | 128 | 16 | 16 | 16 | 16 | 16 | 15 | 16 | 17 |

Candidates for the Bachelor of Science degree in Engineering (Engineering Physics)—B.S.E. (Eng. Physics)—must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

**Notes:**

[1]Chemistry: 125, 130 or 210, 211 will count for 5 total credits, 1 of which will be applied according to individual program directives; for students who have advanced placement credit for freshman chemistry, a 100-level or above biology course may be used to fulfill this requirement.

[2]Physics: 140, 141; 240, 241 will count for 10 total credits, 2 of which will be applied according to individual program directives.

[3]Math Electives must be 300-level or higher

[4]If Physics 340 is elected, one additional credit hour is added to unrestricted electives.

[5]Engineering Electives are to be chosen in consultation with the faculty advisor to form a coherent sequence that clearly defines professional goals for the student. Sample elective sequences for a number of different subject areas are available from the academic or faculty counselors.

[6]Students contemplating graduate studies in physics should elect Physics 453, Quantum Mech and Physics 463, Solid State for a complete background.

# INDUSTRIAL AND OPERATIONS ENGINEERING

*Program Advisor*
*Professor Yili Liu*
*1603 Industrial and Operations Engineering Building*
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Industrial and operations engineering is concerned with integrated systems of people, machines, environments and information. Drawing upon their specialized skills in mathematical, physical, and social sciences, (together with principles and methods of engineering analysis), industrial and operations engineers specify, predict, and evaluate systems. Applications arise in industrial and manufacturing systems as well as a variety of non-industrial settings, ranging from health care and education to financial and governmental organizations.

The wide range of tasks an industrial engineer is called upon to perform requires knowledge of operations research, ergonomics, management engineering, statistics, manufacturing engineering, and computer information processing.

## Operations Research

Operations research is an applied science devoted to describing, understanding, and predicting the behavior of systems, and guiding them towards better performance. Courses in this area cover the use of mathematics in constructing models to analyze and design operational systems. Students study a variety of model structures and their application to real-world processes such as production, maintenance, inspection, resource allocation, distribution, and scheduling.

## Ergonomics

Ergonomics emphasizes the technical knowledge necessary to analyze and predict the performance of humans in human-machine systems. Basic courses cover the capabilities and limitations of major human subsystems including cardiovascular, muscular, and cognitive (information processing) systems. Knowledge of these human subsystems is used to aid in the design of effective and safe working environments.

## Management Engineering

In the design and implementation of integrated systems, industrial engineers must be able to master the technology of new systems, to understand the technical change process, and to achieve the benefits of such systems. Management engineering courses emphasize the role of people acting as individuals, and in groups, in operating systems.

Theories of administration, group dynamics, and human motivation are applied to specific managerial problems related to the establishment, clarification and modification of an organization's objectives.

They also cover the design, evaluation, and improvement of human-machine systems for accomplishing these objectives.

## Manufacturing Engineering

Manufacturing engineering is concerned with determining how to manufacture engineered products with minimal capital investments and operating costs in facilities safe to both workers and the environment. Students study methods for evaluating production and inventory systems, facility layout, and material handling systems and are prepared to aid in the daily operation of a manufacturing facility while evaluating operations for the future.

## Quality Engineering

Industrial and Operations Engineering graduates understand how to cope with uncertainty in the design of engineered systems. In particular, they design quality control systems and apply reliability analysis and experimental design techniques to design better products and processes.

## Computer and Information Processing

Computers and information systems are important components in most modern systems. Students are introduced to the basic terminology and concepts of information system design, construction, and usage. The values and limitations of computing capabilities are explored. Emphasis is placed on the use of computer hardware and software systems in information processing and on the interface of information systems with management in helping to achieve the objectives of an organization.

## The IOE Program

The program in Industrial and Operations Engineering at the University of Michigan is designed to prepare students for challenges in the areas described above, or for continuing their academic work to acquire an M.S.E. or Ph.D. degree. Approximately 40 percent of the courses required for the B.S.E. (I.O.E.) degree are common College of Engineering core requirements, in mathematics, basic physical sciences, digital computing, humanities, and social sciences, along with a broad base in engineering fundamentals. Fundamental topics in industrial engineering are provided by the nine 200- and 300-level IOE courses. A solid technical foundation is obtained through 16 credits of departmental IOE electives. In addition, students gain valuable experience applying their knowledge in a senior-level design course.

The opportunity for students to tailor their studies in pursuit of individual interests is provided by an additional 8 credits of technical electives and 12 credits of unrestricted electives. The goal of the technical electives is to provide a background in areas related to industrial and operations engineering. This allows students to deepen their knowledge in specific areas of industrial and operations engineering and provides an opportunity to prepare for advanced studies in other engineering disciplines, or in medicine, law, or business.

The IOE program is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering Technology (ABET).

## Our Mission, Goals, Objectives and Outcomes for Undergraduate Education

### *Mission*

To be an international leader in developing and teaching theory and methods for the design, analysis, implementation, and improvement of integrated systems of people, materials, information, facilities, and technology.

### *Goals*

- To recruit, educate, and support excellent, diverse students and prepare them to be leaders in the practice and further development of industrial and operations engineering.
- To have one of the leading undergraduate programs in the world in industrial and operations engineering.
- To engender the skills and desire to continually learn and grow through a lifelong professional career.

### *Objectives*

We will work with honesty and integrity to provide all of our students with an outstanding education and to advise and assist them in fulfilling their educational and career objectives. Our undergraduate program will provide students with a diverse range of professional objectives with the knowledge, skills and tools to:

- address contemporary and future problems in enterprises;
- develop skills in critical thinking, teamwork, problem solving and communicating with others;
- initiate and manage change in organizations and processes;
- understand their professional and ethical responsibilities;
- appropriately employ information systems and technology; and
- enable enterprises to make optimal decisions under conditions of uncertainty.

### *Outcomes*

All Industrial and Operations Engineering graduates should have:

- an ability to apply knowledge of mathematics, science, and engineering;
- an ability to design and conduct experiments, as well as analyze and interpret data;
- an ability to design and improve integrated systems of people, materials, information, facilities, and technology;
- an ability to function as a member of a multi-disciplinary team;
- an ability to identify, formulate, and solve industrial and operations engineering problems;
- an understanding of professional and ethical responsibility;
- an ability to communicate effectively;
- the broad education necessary to understand the impact of engineering solutions in a global and societal context;
- a recognition of the need for, and an ability to engage in life-long learning;
- a knowledge of contemporary issues;
- an ability to use updated techniques, skills and tools of industrial and operations engineering throughout their professional careers; and
- a base set of skills and knowledge, regardless

of specific professional goals, in human resource management, personal management, macro analysis, critical thinking, operations management, operations research, and information systems (see IOE Core skills list).

## Engineering Global Leadership Program (EGL)

The Engineering Global Leadership Program (EGL), is an exciting honors program offered in IOE and ME for those students with strong GPAs who enjoy learning foreign languages, and studying other cultures. The program is designed to maximize and focus free electives, language, humanities, and social science courses around a region of economic importance to the US. In addition, EGL students are required to take business courses and complete a built-in practical experience to place technical knowledge in an industrial context. This honors program is very rigorous (full class loads every semester and maintenance of a high GPA) but EGL students graduate with both a BSE and a Master's degree and tend to have higher starting salaries than other engineering undergrads.

## Facilities

The department has well-equipped laboratories in human performance, industrial systems, plant flow analysis, quality control, and computation.

In addition to the facilities on campus, the department has excellent relationships with various firms within the Ann Arbor-Detroit area so that students are exposed to actual operating industrial, service, and other business systems.

## Sample Schedule B.S.E. Industrial and Operational Engineering

| | Credit Hours | Terms 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| **Subjects required by all programs (52 hrs.)** *(See pages 78-82 for alternatives.)* | | | | | | | | | |
| Mathematics 115, 116, 215, and 216 | 16 | 4 | 4 | 4 | 4 | - | - | - | - |
| Engr 100, Intro to Engr | 4 | 4 | - | - | - | - | - | - | - |
| Engr 101, Intro to Computers | 4 | - | 4 | - | - | - | - | - | - |
| [1]Chemistry 125 and 130 | (5) 4 | 4 | - | - | - | - | - | - | - |
| [2]Physics 140 with Lab 141; 240 with Lab 241 | (10) 8 | - | 4 | 4 | - | - | - | - | - |
| Humanities and Social Sciences | 16 | - | 4 | - | - | 4 | 4 | 4 | - |
| **Related Engineering Subjects (12 hrs.)** | | | | | | | | | |
| [3]Non-IOE Engineering Courses | 12 | - | - | - | 4 | 4 | - | - | 4 |
| **Required Program Subjects (28 hrs.)** | | | | | | | | | |
| IOE 201, Industrial, Operations Modeling | 2 | - | - | 2 | - | - | - | - | - |
| IOE 202, Operations Modeling | 2 | - | - | 2 | - | - | - | - | - |
| IOE 310, Intro to Optim Methods | 4 | - | - | - | - | 4 | - | - | - |
| IOE 265, Engr Probability and Statistics | 4 | - | - | 4 | - | - | - | - | - |
| IOE 333, Ergonomics | 3 | - | - | - | 3 | - | - | - | - |
| IOE 334, Ergonomics Lab | 1 | - | - | - | 1 | - | - | - | - |
| IOE 316, Intro to Markov Processes | 2 | - | - | - | 2 | - | - | - | - |
| IOE 366, Linear Statistical Models | 2 | - | - | - | 2 | - | - | - | - |
| IOE 373, Data Processing | 4 | - | - | - | - | - | 4 | - | - |
| IOE Senior Design Course [IOE 424 (4) or 481 (4) or 499 (3)] | (3) 4 | - | - | - | - | - | - | - | 4 |
| **[4]Technical Electives (24 hrs.)** | 24 | - | - | - | - | 4 | 8 | 8 | 4 |
| **Unrestricted Electives (12 hrs.)** | 12 | 4 | - | - | - | - | - | 4 | 4 |
| **Total** | 128 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |

Candidates for the Bachelor of Science degree in Engineering (Industrial and Operations Engineering)—(B.S.E. I.O.E.)—must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

**Notes:**

[1]Chemistry: 125, 130 will count for 5 total credits, 1 of which will be applied according to individual program directives.

[2]Physics: 140, 141; 240, 241 will count for 10 total credits, 2 of which will be applied according to individual program directives.

[3]Non-IOE Engineering Courses:

Select 12 hours: 4 hours from any three different groups:

- a) ME 211 or CEE 211 or ME 240
- b) ME 230 or ChemE 230
- c) MSE 220 or ME 382
- d) EECS 210 or BiomedE 458 or EECS 314 or EECS 270
- e) CEE 260 or NERS 211
- f) EECS 280

[4]Technical Electives:

Select at least 16 hours from IOE; at least 4 hours must be from three of the following five groups:

- a) IOE 441, 447, 449
- b) IOE 416, 460, 465, 466
- c) IOE 474
- d) IOE 432, 436, 438, 439, 463
- e) IOE 421, 422, 425, 451, 452, 453

The remaining 8 hours may be selected from any IOE courses and/or from an approved list of non-IOE courses.

## Industrial and Operations Engineering Course Listings

Course descriptions are found also on the College of Engineering web site at http://courses.engin.umich.edu/

**IOE 201. Economic Decision Making**
*Prerequisite: Engr 100, Engr 101 or equivalent. I, II (2 credits) (7-week course)*
Overview of business operations, valuation and accounting principles. Time value of money and net present values. Practical team project experience.

**IOE 202. Operations Modeling**
*Prerequisite: Engr 100, Engr 101 or equivalent. I, II (2 credits) (7-week course)*
Process of mathematically modeling operational decisions including the role of uncertainty in decision-making. Basic tools for solving the resulting models, particularly mathematical programs, statistical models and queueing models. Cases may come from manufacturing and service operations and ergonomics.

**IOE 265 (Stat 265). Probability and Statistics for Engineers**
*Prerequisite: Math 116 and Engr 101. I, II (4 credits)*
Graphical Representation of Data; Axioms of Probability; Conditioning, Bayes Theorem; Discrete Distributions (Geometric, Binomial, Poisson); Continuous Distributions (Normal Exponential, Weibull), Point and Interval Estimation, Likelihood Functions, Test of Hypotheses for Means, Variances, and Proportions for One and Two Populations.

**IOE 310. Introduction to Optimization Methods**
*Prerequisite: Math 216, IOE 201 and Engr 101 or EECS 100. I, II (4 credits)*
Introduction to deterministic models with emphasis on linear programming; simplex and transportation algorithms, engineering applications, relevant software. Introduction to integer, network, and dynamic programming, critical path methods.

**IOE 316. Introduction to Markov Processes**
*Prerequisite: IOE 265 and Math 216. I, II (2 credits) (7-week course)*
Introduction to discrete Markov Chains and continuous Markov processes, including transient and limiting behavior. The Poisson/Exponential process. Applications to reliability, maintenance, inventory, production, simple queues and other engineering problems.

**IOE 333. Ergonomics**
*Prerequisite: IOE 265. I, II (3 credits)*
Introduction to human sensory, decision, control, and motor systems in the context of visual, auditory, cognitive, and manual task evaluation and design. Problems with computer displays, illumination, noise, eye-hand coordination, as well as repetitive and high physical effort tasks are presented. Workplace and vehicle design strategies used to resolve these are discussed.

**IOE 334. Ergonomics Lab**
*Prerequisite: preceded or accompanied by IOE 333. I, II (1 credit)*
Principles of measurement and prediction of human performance in man-machine systems. Laboratory experiments investigating human capabilities of vision, hearing, information processing, memory, motor processes, strength, and endurance.

**IOE 366. Linear Statistical Models**
*Prerequisite: IOE 265 and Math 216. I, II (2 credits) (7-week course)*
Linear statistical models and their application to engineering data analysis. Linear regression and correlation; multiple linear regression, analysis of variance, introduction to design of experiments.

**IOE 373. Data Processing**
*Prerequisite: Engr 101 or EECS 100. I, II (4 credits)*
Introduction to the systems organization and programming aspects of modern digital computers. Concepts of algorithms and data structure will be discussed with practical business applications.

**IOE 416. Queueing Systems**
*Prerequisite: IOE 316. I (2 credits)*
Introduction to queueing processes and their applications. The M/M/s and M/G/1 queues. Queue length, waiting time, busy period. Examples from production, transportation, communication, and public service.

**IOE 421. Work Organizations**
*Prerequisite: IOE 201, 202 and senior standing. I (4 credits)*
Applications of organizational theory to the analysis and design of work organizations is taught through lectures, projects in real organizations, experiential exercises, and case studies. Topics include: open-systems theory, organizational structure, culture, and power. A change strategy: current state analysis, future state vision, and strategies for organizational transformation.

**IOE 422. Entrepreneurship**
*Prerequisite: senior standing. I (4 credits)*
Engineering students will learn the dynamics of turning an innovative idea into a successful commercial venture, including the role of e-commerce. By creating an actual business plan they will learn about innovation and creativity, risk management, stress and failure, ethics and other necessary business skills.

**IOE 424. Practicum in Production and Service Systems**
*Prerequisite: senior standing. Not for graduate credit. I, II (4 credits)*
Student teams will work with an organization on an Industrial and Operations Engineering design project with potential benefit to the organization and the students. The final report should demonstrate a mastery of the established technical communication skills. The report will be reviewed and edited to achieve this outcome.

**IOE 425 (Mfg 426). Manufacturing Strategies**
*Prerequisite: senior standing. I, II (2 credits)*
Review of philosophies, systems, and practices utilized by world-class manufacturers to meet current manufacturing challenges, focusing on "lean production" in the automotive industry, including material flow, plant-floor quality assurance, job design, work and management practices. Students tour plants to analyze the extent and potential of the philosophies.

**IOE 432. Industrial Engineering Instrumentation Methods**
*Prerequisite: IOE 265. IIIa (4 credits)*
The characteristics and use of analog and digital instrumentation applicable to industrial engineering problems. Statistical methods for developing system specifications. Applications in physiological, human performance, and production process measurements are considered.

**IOE 433 (EIH 556) (Mfg 433). Occupational Ergonomics**
*Prerequisite: Not open to students who have credit for IOE 333. I (3 credits)*
Principles, concepts, and procedures concerned with worker performance, health, and safety. Topics include biomechanics, work physiology, psychophysics, work stations, tools, work procedures, work standards, musculoskeletal disorders, noise, vibration, heat stress, and the analysis and design of work.

**IOE 436. Human Factors in Computer Systems**
*Prerequisite: IOE 333. II (4 credits)*
This course discusses how to design and evaluate computer systems for ease of use. Topics to be covered include keyboards and how people type, vision and video display design, human body size and computer furniture, regulations concerning working conditions, software issues, methods for studying user performance, documentation, and information systems of the future.

**IOE 438. Occupational Safety Management**
*Prerequisite: IOE 265. II (2 credits)*
Survey of occupational safety management methods, theories and activities. Topics include: history of safety engineering, management, and worker compensation; collection and critical analysis of accident data; safety standards, regulations and regulatory agencies; theories of self-protective behavior and accident prevention; and analysis of safety program effectiveness.

**IOE 439. Advanced Topic in Safety Management**
*Prerequisite: IOE 438. II (2 credits)*
Lectures and case studies addressing advanced topics in occupational and product safety management. Topics include: analysis of human factors related to injury prevention; research methods related to accident/incident data; safety standards development; methods of risk assessment and reduction; and advanced hazard communication. A wide variety of case studies are analyzed.

**IOE 441 (Mfg 441). Production and Inventory Control**
*Prerequisite: IOE 310, IOE 316. I, II (4 credits)*
Basic models and techniques for managing inventory systems and for planning production. Topics include deterministic and probabilistic inventory models; production planning and scheduling; and introduction to factory physics.

**IOE 447 (Mfg 447). Facility Planning**
*Prerequisite: IOE 310, IOE 316. I (4 credits)*
Fundamentals in developing efficient layouts for single-story and multi-story production and service facilities. Manual procedures and microcomputer-based layout algorithms. Algorithms to determine the optimum location of facilities. Special considerations for multi-period, dynamic layout problems.

**IOE 449 (Mfg 449). Material Handling Systems**
*Prerequisite: IOE 310, IOE 316. II alternate years (2 credits)*
Review of material handling equipment used in warehousing and manufacturing. Algorithms to design and analyze discrete parts material storage and flow systems such as Automated Storage/Retrieval Systems, order picking, conveyors, automated guided vehicle systems, and carousels.

**IOE 451. Engineering Economy**
*Prerequisite: IOE 201. (2 credits) (Not for IOE graduate credit)*
The logic of economic decision making is developed with emphasis on engineering, management, and personal finance. Measures of worth are discussed in detail and compared. Decisions involving taxes, depreciation, multiple alternatives, and replacement are considered.

**IOE 452 (Mfg 455). Capital Budgeting**
*Prerequisite: IOE 201, IOE 310, IOE 366. II (2 credits)*
The financial background for capital budgeting decisions is developed. Decisions with capital rationing, portfolio optimization, and rate selection are considered. Examples and cases are used to illustrate the capital asset pricing model and efficient market theory.

**IOE 453 (Mfg 456). Financial Engineering**
*Prerequisite: IOE 201, IOE 310, IOE 366. II (2 credits)*
The tools, methodology, and basic theory of financial engineering is developed. Decisions involving option pricing, hedging with futures, asset-liability, matching, and structuring synthetic securities are considered and illustrated with examples and cases.

**IOE 460. Decision Analysis**
*Prerequisite: IOE 265, IOE 310. II (2 credits)*
Analysis of decisions under uncertainty. Decision trees, influence diagrams, value of information, attitudes towards risk, expected utility; applications from production, inspection, quality control, medicine, finance.

**IOE 463 (Mfg 463). Work Measurement and Prediction**
*Prerequisite: IOE 333, IOE 334, IOE 366. I (2 credits)*
Contemporary work measurement techniques are used to evaluate, predict, and enhance human performance through improved design of manufacturing and service work environments. Lectures and laboratory exercises cover the following topics: human variability in work performance, time study, learning curves, performance rating, allowances, work sampling, and pre-determined time systems.

**IOE 465. Design and Analysis of Experiments**
*Prerequisite: IOE 366. I (4 credits)*
Linear Models, Multi-collinearity and Robust Regression, Comparative Experiments, Randomized Blocks and Latin Squares, Factorial Designs, Confounding, Mixed Level Fractional Factorials, Random and Mixed Models, Nesting and Split Plots, Response Surface Methods, Taguchi Contributions to Experimental Design.

**IOE 466 (Mfg 466) (Stat 466). Statistical Quality Control**
*Prerequisite: IOE 265 (Stat 265) and IOE 366 or Stat 403. I, II (4 credits)*
Quality Improvement Philosophies; Modeling Process Quality, Statistical Process Control, Control Charts for Variables and Attributes, CUSUM and EWMA, Short Production Runs, Multivariate Quality Control, Auto Correlation, Engineering Process Control, Economic Design of Charts, Fill Control, Precontrol, Adaptive Schemes, Process Capability, Specifications and Tolerances, Gage Capability Studies, Acceptance Sampling by Attributes and Variables, International Quality Standards.

**IOE 474. Simulation**
*Prerequisite: IOE 316, IOE 366, IOE 373. I, II (4 credits)*
Simulation of complex discrete-event systems with applications in industrial and service organizations. Course topics include modeling and programming simulations in one or more high-level computer packages such as ProModel or GPSS/H; input distribution modeling; generating random numbers; statistical analysis of simulation output data. The course will contain a team simulation project.

**IOE 481. Practicum in Hospital Systems**
*Prerequisite: senior standing, permission of instructor; not for graduate credit. I, II (4 credits)*
Student team projects in hospital systems. Projects will be offered from areas of industrial and operations engineering, including work measurement and control, systems and procedures, management, organization and information systems. Lectures will deal with the hospital setting and project methodologies. The final report should demonstrate a mastery of the established technical communication skills. The report will be reviewed and edited to achieve the outcome.

**IOE 490. Directed Study, Research, and Special Problems I**
*Prerequisite: permission of department; mandatory pass/fail. (2-4 credits)*
Individual or group study, design, or laboratory research in a field of interest to the student or group. Topics may be chosen from any area of industrial and operations engineering including management, work measurement, systems, and procedures.

**IOE 491. Special Topics in Industrial and Operations Engineering**
*(to be arranged)*
Selected topics of current interest in industrial and operations engineering.

**IOE 499. Senior Design Projects**
*Prerequisite: senior standing, permission of advisor. I, II (4 credits)*
Selected design projects in industrial and operations engineering to be conducted for project sponsors. The final report submitted by the students should demonstrate a mastery of the established communication skills. The final project report will be reviewed to achieve this outcome.

**IOE 510 (Math 561) (SMS 518). Linear Programming I**
*Prerequisite: Math 217, Math 417, or Math 419. I, II, IIIa (3 credits)*
Formulation of problems from the private and public sectors using the math-

ematical model of linear programming. Development of the simplex algorithm; duality theory and economic interpretations. Postoptimality (sensitivity) analysis application and interpretations. Introduction to transportation and assignment problems; special purpose algorithms and advance computational techniques. Students have opportunities to formulate and solve models developed from more complex case studies and to use various computer programs.

**IOE 511 (Aero 577) (Math 562). Continuous Optimization Methods**

*Prerequisite: Math 217, Math 417 or Math 419. I, II (3 credits)*

Survey of continuous optimization problems. Unconstrained optimization problems: unidirectional search techniques; gradient, conjugate direction, quasi-Newton methods. Introduction to constrained optimization using techniques of unconstrained optimization through penalty transformations, augmented Lagrangians, and others. Discussion of computer programs for various algorithms.

**IOE 512. Dynamic Programming**

*Prerequisite: IOE 510, IOE 316. II (3 credits)*

The techniques of recursive optimization and their use in solving multistage decision problems, applications to various types of problems, including an introduction to Markov decision processes.

**IOE 515. Stochastic Processes**

*Prerequisite: IOE 316 or Stat 310. I (3 credits)*

Introduction to non-measure theoretic stochastic processes. Poisson processes, renewal processes, and discrete time Markov chains. Applications in queueing systems, reliability, and inventory control.

**IOE 517 (EECS 509). Traffic Modeling**

*Prerequisite: IOE 316, Stat 310, or EECS 401. I alternate years (3 credits)*

Traffic Models and their analysis in the context of ITS (Intelligent Transportation Systems). Those aspects of traffic theory relevant to ITS are presented including traffic flow and signalized intersections, with particular emphasis on the optimization via route guidance and signal control of large scale traffic networks.

**IOE 522. Theories of Administration**

*Prerequisite: IOE 421. II (3 credits)*

Provide insight into leading theories concerning the administration of research and industrial organizations. Treat the concepts needed for describing, assessing, and diagnosing organizations; processes of organizational communication, motivation, and conflict management; adaptation of organization systems to the requirements of work and information technologies.

**IOE 523. Comparative Technology Management Seminar**

*Prerequisite: IOE 421. II (3 credits)*

U.S. Technology management systems are compared to those of other countries. Early offerings of the course focus on Japan, though this may shift to other countries or regions. Covers the technology life cycle from basic research to product development to manufacturing systems and the implications for technology management in the U.S.

**IOE 533 (Mfg 535). Human Factors in Engineering Systems I**

*Prerequisite: IOE 365, IOE 333, IOE 433 (EIH 556). I (3 credits)*

Principles of engineering psychology applied to engineering and industrial production systems. Visual task measurement and design, psychophysical measurements, signal detection theory and applications to industrial process control. Human information processing, mental workload evaluation, human memory and motor control processes.

**IOE 534 (BiomedE 534) (Mfg 534). Occupational Biomechanics**

*Prerequisite: IOE 333, IOE 334, or IOE 433 (EIH 556). II (3 credits)*

Anatomical and physiological concepts are introduced to understand and predict human motor capabilities, with particular emphasis on the evaluation and design of manual activities in various occupations. Quantitative models are developed to explain (1) muscle strength performance; (2) cumulative and acute musculoskeletal injury; (3) physical fatigue; and (4) human motion control.

**IOE 536. Cognitive Ergonomics**

*Prerequisite: IOE 333 or IOE 433. (3 credits)*

Theories and concepts of human information processing are introduced to analyze human perceptual and cognitive performance in human machine information systems such as intelligent transportation and manufacturing systems. Conceptual and quantitative models, interface design techniques, and research and evaluation methods are presented. Samples of on-going research are also discussed.

**IOE 539 (Mfg 539). Occupational Safety Engineering**

*Prerequisite: IOE 265 or Biostat 500. I (3 credits)*

Design/modification of machinery/products to eliminate or control hazards arising out of mechanical, electrical, thermal, chemical, and motion energy sources. Application of retrospective and prospective hazard analysis, systems safety, expert systems and accident reconstruction methodologies. Case examples: industrial machinery and trucks, construction and agriculture equipment, automated manufacturing systems/processes.

**IOE 541 (Mfg 541). Inventory Analysis and Control**

*Prerequisite: IOE 310, IOE 316. II. (3 credits)*

Models and techniques for managing inventory systems and for planning production. Topics include single item and multi-item inventory models, production planning and control, and performance evaluation of manufacturing systems.

**IOE 543 (Mfg 543). Scheduling**

*Prerequisite: IOE 316, IOE 310. II alternate years (3 credits)*

The problem of scheduling several tasks over time, including the topics of measures of performance, single-machine sequencing, flow shop scheduling, the job shop problem, and priority dispatching. Integer programming, dynamic programming, and heuristic approaches to various problems are presented.

**IOE 545 (Mfg 545). Queueing Networks**

*Prerequisite: IOE 515 or EECS 501. (3 credits)*

Introduction to queueing networks. Topics include product and non-product form networks, exact results and approximations, queueing networks with blocking, and polling systems. Applications from manufacturing and service industries are given as examples.

**IOE 547 (Mfg 548). Plant Flow Systems**

*Prerequisite: IOE 310, IOE 416. II (3 credits)*

Analytical models for the design and throughput performance evaluation of material handling systems used in discrete parts flow production facilities. Analysis of design and control issues for manual and automated handling systems including lift trucks, micro-load automatic storage/retrieval systems and automated guided vehicle systems.

**IOE 548. Integrated Product Development**

*Prerequisite: graduate standing, co-reg. I (3 credits)*

Cross-disciplinary teams compete to design, manufacture, plan mass production and market a defined product. Major objectives are integration of engineering and business aspects of these issues.

**IOE 552. Financial Engineering I**

*Prerequisite: IOE 452. I (3 credits)*

Theory and applications of financial engineering. Designing, structuring and pricing financial engineering products (including options, futures, swaps and other derivative securities) and their applications to financial and investment risk management. Mathematical methodology that forms the basis of financial engineering, applied stochastic processes and numerical methods in particular.

**IOE 553. Financial Engineering II**

*Prerequisite: IOE 552. II (3 credits)*

Advanced issues in financial engineering: stochastic interest rate modeling and fixed income markets, derivative trading and arbitrage, international finance, risk management methodologies including Value-at-Risk and credit risk. Multivariate stochastic calculus methodology in finance: multivariate Itoís lemma, Itoís stochastic integrals, the Feynman-Kac theorem and Girsanovís theorem.

**IOE 560 (Stat 550) (SMS 603). Bayesian Decision Analysis**
*Prerequisite: IOE 366 or Stat 426. (3 credits)*
Axiomatic foundations for, and assessment of, probability and utility; formulation of decision problems; risk functions, admissibility; likelihood functions and the likelihood principle; natural conjugate a priori distributions; Baysian regression analysis and hypothesis testing; hierarchical models; credible intervals; numerical analysis; applications to decision-making.

**IOE 562 (Stat 535). Reliability**
*Prerequisite: IOE 316 and IOE 366 or Stat 425 and Stat 426. I (3 credits)*
Reliability concepts and methodology for modeling, assessing and improving product reliability: common models for component and system reliability; analysis of field and warranty data; component reliability inference; repairable systems; accelerated stress testing for reliability assessment; reliability improvement through experimental design.

**IOE 563. Labor and Legal Issues in Industrial Engineering**
*Prerequisite: IOE 433 or IOE 463. (3 credits)*
A case study approach to engineering related issues in union-management relations, professional and product liability, and worker rights legislation.

**IOE 565 (ME 563) (Mfg 561). Time Series Modeling, Analysis, Forecasting**
*Prerequisite: IOE 366 or ME 401. I (3 credits)*
Time series modeling, analysis, forecasting, and control, identifying parametric time series, autovariance, spectra, Green's function, trend and seasonality. Examples from manufacturing, quality control, ergonomics, inventory, and management.

**IOE 566 (Mfg 569). Advanced Quality Control**
*Prerequisite: IOE 466. (3 credits)*
An applied course on Quality Control including Statistical Process Control Modifications, Linear, Stepwise and Ridge Regression Applications, Quality Function Deployment, Taguchi Methods, Quality Policy Deployment, Tolerancing Systems, Process Control Methodologies and Measurement Systems and Voice of the Customer Methodologies Time Series, Experimental Design, Total Quality Management and case studies.

**IOE 567 (Mfg 568). Advanced Work Measurement and Design**
*Prerequisite: IOE 433 or IOE 463. (3 credits)*
Nontraditional approaches to job evaluation are applied to a variety of manufacturing and service jobs. Topics include computer-aided job analyses and design, ergonomic work measurement, evaluation of "white collar" productivity

**IOE 573. Analysis, Design, and Management of Large-Scale Administrative Information Processing Systems**
*Prerequisite: IOE 473. (3 credits)*
Introduction to informal and formal techniques or analysis, design, and management of large scale information processing systems in administrative environments; presentation of techniques to control and aid in the process by which computer systems are developed with major emphasis on the collection and analysis of user requirements.

**IOE 574. Simulation Analysis**
*Prerequisite: IOE 515. II alternate years (3 credits)*
Underlying probabilistic aspects of simulation experiments, statistical methodology for designing simulation experiments and interpreting output. Random number generators, variate and process generation, output analysis, efficiency improvement techniques, simulation and optimization, how commercial simulation software works. Applications from telecommunications, manufacturing statistical analysis.

**IOE 575. Information Processing System Engineering**
*Prerequisite: IOE 473. (3 credits)*
Software design methodologies for development of large-scale information processing systems. Application of database management systems, distributed processing, microprocessors and communication networks. Design and use of computer-aided software development systems. Software engineering and project management. Ergonomics aspects of information systems. Emphasis is placed on practical experience in software design projects.

**IOE 583 (ME 583) (Mfg 583) (EECS 566). Scientific Basis for Reconfigurable Manufacturing**
*Prerequisite: Graduate standing or permission of instructor. II alternate years (3 credits)*
Principles of reconfigurable manufacturing systems (RMS). Students will be introduced to fundamental theories applicable to RMS synthesis and analysis. Concepts of customization, integratability, modularity, diagnosability, and convertability. Reconfiguration design theory, life-cycle economics, open-architecture principles, controller configuration, system reliability, multi-sensor monitoring, and stream of variations. Term projects.

**IOE 588 (ME 588) (Mfg 588). Assembly Modeling for Design and Manufacturing**
*Prerequisites: ME 381 and ME 401 or equivalent. I alternate years (3 credits)*
Assembly on product and process. Assembly representation. Assembly sequence. Datum flow chain. Geometric Dimensioning & Tolerencing. Tolerance analysis. Tolerance synthesis. Robust design. Fixturing. Joint design and joining methods. Stream of variation. Auto body assembly case studies.

**IOE 590. Directed Study, Research, and Special Problems II**
*Prerequisite: permission of instructor. (3 credits maximum)*
Continuation of IOE 490.

**IOE 591. Special Topics**
*Prerequisite: permission of instructor. (to be arranged)*
Selected topics of current interest in industrial and operations engineering.

**IOE 593. Ergonomics Professional Project**
*Prerequisite: graduate standing, permission of instructor. I, II, III, IIIa, IIIb (2-4 credits)*
Students work as part of a team within a production or service organization on a design project that emphasizes the application of ergonomic principles to enhance the safety, productivity, and/or quality aspects of a human machine system.

**IOE 600 (Aero 651) (EECS 600). Function Space Methods in System Theory**
*Prerequisite: EECS 400 or Math 419. I, II (3 credits)*
Introduction to the description and analysis of systems using function analytic methods. Metric spaces, normed linear spaces, Hilbert spaces, resolution spaces. Emphasis on using these concepts in systems problems.

**IOE 610 (Math 660). Linear Programming II**
*Prerequisite: IOE 510, (Math 561). II (3 credits)*
Primal-dual algorithm. Resolution of degeneracy, upper bounding. Variants of simplex method. Geometry of the simplex method, application of adjacent vertex methods in non-linear programs, fractional linear programming. Decomposition principle, generalized linear programs. Linear programming under uncertainty. Ranking algorithms, fixed charge problem. Integer programming. Combinatorial problems.

**IOE 611 (Math 663). Nonlinear Programming**
*Prerequisite: IOE 510, (Math 561). I (3 credits)*
Modeling, theorems of alternatives, convex sets, convex and generalized convex functions, convex inequality systems, necessary and sufficient optimality conditions, duality theory, algorithms for quadratic programming, linear com-

plementary problems, and fixed point computing. Methods of direct search, Newton and Quasi-Newton, gradient projection, feasible direction, reduced gradient; solution methods for nonlinear equations.

**IOE 612. Network Flows**
*Prerequisite: IOE 510. (3 credits)*
Flow problems on networks. Maximum flow minimum cut theorem. Labeling algorithms. Circulation and feasibility theorems. Sensitivity analysis. Incidence matrices. Shortest routes. Minimum cost flows, out-of-kilter algorithm. Critical path networks, project cost curves. Multi-commodity flow problem, biflows. Matching problems in graph theory.

**IOE 614. Integer Programming**
*Prerequisite: IOE 510. (3 credits)*
Modeling with integer variables, total unimodularity, cutting plane approaches, branch-and-bound methods, Lagrangian relaxation, Bender's decomposition, the knapsack, and other special problems.

**IOE 615. Advanced Stochastic Processes**
*Prerequisite: IOE 515 and Math 451. II odd years (3 credits)*
Designed for students planning to do research on stochastic models in operations research (e.g., queuing systems, stochastic scheduling, financial models, simulation, etc.) Topics covered include Martingales, Brownian motion, diffusion processes, limit theorems, and coupling.

**IOE 616. Queueing Theory**
*Prerequisite: IOE 515. II alternate years (3 credits)*
Theoretical foundations, models and techniques of queueing theory. Rigorous treatment of elementary through advanced queueing systems and queueing networks. Topics include Markov Renewal and Semi-Regenerative Processes.

**IOE 633 (Mfg 634). Man-Machine Systems**
*Prerequisite: IOE 533 or IOE 536 or equivalent. II (3 credits)*
Introduction to advanced concepts in the identification, design, analysis, development, and implementation of human operated systems; existing and emerging systems identified from industrial and service organizations. Students handle case examples. Relevant theories of communication, decision, and control augmented by readings and laboratory demonstrations when appropriate.

**IOE 634 (EIH 705). Work-Related Upper Limb Disorders**
*Prerequisite: graduate standing and previous ergonomics, biomechanics or work physiology course. II (2 credits)*
For students with an advanced interest in the causes of work-related muscle, tendon, and nerve disorders and in the analysis and design of jobs. The course format includes (1) lectures, discussions, and readings for an overview; (2) work site visits with written and oral reports on analysis and design of jobs; and (3) oral and written reports comparing published papers chosen by the students.

**IOE 635 (BiomedE 635). Laboratory in Biomechanics and Physiology of Work**
*Prerequisite: IOE 534 (BiomedE 534). II (2 credits)*
This laboratory is offered in conjunction with the Occupational Biomechanics lecture course (IOE 534) to enable students to examine experimentally (1) musculoskeletal reactions to volitional acts; (2) the use of electromyography (EMGs) to evaluate muscle function and fatigue; (3) biomechanical models, (4) motion analysis system; and (5) musculoskeletal reactions to vibrations.

**IOE 636. Laboratory in Human Performance**
*Prerequisite: preceded or accompanied by IOE 533. I alternate years (2 credits)*
This optional lab is offered in conjunction with IOE 533 to provide an experimental perspective on (1) the major processes of human behavior (reflexes, motor control); (2) information measurement; (3) psychophysics; and (4) controls and displays.

**IOE 640. Mathematical Modeling of Operational Systems**
*Prerequisite: IOE 510, IOE 515. II alternate years (3 credits)*
The art and science of developing, using and explicating mathematical models, presented in a studio/workshop environment. Structuring of a variety of operational situations" so they can be reasonably represented by a mathematical model. Extensive class discussion and out-of-class investigation of potential mathematical approaches to each situation. Incorporation of data analysis.

**IOE 641. Supply Chain Management**
*Prerequisite: IOE 510, IOE 515 and IOE 541. I alternate years (3 credits)*
Structural analyses of production and inventory systems. Review of issues in supply chain management. Topics include inventory systems with stochastic lead time, multi-echelon supply systems, and coordination of material flows, information flows and financial flows in a supply chain.

**IOE 645 (Mfg 645) (Stat 645). Topics in Reliability and Maintainability**
*Prerequisite: IOE 515 (Stat 526) and IOE 562 (Stat 535). II alternate years (3 credits)*
Advanced topics in reliability and maintainability. Examples include models for component and system reliability, probabilistic design, physics of failure models, degradation modeling and analysis, models form maintainability and availability, and maintenance and monitoring policies.

**IOE 690. Graduate Study in Selected Problems I**
*Prerequisite: permission of graduate committee (to be arranged)*

**IOE 691. Special Topics**
*Prerequisite: permission of instructor (to be arranged)*
Selected topics of current interest in industrial and operations engineering.

**IOE 712. Infinite Horizon Optimization**
*Prerequisite: IOE 512. II alternate years (3 credits)*
A seminar on optimization problems with an infinite time horizon. Topics include topological properties, optimality definitions, decision/forecast horizons, regenerative models, and stopping rules. Applications discussed include capacity expansion, equipment replacement, and production/inventory control.

**IOE 790. Graduate Study in Selected Problems II**
*Prerequisite: permission of graduate committee (to be arranged)*

**IOE 800. First-Year Doctoral Seminar**
*Prerequisite: permission of instructor. I (1 credit)*
Presentation by IOE faculty members of current and future research activities within the department. Discussion of procedural, philosophical, and professional aspects of doctoral studies in industrial and operations engineering.

**IOE 801. Directed Research**
*Prerequisite: IOE 800, concurrent with IOE 802; mandatory satisfactory/unsatisfactory. (1-3 credits)*
Directed research on a topic of mutual interest to the student and the instructor. This course complements IOE 800, First-Year Doctoral Seminar. Research presented in IOE 802.

**IOE 802. Research Presentation**
*Prerequisite: IOE 800, concurrent with IOE 801; mandatory satisfactory/unsatisfactory. II (1 credit)*
Students present oral and written technical material, including research in IOE 801.

**IOE 810. Seminar in Mathematical Programming**
*Prerequisite: permission of instructor. (1-2 credits)*

**IOE 815. Seminar in Stochastic Service Systems**
*Prerequisite: permission of instructor (1-3 credits)*
A working seminar for researchers in stochastic service systems.

**IOE 825. Seminar in Design and Manufacturing**
*Prerequisite: graduate standing; mandatory satisfactory/unsatisfactory. I, II (1 credit)*
Invited speakers present advanced concepts in manufacturing.

**IOE 836. Seminar in Human Performance**
*Prerequisite: graduate standing. (1-2 credits)*
Case studies of research techniques used in the human performance and safety fields. Speakers actively engaged in research will discuss their methods and results.

**IOE 837. Seminar in Occupational Health and Safety Engineering**
*Prerequisite: graduate standing. (1-2 credits)*
This seminar provides an opportunity for graduate students interested in occupational health and safety engineering problems to become acquainted with various related contemporary research and professional activities, as presented by both staff and guest speakers.

**IOE 843. Seminar in Operations Research**
*(1-2 credits)*
Study of recent developments and on-going research in OR methodology, operational science and OR practice.

**IOE 873. Seminar in Administrative Information Processing Systems**
*Prerequisite: IOE 575. (1-3 credits)*
Recent developments, case studies, and individual or group development projects in administrative information processing systems.

**IOE 899. Seminar in Industrial and Operations Engineering**
*Prerequisite: permission of instructor; not for master's degree; mandatory satisfactory/unsatisfactory. I, II (1 credit)*
Presentation by IOE faculty members and outside speakers on current and future research activities in industrial and operations engineering.

**IOE 906. Master's Thesis Project**
*Prerequisite: permission of department.*
*(6 credits maximum total-may be spread over several terms)*

**IOE 916. Professional Thesis Project**
*Prerequisite: permission of department. (to be arranged)*

**IOE 990. Dissertation/Pre-Candidate**
*Prerequisite: permission of department. I, II, III (2-8 credits); IIIa, IIIb (1-4 credits)*
Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**IOE 995. Dissertation/Candidate**
*Prerequisite: Graduate School authorization for admission as a doctoral candidate. I, II, III (8 credits); IIIa, IIIb (4 credits)*
Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

## Industrial and Operations Engineering Faculty

Lawrence M. Seiford, Ph.D., *Chair and Professor*

### Professors

Thomas Armstrong, Ph.D.
James C. Bean, Ph.D.; *also Associate Dean for Graduate Education*
Yavuz Bozer, Ph.D.
Don B. Chaffin, Ph.D., P.E., *G. Lawton and Louise G. Johnson Professor of Engineering*
Gary D. Herrin, Ph.D.; *also Assistant Dean for Students*
Barry H. Kantowitz, Ph.D.; *also Director of UMTRI*
W. Monroe Keyserling, Ph.D.
Jeffrey K. Liker, Ph.D.
Katta G. Murty, Ph.D.
Vijay Nair, Ph.D.
Stephen M. Pollock, Ph.D., *Herrick Professor of Manufacturing*
Romesh Saigal, Ph.D.
Robert L. Smith, Ph.D.
Chelsea C. White III, Ph.D.
C. Jeff Wu, Ph.D.

### Adjunct Professor

Seth Bonder, Ph.D.

### Professors Emeritus

Walton M. Hancock, D. Eng., P.E.
Daniel Teichroew, Ph.D.
Richard C. Wilson, Ph.D.

### Associate Professors

Izak Duenyas, Ph.D.
Yili Liu, Ph.D.
Bernard J. Martin, Ph.D.
Jianjun Shi, Ph.D.

### Adjunct Associate Professors

Richard J. Coffey, Ph.D.
Paul A. Green, Ph.D.

### Associate Professor Emeritus

James M. Miller, Ph.D., P.E.

### Assistant Professors

Stephen E. Chick, Ph.D.
Marina A. Epelman, Ph.D.
Shane G. Henderson, Ph.D.
Jussi Keppo, Ph.D.
Mark E. Lewis, Ph.D.

### Adjunct Assistant Professors

Patrick C. Hammett, Ph.D.

### Lecturers

James A. Foulke, B.S.E. (E.E.)
Charles Woolley, M.S. (Bio.E.)

### Adjunct Lecturers

Andrew S. Crawford, M.B.A.
Glenn H. Mazur, M.B

## Industrial and Operations Engineering Contact Information

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# INTERDISCIPLINARY DEGREE PROGRAMS

*Program Advisor*
*Professor William Schultz*
*2027 AutoLab*
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Recent technological, economic, and social developments have significantly extended the range of problems to which engineering skills and methodologies must be applied. Problems in environmental quality, transportation systems, and urban planning, among others, challenge students to develop programs combining technical knowledge with social and political awareness. In addition, the complexity of our technological society requires that some engineers integrate studies in several technical areas.

To meet these needs, the Interdisciplinary Engineering Program—B.S. (Engineering)—allows students to combine studies in several engineering fields or to combine studies in engineering with studies in other fields. This program can prepare students for a wide variety of career and graduate school opportunities while providing a distinctive undergraduate education.

The program, however, is suited only for those students who have clearly defined career goals. Because the degree is non-departmental, the program does not provide the conventional career opportunities available to students in departmental programs.

Successful completion of the Interdisciplinary Undergraduate Degree Program results in a B.S. degree rather than a B.S.E. degree. Students who need a standard engineering background should consider a departmental B.S.E. program.

## Interdisciplinary Areas

Students with interdisciplinary goals devise a program option based on the course offerings of various departments in the College and elsewhere in the University. These programs may be one of the following:

1. *A pre-professional or pre-graduate program.* The student chooses, for example, a pre-law, pre-medicine, pre-dentistry, pre-public administration, pre-business administration, pre-bioengineering, or pre-public systems engineering option. Most B.S. (Engineering) students have an option in one of these areas.
2. *An interdepartmental College-wide program.* The student crosses traditional boundaries in technical disciplines to study in areas such as manufacturing, integrated transportation systems, or technical communication. Before considering an option in one of the areas, students should investigate the possibilities in departmental programs.
3. *An interdisciplinary University-wide program.* The student combines studies in the mathematical and physical sciences, the social sciences, natural resources, business administration, architecture, or industrial design with complementary studies in engineering. Most students obtain combined or dual degrees when they choose an option in one of these areas.

Students are able to pursue these goals by choosing from advanced courses in other fields and colleges as well as in engineering.

Students also should note that this program does not meet the requirement of the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET) for Professional Engineering Certification.

## Program Design

Each student is asked to define his or her own educational goals and to design a program with the advice of the program advisor. It is very important to choose a purposeful sequence of advanced engineering concentration courses to complement an integrated sequence of program option courses. Together these form a "major."

Such a program, however, results from the student's own decisions. Since there is no structure of prerequisite and required courses in the junior and senior years, within the constraints explained below, this program is flexible and allows considerable freedom to choose courses.

The outline of studies demonstrates the well-rounded college education provided by the Interdisciplinary Engineering Program. Few degree programs in any university allow such a balanced distribution of science, mathematics, social science, humanities, and engineering courses.

**Note:** The combined hours for Engineering Science and Engineering Concentration courses must total at least 40 hours.

## Program Option Courses

This group of courses is selected by students to provide a unified program of study oriented to their educational career goals. The program option can include courses from throughout the University, including additional engineering courses. For most program options, these should be 300-, 400-, and 500-level courses.

Each student is encouraged to design a curriculum that reflects his/her individual goals. Some of the possible options are identified below. (Some options involve combined or dual degree programs with other schools and colleges; although, that is not the route most students take.)

### Pre-Law

Students choose this option to prepare for law school to become attorneys in a law firm or to specialize in an area such as corporate law where they use their technical training as a member of a corporate staff. However, a B.S.E. degree from an engineering department is a viable pre-law alternative.

### Pre-Medicine

Students choose this option to become physicians or to go into biomedical research where they can use their technical training. However, a chemical engineering degree is also an appropriate pre-medical degree.

### Pre-Bioengineering

Students choose this option to prepare for a graduate program in bioengineering, a field related to medical research in which analytical methods are applied to problems in living systems and in design of new biological structures. However, graduate programs in bioengineering do not require undergraduate training in bioengineering, so several other B.S.E. degrees are also excellent preparation.

### Pre-Business Administration or Business Administration

Some students combine business courses with engineering courses to prepare for a career in business. Some students earn a Master of Business Administration (M.B.A.) after completing a B.S. in Engineering. About half of all engineers who enter industry eventually assume managerial responsibilities. Students interested in this program option should consider whether or not a degree in Industrial and Operations Engineering would be more appropriate than the B.S. (Engineering) degree. Furthermore, any engineering degree provides sound preparation for an M.B.A. program.

### Technical Sales and Applications Engineering

Students combine engineering, communications, and business to prepare for positions in these fields. Many companies require sales engineers to design and market products that meet the needs of other corporations and government agencies. These persons serve as liaison between their corporations' research, design, product, and manufacturing engineers and the customers' engineers and managers.

### Appropriate Technology

Students interested in alternative technologies design program options in appropriate technology, alternative energy resources, or environmental systems.

### Urban and Regional Planning

An increasing number of engineers become planners and administrators in urban systems because they know sophisticated technology or are trained in problem solving and systems design. Related options are in architecture, sociology, natural resources, and transportation. This option primarily is a pre-graduate-school option.

### Industrial Design

Some students pursue a combined degree program with the School of Art, usually in industrial design, but occasionally in graphics. The combination prepares students for careers meeting challenges in human/technology interface systems or in computer graphics.

### Technical and Professional Communication

Students choose this option either to enhance their qualifications for careers as managers in industry, business, and government or to prepare themselves for careers as technical communicators. The option is distinctive among technical communication programs in the United States because its graduates combine engineering skills with communication skills. It is good preparation for a graduate program in technical communication.

### Science

Students choose this option to prepare for a graduate program in mathematics, biology, or one of the physical sciences. Students choosing this option select a program of study roughly equivalent to that of a mathematics or science student in LSA. Other options for such students are the Pre-Bioengineering option and the Engineering Physics option.

## Engineering Concentration Courses

The engineering concentration courses complement the program option courses. The student elects a sequence of engineering courses that must have coherence with respect to subject matter and progression with respect to level of study. In environmental studies, for example, program option courses in the life sciences, natural resources, or geophysical sciences are complemented by engineering concentration courses from Civil and Environmental Engineering, Chemical Engineering, Aerospace Engineering, and Atmospheric, Oceanic and Space Sciences. In business administration, courses in systems, planning, management, operations, decision-making, and design—from several engineering fields—complement the program option. These should be 300-, 400-, and 500-level courses.

## Engineering Science Courses

The Engineering Science courses provide science-based skills applicable to engineering problems. Most courses are at the 200- and 300-level and are prerequisites for many advanced engineering courses. These courses for the most part are those required in all engineering degree programs.

Each student in the program must select courses from the list in at least four of the following areas:

*Computer Methods*
CEE 303 (4) or AOSS 408 (3)

*Electrical*
EECS 210 (4) or EECS 230 (4)

*Environmental*
AOSS 304 (3), AOSS 305 (3), CEE 260 (4)

*Materials*
MSE 150 (4) or MSE 250 (4), ME 382 (4)

*Mechanical*
ME 211 (4), ME 240 (4), NAME 320 (4) or ME 320 (3)

*Systems*
IOE 201 (2) and 202 (2), IOE 265 (4), IOE 310 (4)

*Thermodynamics*
ME 230 (4) or ChemE 230 (4)

Together with the Engineering Concentration courses, these courses provide the engineering basis of the B.S. (Engineering) degree. These requirements must be adhered to.

## Educational Goals Statement

For the Interdisciplinary Engineering program, students are asked to write a statement of their educational goals and career objectives, explaining how their course selections will contribute toward these goals. Goals may be modified as the student progresses. Finally, students are encouraged to explore postgraduate opportunities and alternative career paths.

## Sample Schedule B.S. Engineering

| | Credit Hours | Terms 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| **Subjects required by all programs (52 hrs.)** | | | | | | | | | |
| Mathematics 115, 116, 215, and 216 | **16** | 4 | 4 | 4 | 4 | - | - | - | - |
| Engr 100, Intro to Engr | **4** | 4 | - | - | - | - | - | - | - |
| Engr 101, Intro to Computers | **4** | - | 4 | - | - | - | - | - | - |
| [1]Chemistry 125 and 130 | **(5) 4** | - | - | 4 | - | - | - | - | - |
| [2]Physics 140 with Lab 141; 240 with Lab 241 | **(10) 8** | 4 | 4 | | - | - | - | - | - |
| Humanities and Social Sciences *(Include one 4-hour course in Economics)* | **16** | 4 | 4 | - | 4 | - | - | 4 | - |
| **Engineering Science (18-20 hrs.)** | **18-20** | - | - | 3 | 6 | 6 | 3 | - | - |
| **Program Subjects (40-42 hrs.)** | | | | | | | | | |
| Engineering Concentration | 20-22 | - | - | - | 3 | 3 | 6 | 6 | 4 |
| Program Option Courses | 20 | - | - | 3 | - | 3 | 4 | 4 | 6 |
| **[3]Unrestricted Electives (13-17 hrs.)** | **13-17** | - | - | 3 | 3 | - | - | 5 | 5 |
| **Total** | **128** | 16 | 16 | 17 | 16 | 16 | 17 | 15 | 15 |

Candidates for the Bachelor of Science degree (Engineering)—(B.S. Engineering)—must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

**Notes:**
[1]Chemistry:125, 130 will count for 5 total credits, 1 of which will be applied according to individual program directives.
[2]Physics: 140, 141; 240, 241 will count for 10 total credits, 2 of which will be applied according to individual program directives.

**Additional Note:**
The combined hours for Engineering Science and Engineering Concentration courses must total at least 40 hours.

# MATERIALS SCIENCE AND ENGINEERING

*Program Advisor*
*Professor William F. Hosford*
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Materials Science and Engineering is widely recognized as one of the most promising technical fields of the 21st century.

Materials scientists and engineers specialize in the characterization, development, production, and use of the metallic, ceramic, polymeric, and electronic materials that are employed in all fields of technology.

Engineering materials have been crucial to the development of civilization since the dawn of history as evidenced by the identification of the Stone Age, the Bronze Age, and the Iron Age with the most advanced materials then available for constructing tools and weapons. More recently, materials scientists and engineers have developed a variety of important materials to meet the needs of our modern technological society, including high-temperature superconductors; ultra-high-purity semiconductor materials for solid-state electronic devices; high-strength alloys for use at the extreme temperatures encountered in jet and rocket engines; strong, light alloys and composites for aerospace applications; specialized glasses and ceramics with high thermal, mechanical, and chemical stability; and a host of polymeric materials, some with unique functional characteristics and others which replace metal, glass, wood, and natural fibers in dozens of applications.

The future role of materials scientists and engineers promises to be even more important and challenging. It is widely recognized that the world is facing a critical energy shortage. Materials scientists and engineers are rising to this challenge in a variety of ways. They are involved with the search to reduce the weight of automobiles and other transportation systems for fuel savings.

Materials scientists and engineers are actively engaged in reducing the impact of modern society on our environment. They are on the forefront of recycling technologies; more energy efficient ways of processing materials are being developed. New materials and processes are being developed to replace environmentally unfriendly methods we currently use (sputtering and vapor deposition instead of plating, biodegradable plastics, etc.)

In addition to these newly developing fields, materials scientists and engineers are in constant demand for a number of more traditional, but equally important and rewarding, activities. These include processing basic materials into forms suitable for use in various manufacturing processes; managing manufacturing processes that critically involve the manipulation of materials properties; modifying existing materials and the development of new materials to meet advanced design requirements; cooperating with mechanical, chemical, aeronautical, automotive and other types of engineers in selecting appropriate materials in the design of various devices; evaluating the performance of materials in service, and particularly, determining the causes and cures for in-service failures; as well as various kinds of supervisory, research, teaching, and management activities.

The tremendous range of materials science and engineering opportunities apply equally in metals, polymers, ceramics and electronic materials. Applications range from the manufacture of basic tools and machines to the development of high-temperature superconductors and components of space probes.

The program in materials science and engineering at the University of Michigan has been carefully designed to prepare students for all the types of activities described above, or for continuing their academic work to acquire a master's or doctoral degree.

Introductory courses (either MSE 220 or MSE 250) and MSE 242, and a second-level course (MSE 350) provide a foundation of basic principles applicable to all classes of materials. Other courses include thermodynamics transport phenomena and mechanical behavior.

Two required laboratory courses give our students a working knowledge of equipment and methods practiced in the materials industry, including processing that uses thermal, chemical, and mechanical methods; characterization using mechanical testing machines, microscopy and diffraction instruments; and analysis of experimental data using statistical and digital methods.

A course in organic chemistry (Chem 210) is required. It may be used to satisfy the engineering requirement for a chemistry course or the technical elective requirement. Statics (ME 211) is also required.

Students have an opportunity to tailor their program of study to meet their interests. They choose three senior-level courses from a group of six covering metals, polymers, ceramics, biomaterials, electrical, magnetic optical properties, and materials characterization. They also choose one additional MSE course, plus 12 hours of technical electives and 12 hours of free electives.

All engineering students are required to take 16 credits of humanities or social sciences to broaden their education. For Master of Science in Engineering (M.S.E.) students, one of the social sciences must be macro- or micro-economics.

This program is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

## Our Mission, Goals, Objectives and Outcomes for Undergraduate Education

### *Mission*

To provide internationally recognized leadership in education, research and service in the field of materials science and engineering through educational programs that graduate students with strong backgrounds in scientific and engineering problem-solving methods.

### *Goals*

- To provide excellent, diverse students with the knowledge and engineering skills in a quality learning environment that will enable them to become flexible, effective life-long learners and leaders in their field.
- To have the leading undergraduate program in the world in materials science and engineering, one that integrates a strong scientific base with substantive engineering hands-on experience.
- To generate knowledge which has the highest possible impact on the quality of life and the technological strength of our State and our Nation.

### *Objectives*

- To provide students with a strong educational foundation in materials science and engineering, with emphasis on the fundamental scientific and engineering principles which underlie the application of knowledge of structure, properties, processing and performance of all classes of materials to engineering systems.
- To teach students all levels of design which relate to materials (electronic, atomistic, molecular, microstructural, mesoscopic, macroscopic), as well as the design of engineering processes and systems.
- To prepare students for a broad range of career opportunities by providing ample flexibility within the program of study for educational experimentation.
- To provide students with opportunities to work in teams, solve open-ended problems, develop skills for critical thinking, and communicate effectively with others orally, in writing, and by listening.
- To provide students with an awareness and understanding of professional, ethical, and legal responsibilities as an integral part of an engineering education.

### *Outcomes*

The outcomes that we desire are that our graduates demonstrate:

- An ability to apply knowledge of mathematics, science, and engineering within their chosen field.
- An ability to formulate engineering problems and develop practical solutions.
- An initial ability to design products and processes applicable to their chosen field.
- An ability to design, conduct, analyze, and interpret the results of engineering experiments.
- An ability to work effectively in diverse teams and provide leadership to teams and organizations.
- An ability for effective oral, graphic and written communication.
- A broad education necessary to understand the impact of engineering decisions in a global/society/economic/environmental context.
- An understanding of professional and ethical responsibility.
- A recognition of the need for and an ability to engage in life-long learning.
- A broad education necessay to contribute effectively beyond their professional careers.
- A sense of responsibility to make a contribution to society.

## Combined Degrees

Materials are critically involved in most fields of engineering; therefore, it is often advantageous to obtain a B.S.E. degree in Materials Science and Engineering in combination with a B.S.E. degree in other fields such as Mechanical, Chemical, Electrical, and Aerospace Engineering. As early as possible, students interested in combined degree programs should consult with the program advisors in both programs to work out optimum combinations of courses.

## Facilities

The facilities for the program in materials science and engineering are housed primarily in the H. H. Dow Building. These include laboratories equipped for basic studies of the structures and properties of metals, polymers, ceramics and electronic materials; special-purpose laboratories for studies of crystal plasticity, high-temperature alloys, and structural composites; and instrument laboratories containing optical and electron microscopes, x-ray diffraction and spectroscopic apparatus, and precision mechanical-testing equipment.

## Sample Schedule B.S.E. Materials Science and Engineering

| | Credit Hours | Terms 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| **Subjects required by all programs (55 hrs.)** | | | | | | | | | |
| Mathematics 115, 116, 215, and 216 | 16 | 4 | 4 | 4 | 4 | - | - | - | - |
| Engr 100, Intro to Engr | 4 | 4 | - | - | - | - | - | - | - |
| Engr 101, Intro to Computers | 4 | - | 4 | - | - | - | - | - | - |
| Chemistry* | 5 | 5 | - | - | - | - | - | - | - |
| Physics 140 with Lab 141 or | 5 | - | 5 | - | - | - | - | - | - |
| 240 with Lab 241 | 5 | - | - | 5 | - | - | - | - | - |
| Humanities and Social Sciences** | 16 | 3 | 3 | - | - | - | 5 | - | 5 |
| **Science and Technical Subjects (14 hrs.)** | | | | | | | | | |
| ME 211, Intro to Solid Mechanics | 4 | - | - | - | 4 | - | - | - | - |
| Science and Technical Electives | 10 | - | - | - | - | 3 | 4 | - | 3 |
| **Program Subjects (47 hrs.)** | | | | | | | | | |
| MSE 250, Princ. of Engr Metals or MSE 220, Intro to Materials and Manufact. | 4 | - | - | 4 | - | - | - | - | - |
| MSE 242, Physics of Materials | 4 | - | - | - | 4 | - | - | - | - |
| MSE 350, Princ. of Engr Materials II | 4 | - | - | - | - | 4 | - | - | - |
| MSE 360, Experimental Methods in MSE Lab I | 3 | - | - | - | - | 3 | - | - | - |
| MSE 365, Experimental Methods in MSE Lab II | 3 | - | - | - | - | - | 3 | - | - |
| MSE 420, Mech. Behavior of Materials | 3 | - | - | - | - | - | - | 3 | - |
| MSE 430, Thermodynamics of Materials | 4 | - | - | - | - | - | - | 4 | - |
| MSE 435, Kenetics and Trans in Matls Engr | 4 | - | - | - | - | - | 4 | - | - |
| MSE 480, Materials and Engr Design | 3 | - | - | - | - | - | - | 3 | - |
| MSE 489, Materials Processing Design | 3 | - | - | - | - | - | - | - | 3 |
| **Elect 3 of the following:** | 9 | - | - | - | - | - | - | 6 | 3 |
| MSE 400, EMO Matls for Modern Device Tech (3) | | | | | | | | | |
| MSE 410, Design and Applic of Biomatls (4) | | | | | | | | | |
| MSE 412, Polymeric Materials (3) | | | | | | | | | |
| MSE 440, Ceramic Materials (3) | | | | | | | | | |
| MSE 465, Struc. & Chem. Charac of Matls. (3) | | | | | | | | | |
| MSE 470, Adv. Physical Metallurgy (3) | | | | | | | | | |
| MSE Elective (3) | 3 | - | - | - | - | - | - | - | 3 |
| **Unrestricted Electives (12 hrs.)** | 12 | - | - | 3 | 4 | 5 | - | - | - |
| **Total** | 128 | 16 | 16 | 16 | 16 | 15 | 16 | 16 | 17 |

Candidates for the Bachelor of Science degree in Engineering (Materials Science and Engineering)—(B.S.E. Matl. Sci. & E.)—must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

**Notes:**

* Either Chem 125 &130 or Chem 210 & 211 may be used to satisfy this requirement. However, Chem 210 is required by the program. Excess Chemistry may be used to satisfy Sci/Tech electives.

**Economics is required.

## Materials Science and Engineering Course Listings

Course descriptions are found also on the College of Engineering web site at http://courses.engin.umich.edu/

**MSE 150 (Eng 150). Introduction to Engineering Materials**
*Prerequisite: Chem 130 or Chem 210. II (4 credits)*
Engineering materials, covering the structure, properties, and processing aspects of metals, polymers, and ceramics.

**MSE 220. Introduction to Materials and Manufacturing**
*Prerequisite: Chem 130 or Chem 210. I, II (4 credits)*
Introduction to Materials Engineering and materials processing in manufacturing. The engineering properties of metals, polymers, semiconductors, ceramics, and composites are correlated with the internal structure of the materials and the service conditions.

**MSE 242. Physics of Materials**
*Prerequisite: preceded or accompanied by Physics 240, Math 216. II (4 credits)*
Basic principles and applications of solid state physics. Mathematical and physical description of classical and quantum mechanics, crystallography and diffraction. Applications to solids, including band structure, bonding and physical properties.

**MSE 250. Principles of Engineering Materials**
*Prerequisite: Chem 130 or Chem 210. (4 credits)*
A student can receive credit for only one: MSE 150, or MSE 220, or MSE 250 Introductory course to engineering materials. Properties (mechanical, thermal and electrical) of metals, polymers, ceramics and electronic materials. Correlation of these properties with: (1) their internal structures (atomic, molecular, crystalline, micro- and macro-); (2) service conditions (mechanical, thermal, chemical, electrical, magnetic, and radiation); and (3) processing.

**MSE 350. Principles of Engineering Materials II**
*Prerequisite: MSE 250. I (4 credits)*
Structure and reaction kinetics of crystalline and amorphous engineering materials. Phase diagrams. Equilibrium and non-equilibrium phase transformations. Crystal chemistry. Defects. Surfaces. Diffusion. Sintering.

**MSE 360. Experimental Methods in MSE Lab I**
*Prerequisite: Accompanied or preceded by MSE 350. I (3 credits)*
Introduction to experimental techniques in MSE, including statistical analysis of data. Written and oral technical communication. Laboratories and computer simulations based on principles emphasized in Fundamentals of Materials Science. Processing, properties, and structures with a focus on mircrostructure and mechanical behavior. Continued as MSE 368.

**MSE 365. Experimental Methods in MSE Lab II**
*Prerequisite: MSE 364 and preceded or accompanied by MSE 242. II (3 credits)*
Laboratory experiences and computer simulations based on principles emphasized in Physics of Materials and Fund. of MSE X-ray diffraction. Processing, properties, and microstructure with a focus on electronic and magnetic phenomena.

**MSE 400. Electronic, Magnetic and Optical Materials for Modern Device Technology**
*Prerequisites: MSE 242 and either MSE 220 or 250 or equivalents. I even years (3 credits)*
Application of solid-state phenomena in engineering structures such as microelectronic, magnetic and optical devices. Review of quantum mechanical descriptions of crystalline solids. Microelectronic, magnetic and optical properties of devices, fabrication and process methods. Special attention given to semiconductor manufacturing including methods and front-end technology and packaging.

**MSE 410 (BiomedE 410). Design and Applications of Biomaterials**
*Prerequisite: MSE 220 or 250 or permission of instructor. I (4 credits)*
Biomaterials and their physiological interactions. Materials used in medicine/dentistry: metals, ceramics, polymers, composites, resorbable smart, natural materials. Material response/degradation: mechanical breakdown, corrosion, dissolution, leaching, chemical degradation, wear. Host responses: foreign body reactions, inflammation, wound healing, carcinogenicity, immunogenicity, cytotoxicity, infection, local/systemic effects.

**MSE 412 (ChemE 412) (MacroSE 412). Polymeric Materials**
*Prerequisites: MSE 220 or 250. I (3 credits)*
The synthesis, characterization, microstructure, rheology, and properties of polymer materials. Polymers in solution and in the liquid, liquid-crystalline, crystralline, and glassy states. Engineering and design properties, including viscoelasticity, yielding, and fracture. Forming and processing methods. Recycling and environmental issues.

**MSE 414 (ChemE 414) (MacroSE 414) (Mfg 414). Applied Polymer Processing**
*Prerequisites: MSE 413 or equivalent. II (3 credits)*
Theory and practice of polymer processing. Non-Newtonian flow, extrusion, injection-molding, fiber, film, and rubber processing. Kinetics of and structural development during solidification. Physical characterization of microstructure and macroscopic properties. Component manufacturing and recycling issues, compounding and blending.

**MSE 420. Mechanical Behavior of Materials**
*Prerequisite: ME 211, MSE 350. I (3 credits)*
Macroscopic and microscopic aspects of deformation and fracture. Plasticity, general continuum approach. Microscopic hardening mechanisms. Rate and temperature dependent deformation. Deformation and fracture mechanism maps. Fracture mechanics. Fatigue behavior.

**MSE 422. Mechanical Behavior of Materials**
*Prerequisite: ME 211, MSE 350. I (4 credits)*
Macroscopic and microscopic aspects of deformation and fracture. Plasticity, general continuum approach. Microscopic hardening mechanisms. Rate and temperature dependent deformation. Fracture , fatigue, and creep behavior.

**MSE 430. Thermodynamics of Materials**
*Prerequisite: Chem 210, Phys 140-141, Math 215 or Math 285, MSE 350. I (4 credits)*
The laws of thermodynamics and their consequences. Applications to solid and liquid materials. Mass and energy balances. Gas reactions. Phase diagrams. Ellingham, Pourbaix and stability diagrams. Defects in solids. Interfaces. Statistical thermodynamics.

**MSE 435. Kinetics and Transport in Materials Engineering**
*Prerequisite: Math 216, MSE 150 or 220 or MSE 250. I (4 credits)*
Principles of reaction kinetics. Fluid, energy, and mass transport, with applications to materials systems.

**MSE 440. Ceramic Materials**
*Prerequisites: MSE 350. II (3 credits)*
Chemistry, structure, processing, microstructure and property relationships and their applications in design and production of ceramic materials.

**MSE 465. Structural and Chemical Characterization of Materials**
*Prerequisites: MSE 220/250, MSE 242, MSE 360, MSE 365 (concurrent). II (3 credits)*
Study of the basic structural and chemical characterization techniques that are commonly used in materials science and engineering. X-ray, electron and neutron diffraction, a wide range of spectroscopies, microscopies, and

scanning probe methods will be covered. Lectures will be integrated with a laboratory where the techniques will be demonstrated and/or used by the student to study a material. Techniques will be presented in terms of the underlying physics and chemistry.

**MSE 470. Advanced Physical Metallurgy**
*Prerequisite: MSE 350. II (3 credits)*
Phase transformations and hardening mechanisms in metallic systems. Nucleation, diffusion-controlled growth, spinodal decomposition and martensitic reactions. Strengthening mechanisms based on two-phase microstructure. Thermal stability.

**MSE 472. Physical Metallurgy**
*Prerequisite: MSE 364, ME 211. II (4 credits)*
Solidification, annealing, phase transformation and hardening mechanisms in metallic solutions. Nucleation, diffusion-controlled growth, spinodal decomposition and martesitic reactions. Uses and properties of alloys.

**MSE 480. Materials and Engineering Design**
*Prerequisite: senior standing. I (3 credits)*
Design concepts. Engineering economics. Various design criteria, processes, and process control. Materials substitution. Competitive design. Case histories. Professional and ethical considerations. Written and oral presentations of solutions to design problems.

**MSE 485 (Mfg 458). Design Problems in Materials Science and Engineering**
*Prerequisite: MSE 480. I, II (1-4 credits) (to be arranged)*
Design problem supervised by a faculty member. Individual or group work in a particular field of materials of particular interest to the student. The design problem is arranged at the beginning of each term by mutual agreement between the student and a faculty member. Written and oral reports are required.

**MSE 489. Materials Processing Design**
*Prerequisites: Preceded or accompanied by MSE 430 and MSE 435. II (3 credits)*
The design of production and refining systems for engineering materials. Design of problems for the extraction and refining of metals, production and processing of ceramics, polymeric materials, and electronic materials. Written and oral presentation fo solutions to processing design problems.

**MSE 490. Research Problems in Materials Science and Engineering**
*Prerequisite: Not open to graduate students. I, II, III, IIIa, IIIb (to be arranged)*
Individual or group work in a particular field or on a problem of special interest to the student. The program of work is arranged at the beginning of each term by mutual agreement between the student and a faculty member. Written and oral reports are required. Laboratory and conferences.

**MSE 493. Special Topics in Materials Processing and Applications**
*Prerequisite: MSE 350. (to be arranged)*
Selected topics of current interest for students entering industry.

**MSE 501. Structure and Processing of Electrical Materials**
*Prerequisite: MSE 440 or EECS 314. (2 credits)*
The role of chemistry, structure, and processing in determining the properties of electrical materials.

**MSE 502. Materials Issues in Electronics**
*Prerequisites: MSE 242 and MSE 400 or equivalent. II (3 credits)*
This course covers the key materials issues, including defects, diffusion, and oxidation relevant to the conversion of a material into an electronic device.

**MSE 505. Materials Science of Thin Films**
*Prerequisites: MSE 242 and MSE 400 or equivalent. I (3 credits)*
Thermodynamics and kinetics of film nucleation, growth, structure and stability for a single crystal, polycrystalline, and amorphous thin films.

**MSE 510 (ChemE 511). Materials Chemistry**
*(3 credits)*

**MSE 511 (ChemE 511) (MacroSE 511). Rheology of Polymeric Materials**
*Prerequisite: a course in fluid mechanics or permission from instructor. I (3 credits)*
An introduction to the relationships between the chemical structure of polymer chains and their rheological behavior. The course will make frequent reference to synthesis, processing, characterization, and use of polymers for high technology applications.

**MSE 512 (ChemE 512) (MacroSE 512). Polymer Physics**
*Prerequisite: senior or graduate standing in engineering or physical science. II (3 credits)*
Structure and properties of polymers as related to their composition, annealing and mechanical treatments. Topics include creep, stress relaxation, dynamic mechanical properties, viscoelasticity, transitions, fracture, impact response, dielectric properties, permeation, and morphology.

**MSE 514 (MacroSE 514) (Mfg 514). Composite Materials**
*Prerequisite: MSE 350. I alternate years (3 credits)*
Behavior, processing, and design of composite materials, especially fiber composites. Emphasis is on the chemical and physical processes currently employed and expected to guide the future development of the technology.

**MSE 515 (MacroSE 515). Mechanical Behavior of Solid Polymeric Materials**
*Prerequisite: ME 211, MSE 412. II even years (3 credits)*
The mechanical behavior of polymers from linear viscoelastic to yield and fracture are covered. Specific topics include dynamic-mechanical relaxations, creep, yielding, craz-ing, fatigue, and fracture mechanics. The materials include toughened plastics, polymer alloys and blends, and composite materials. Structured design with plastics is also considered.

**MSE 516 (ME 516). Mechanics of Thin Films and Layered Materials**
*Prerequisite: ME 311 or graduate standing. I alternate years (3 credits)*
Stresses and deformations in layered materials; energy-release rates and delamination; fracture mechanics of layered materials; spalling; interfacial fracture mechanics; mixed-mode fracture; buckling-driven delamination; cracking of thin films; effects of plasticity on fracture; stress-relaxation mechanisms in multi-layered materials; adhesion and fracture tests.

**MSE 520. Advanced Mechanical Behavior**
*Prerequisite: graduate standing. II (3 credits)*
Advanced studies of deformation and failure in materials. Macroscopic and microscopic aspects of deformation. Elasticity and plasticity theories and problems in deformation processing. Fracture mechanics and composite toughening mechanisms. Mechanisms of creep deformation.

**MSE 523 (Mfg 582) (ME 582). Metal-Forming Plasticity**
*Prerequisite: ME 211. II (3 credits)*
Elastic and plastic stress-strain relations; yield criteria and flow rules; analyses of various plastic forming operations. Effects of hardening and friction, temperature, strain rate, and anisotropy.

**MSE 525. Dislocations and Plastic Flow of Materials**
*Prerequisite: MSE 420 or graduate standing in engineering or physical science. II (3 credits)*

Fundamentals of dislocation theory. Applications to the understanding of physical and mechanical behavior of materials. Dislocation bases for alloy design.

**MSE 526. Micromechanisms of Strengthening and Flow**
*Prerequisite: MSE 420 or MSE 470. II (3 credits)*
Micromechanisms responsible for strengthening and deformation in structural materials. Quantitative analyses of microscopic processes. Theories of work hardening, polycrystalline strengthening, dislocation-precipitate interactions, kinetics of slip and climb processes, diffusion-assisted flow, grain boundary sliding and migration processes, physical basis for constitutive equation.

**MSE 532. Advanced Thermodynamics of Materials**
*Prerequisite: MSE 430 or equivalent. I (3 credits)*
Classical and statistical thermochemistry with emphasis on topics important in materials science and engineering, including thermodynamics of solids, solution thermochemistry, heterogeneous equilibria of stable and metastable phases, multicomponent systems, coherent equilibria and strain effects interfaces and adsorption, polymer alloys and solutions.

**MSE 535. Kinetics, Phase Transformations, and Transport**
*Prerequisite: MSE 430 or equivalent. I (3 credits)*
Fundamentals of phase change, diffusion, heat transport, nucleation, and growth applied to solidification, ordering, spinodal decomposition, coarsening, reactions, massive transformations, diffusion-limited transformations and glass transitions.

**MSE 542 (Mfg 542). Reactions in Ceramic Processes**
*Prerequisite: MSE 440 or graduate standing. I, II (3 credits)*
Dissociation, sintering, vitrification, devitrification, and thermochemical reactions in ceramic processing.

**MSE 543. Structures of Ceramic Compounds**
*Prerequisite: MSE 440 or graduate standing. (3 credits)*
Structures and crystal chemistry of ceramic compounds.

**MSE 544. Properties of Ceramic Compounds**
*Prerequisite: MSE 440 or graduate standing. (3 credits)*
Consideration of mechanical, thermal, dielectric, ferroelectric, magnetic, and semiconducting properties of ceramic compounds.

**MSE 550. Fundamentals of Materials Science and Engineering**
*Prerequisite: none. I (3 credits)*
An advanced level survey of the fundamental principles underlying the structures, properties, processing, and uses of engineering materials.

**MSE 555. Physical Properties of Materials**
*Prerequisite: MSE 400 or MSE 550. II (3 credits)*
An introduction to the quantum and statistical mechanics and the mathematics of crystal physics. Application of these methods to the electronic and vibrational properties of solids. The relationship of these to the thermodynamic properties of solids will be emphasized.

**MSE 556. Molecular Simulation of Materials**
*Prerequisite: none. I (3 credits)*
Practical and theoretical consideration in the simulation of materials on the molecular level. Molecular dynamics and Monte Carlo techniques. Empirical interaction potentials for metals, ceramics, and polymers. Statistical mechanics and thermodynamics of simulated systems.

**MSE 560. Structure of Materials**
*Prerequisite: MSE 550. II (3 credits)*
Atomic arrangements in crystalline and noncrystalline materials. Crystallography, kinematic and dynamical theories of diffraction, applications to x-rays, electrons and neutrons. Interpretation of diffraction patterns and intensity distributions, applications to scattering in perfect and imperfect crystals, and amorphous materials. Continuum description of structure emphasizing the tensor analysis of distortions in solids.

**MSE 562. Electron Microscopy I**
*Prerequisite: MSE 460. II (4 credits)*
An introduction to electron optics, vacuum techniques, and the operation of electron optical instruments. The theory and applications of transmission and scanning electron microscopy and electron microprobe analysis in the study of nonbiological materials.

**MSE 574. High-Temperature Materials**
*Prerequisite: MSE 350. (3 credits)*
Principles of behavior of materials at high temperatures. Microstructure-property relationships including phase stability and corrosion resistance to high temperature materials. Fracture and fatigue at elevated temperatures. Damage accumulation behavior and engineering applications of service life techniques.

**MSE 577 (Mfg 577). Failure Analysis of Materials**
*Prerequisite: MSE 350. II (3 credits)*
Analysis of failed structures due to tensile overload, creep, fatigue, stress corrosion, wear and abrasion, with extensive use of scanning electron microscope. Identification and role of processing defects in failure.

**MSE 580 (Mfg 586). Materials Science and Engineering Design**
*Prerequisite: none. I (2 credits)*
Design of materials processing systems. Selection and use of materials in engineering applications; economic aspects of design; estimating procedures.

**MSE 583 (BiomedE 583) (ChemE 583). Biocompatibility of Materials**
*Prerequisite: undergraduate course in biology and/or physiology; undergraduate course in biochemistry, organic chemistry, or molecular biology. II (2 credits)*
This course describes the interactions between tissue and materials and the biologic/pathologic processes involved. In addition, specifications which govern biocompatibility testing, various strengths and weaknesses of a number of approaches to testing, and future directions are discussed.

**MSE 585. Materials or Metallurgical Design Problem**
*Prerequisite: MSE 480 or to be taken concurrently with MSE 580. I (2 credits)*
Engineering design and economic evaluation of a specific process and/or materials application. Original and individual work and excellence of reporting emphasized. Written and oral presentation of design required.

**MSE 590. Materials Science and Engineering Research Survey**
*(1 credit)*
Research activities and opportunities in the Materials Science and Engineering programs. Lecture by faculty and guest lecturers. Brief weekly reports.

**MSE 622 (Mfg 622) (NERS 622). Ion Beam Modification and Analysis of Materials**
*Prerequisite: NERS 421, NERS 521 or MSE 350 or permission of instructor. II alternate years (3 credits)*
Ion-solid interactions, ion beam mixing, compositional changes, phase changes, micro-structural changes; alteration of physical and mechanical properties such as corrosion, wear, fatigue, hardness; ion beam analysis techniques such as RBS, NRA, PIXE, ion channeling, ion microprobe; accelerator system design and operation as it relates to implantation and analysis.

**MSE 662. Electron Microscopy II**
*Prerequisite: MSE 562. (3 credits)*
Advanced methods in electron microscopy such as high resolution bright field and dark field imaging, micro and convergent beam diffraction, analysis of thin film specimens, and electron energy loss spectroscopy. Two lectures and one three-hour laboratory-discussion session per week.

**MSE 690. Research Problems in Materials Science and Engineering**

*Prerequisite: I, II, III (to be arranged)*

Laboratory and conferences. Individual or group work in a particular field or on a problem of special interest to the students. The program of work is arranged at the beginning of each term by mutual agreement between the student and a member of the faculty. Any problem in the field of materials and metallurgy may be selected. The student writes a final report on this project.

**MSE 693. Special Topics in Materials Science and Engineering**
*(to be arranged)*

**MSE 751 (ChemE 751) (Chem 751) (MacroSE 751) (Physics 751). Special Topics in Macromolecular Science**
*Prerequisite: permission of instructor. (2 credits)*

Advanced topics of current interest will be stressed. The specific topics will vary with the instructor.

**MSE 890. Seminar in Materials Science and Engineering**
*(to be arranged)*

Selected seminar topics in metallurgy, ceramics, polymers, or electronic materials.

**MSE 990. Dissertation/Pre-Candidate**
*I, II, III (2-8 credits); IIIa, IIIb (1-4 credits)*

Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**MSE 995. Dissertation/Candidate**
*Prerequisite: Graduate School authorization for admission as a doctoral candidate I, II, III (8 credits); IIIa, IIIb (4 credits)*

Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

## Materials Science and Engineering Faculty

John W. Halloran, Ph.D., *Chair and Professor*

### Professors

John C. Bilello, Ph.D.; *also Applied Physics*
Rodney C. Ewing, Ph.D.; *also Nuclear Engineering and Radiological Sciences and Geological Sciences*
Frank E. Filisko, Ph.D., P.E.; *also Macromolecular Science and Engineering*
Amit K. Ghosh, Ph.D.
Ronald Gibala, Ph.D.; *also Macromolecular Science and Engineering*
William F. Hosford, Jr., Sc.D.
J. Wayne Jones, Ph.D.; *also Associate Dean for Undergraduate Education*
Richard M. Laine, Ph.D.; *also Chemistry; Macromolecular Science and Engineering*
Jyotirmoy Mazumder, Ph.D., D.I.C., *Robert H. Lurie Professor of Engineering; also Mechanical Engineering*
Robert D. Pehlke, Sc.D., P.E.
Tresa M. Pollock, Ph.D.
Richard E. Robertson, Ph.D.; *also Macromolecular Science and Engineering*
David J. Srolovitz, Ph.D.; *also Applied Physics*
Gary S. Was, Sc.D.; *also Associate Dean for Research and Professor, Nuclear Engineering and Radiological Sciences*
Albert F. Yee, Ph.D.; *also Macromolecular Science and Engineering; Chemical Engineering*

### Professors Emeritus

Wilbur C. Bigelow, Ph.D.
Edward E. Hucke, Sc.D.
William Cairns Leslie, Ph.D.
Tseng-Ying Tien, Ph.D.
Edwin Harold Young, M.S.E., P.E.; *also Chemical Engineering*

### Associate Professors

Michael Atzmon, Ph.D.; *also Nuclear Engineering and Radiological Sciences*
Sharon C. Glotzer, Ph.D.; *also Chemical Engineering*
John Kieffer, Ph.D.
David C. Martin, Ph.D.; *also Macromolecular Science and Engineering; Biomedical Engineering*
Xiaoqing Pan, Ph.D.
Michael Thouless, Ph.D.; *also Mechanical Engineering*
Steven M. Yalisove, Ph.D.

### Assistant Professors

Rachel S. Goldman, Ph.D.
Joanna Mirecki-Millunchick, Ph.D.
Michael L. Falk, Ph.D; *also Applied Physics*

## Materials Science and Engineering Contact Information

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http://msewww.engin.umich.edu/index.html

# MECHANICAL ENGINEERING

*Program Advisor*
*Professor Noel C. Perkins*
*2212 G.G. Brown*
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*Student Advisor*
*Susan J. Gow*
*Academic Services Office*
*2206 G.G. Brown*
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The scope of mechanical engineering includes all aspects of the mechanics of equipment and processes used in this rapidly developing technical era. Mechanical engineers play a major role in the national space program, in energy utilization and conservation, in the transportation and automotive fields, and in the fields of automation, in manufacturing and biomechanical systems, fluid machinery, production and processing machinery including the petroleum and chemical fields, and consumer goods and appliances.

Mechanical engineers have responsibility for research, design, development, testing, control, and manufacture in these diverse fields. Many mechanical engineering graduates assume positions of management, while others prefer a career along technical lines.

Because a mechanical engineer might work in any one of these fields, the academic program has been planned to offer a challenging and basic education. It is designed to provide a knowledge of the basic physical sciences, and to encourage the development of ingenuity for the purpose of creating well-engineered solutions to technological problems.

A basic science program in physics, chemistry, and mathematics; an engineering science program in thermodynamics, fluid mechanics, heat transfer, solid mechanics, dynamics, materials, and electronics integrated with laboratory experiences in measurement; and studies in design and manufacturing will prepare the student equally well for any of the fields of application.

The program includes a number of technical and non-technical electives that permit the student to undertake further studies in an area of particular interest. There are a number of dual-degree programs available with other departments in the College. There is also a joint-degree program between Mechanical Engineering and Industrial Design. Students interested in any of these programs should contact the Mechanical Engineering Academic Services Office.

Students who do well in their undergraduate program are encouraged to consider graduate work and may take some of their electives in preparation for graduate study.

Information and assistance regarding fellowships and assistantships for graduate study may be obtained in the Academic Services Office of the Department of Mechanical Engineering.

This program is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

## Our Mission, Goal, Objectives and Outcomes for Undergraduate Education

### Mission

To prepare the graduates for diverse careers in both mechanical engineering and non-mechanical engineering fields.

### Goal

To have students graduate with outstanding problem solving skills and a superb knowledge of mechanical engineering that allow them to continue their education throughout their careers and to become leaders in their fields.

### Objectives

- To provide the necessary foundation for entry level engineering positions or further engineering degrees by a rigorous instruction in the engineering sciences and extensive laboratory and design experience.
- To provide an integrated introduction to team work, communications, ethics, and environmental awareness needed to prepare the graduates for successful careers and leadership positions.
- To offer students the opportunity to deepen their technical understanding in a particular subject by a program of related technical electives, or to obtain a broader education in engineering by a flexible choice of technical and free electives.

### Outcomes

The outcomes we desire are that our graduates demonstrate:

- An ability to apply knowledge of mathematics, science, and engineering to mechanical engineering problems.
- An ability to design and conduct experiments, as well as to analyze and interpret data.
- An ability to design thermal and mechanical systems, components, or processes to meet desired needs.

- An ability to function on multi-disciplinary teams.
- An ability to identify, formulate, and solve engineering problems.
- An understanding of professional and ethical responsibility.
- An ability to communicate effectively with written, oral, and visual means.
- The broad education necessary to understand the impact of engineering solutions in a global and societal context.
- A recognition of the need for and an ability to engage in life-long learning.
- A knowledge of contemporary issues.
- An ability to use modern engineering techniques, skills, and computing tools necessary for engineering practice.
- A familiarity with chemistry, calculus-based physics, and advanced mathematics.
- Familiarity with statistics and linear algebra.

## Facilities

The laboratories of the Department of Mechanical Engineering, located in the George Granger Brown Laboratories and Walter E. Lay Automotive Laboratory buildings on the North Campus, provide facilities for both instruction and research.

The George Granger Brown Laboratories Building contains the thermodynamics, heat transfer, and fluid mechanics laboratories; a drop-tower for zero-g heat transfer studies and a large centrifuge for high-g investigations; a two-phase flow loop; holographic measurements laboratory; and thermal systems research.

Also located in this building are the biomechanics laboratory; robotics laboratory; the manufacturing processes and integrated manufacturing laboratories; and the materials laboratories, which provide facilities for investigations in such areas as adaptive controls, welding, acoustic emission, brittle fracture, heat treating, plasticity, friction and wear, surface phenomena, and mechanical properties.

The Walter E. Lay Automotive Laboratory houses the mechanical analysis laboratory with a wide variety of electromechanical instrumentation and computers for the experimental analysis of dynamics of mechanical systems; the cavitation and multiphase flow laboratory for theoretical and experimental investigations into many aspects of such phenomena; the automatic controls laboratory for demonstrating and investigating principles and applications of control systems; the combustion laboratory with a gas chromatograph and an infrared spectrometer; and the facilities for automotive engineering, which include a number of well-instrumented test cells for reciprocating engines, a test cell for a small aircraft gas turbine, as well as a number of single cylinder engines.

## The Engineering Global Leadership Program (EGL)

The Engineering Global Leadership Program (EGL), is an exciting honors program offered in IOE and ME for those students with strong GPAs who enjoy learning foreign languages, and studying other cultures. The program is designed to maximize and focus free electives, language, humanities, and social science courses around a region of economic importance to the US. In addition, EGL students are required to take business courses and complete a built-in practical experience to place technical knowledge in an industrial context. This honors program is very rigorous (full class loads every semester and maintenance of a high GPA) but EGL students graduate with both a BSE and a Master's degree and tend to have higher starting salaries than other engineering undergrads. For more details please see page 199.

## Sample Schedule
## B.S.E. Mechanical Engineering

| | Credit Hours | Terms 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| **Subjects required by all programs (52 hrs.)** | | | | | | | | | |
| Mathematics 115, 116, 215, and 216+ | 16 | 4 | 4 | 4 | 4 | - | - | - | - |
| [1]Engr 100, Intro to Eng | 4 | 4 | - | - | - | - | - | - | - |
| Engr 101, Intro to Computers+ | 4 | - | 4 | - | - | - | - | - | - |
| Chemistry 125 and 130 or Chemistry 210 and 211+ | 5 | - | - | 5 | - | - | - | - | - |
| Physics 140 with Lab 141; 240 with Lab 241+ | 10 | 5 | 5 | | - | - | - | - | - |
| Humanities and Social Sciences | 16 | 4 | 4 | - | 4 | - | - | 4 | - |
| **[2]Advanced Mathematics (3 hrs.)** | 3 | - | - | - | - | 3 | - | - | - |
| **Related Program Subjects (4 hrs.)** | | | | | | | | | |
| EECS 210, Intro to Electrical Engr or EECS 314, Cct Analy and Electronics | 4 | - | - | - | - | - | - | 4 | - |
| **Program Subjects (44 hrs.)** | | | | | | | | | |
| ME 211, Intro to Solid Mechanics+ | 4 | - | - | 4 | - | - | - | - | - |
| ME 230, Thermal Sciences I+ | 4 | - | - | - | - | 4 | - | - | - |
| ME 240, Intro to Dynamics and Vibrations+ | 4 | - | - | - | 4 | - | - | - | - |
| ME 250, Design and Manufacturing I+ | 4 | - | - | - | 4 | - | - | - | - |
| ME 330, Thermal Sciences II+ | 4 | - | - | - | - | - | 4 | - | - |
| ME 350, Design and Manufacturing II+ | 4 | - | - | - | - | 4 | - | - | - |
| ME 360, Systems and Controls+ | 4 | - | - | - | - | - | 4 | - | - |
| ME 382, Engineering Material+ | 4 | - | - | - | - | 4 | - | - | - |
| ME 395, Laboratory I+ | 4 | - | - | - | - | - | 4 | - | - |
| ME 450, Design and Manufacturing III | 4 | - | - | - | - | - | - | - | 4 |
| ME 495, Laboratory II | 4 | - | - | - | - | - | - | 4 | - |
| **[2]Technical Electives (12 hrs.)** | 12 | - | - | - | - | - | - | 3 | 9 |
| **[3]Unrestricted Electives (10 hrs.)** | 10 | - | - | 4 | - | - | 4 | 2 | - |
| **Total** | 128 | 17 | 17 | 17 | 16 | 15 | 16 | 17 | 13 |

Candidates for the Bachelor of Science degree in Engineering (Mechanical Engineering)—(B.S.E. M.E.)—must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

**Notes:**

[1]College policy states that a C or better grade must be earned.

[2]Advanced Mathematics and Technical Electives: A list of approved courses is available in your Program Advising Office.

[3]Unrestricted Electives: College policy states that no more than 3 hours may be in Performance. Hours may vary according to classes taken.

(+) "D+" rule: Students must earn a "C-" or better in prerequisite courses indicated by the (+) symbol; anything less must be repeated.

"D-" rule: No grade less than "D" shall be earned in any course used for degree credit.

## Mechanical Engineering Course Listings

Course descriptions are found also on the College of Engineering web site at http://courses.engin.umich.edu/

### ME 211. Introduction to Solid Mechanics

*Prerequisite: Physics 140, Math 116. I, II, IIIa (4 credits)*

Statics: moment and force resultants, equilibrium. Mechanics of deformable bodies: stress/strain, classification of material behavior, generalized Hooke's law. Engineering applications: axial loads, torsion of circular rods and tubes, bending and shear stresses in beams, deflection of beams, combined stresses, stress and strain transformation. Four lecture classes per week.

### ME 230. Thermal and Fluid Sciences I

*Prerequisite: Chem 130, Chem 125, and Math 116. I, II, IIIa (4 credits)*

Introduction to engineering thermodynamics and heat transfer. First law, second law, system and control volume analyses; properties and behavior of pure substances; application to thermodynamic systems. Heat transfer mechanisms. Steady and transient heat conduction in solids; approximate and exact solution procedures. Thermal radiation.

### ME 240. Introduction to Dynamics and Vibrations

*Prerequisite: Physics 140, preceded or accompanied by Math 216. I, II, IIIa (4 credits)*

Vector description of force, position, velocity and acceleration in fixed and moving reference frames. Kinetics of particles, of assemblies of particles and of rigid bodies. Energy and momentum concepts. Euler's equations. Moment of inertia properties. The simple oscillator and its applications.

### ME 250. Design and Manufacturing I

*Prerequisite: Math 116, Eng 101 or equivalent. I, II (4 credits)*

Basics of mechanical design: visual thinking, engineering drawing, and machine anatomy. Basics of manufacturing: processes, materials, and thermo-fluid aspects. Use of computers in various phases of design and manufacturing. Exposure to CAD systems and basic machine shop techniques. Design/manufacturing project. Three hours lecture and two hours laboratory.

### ME 305. Introduction to Finite Elements in Mechanical Engineering

*Prerequisite: ME 311. I, II (3 credits)*

Rod element stiffness matrix. The assembly process. Solution techniques, gaussian elimination. Truss examples. Beam elements. Frame examples. Plate bending. Heat conduction. Triangular and quadrilateral elements. The Isoparametric formulation. Plane stress applications. The course is project oriented with a substantial design content. A commercial finite element package is used extensively.

### ME 311. Strength of Materials

*Prerequisite: ME 211, Math 216. I, II, IIIa (3 credits)*

Energy methods; buckling of columns, including approximate methods; bending of beams of unsymmetrical cross-section; shear center and torsion of thin-walled sections; membrane stresses in axisymmetric shells; elastic-plastic bending and torsion; axisymmetric bending of circular plates.

### ME 330. Thermal and Fluid Sciences II

*Prerequisite: ME 230, ME 240, and Math 216. I, II, IIIa (4 credits)*

Fluid statics. Control volume analysis; mass, momentum, energy. Bernoulli equation. Dimensional analysis; similarity in fluid dynamics and convective heat transfer. Simple viscous flows with heat transfer. Internal and external flows with heat transfer; boundary layers, skin friction, heat transfer coefficient, heat exchangers, lift, drag, correlations, introduction to computational approaches.

### ME 336. Thermodynamics II

*Prerequisite: ME 235 or ME 230. I, II (3 credits)*

Thermodynamic power and refrigeration systems; availability and evaluation of thermodynamic properties; general thermodynamic relations, equations of state, and compressibility factors; chemical reactions; combustion; gaseous dissociation; phase equilibrium. Design and optimization of thermal systems.

**ME 350. Design and Manufacturing II**

*Prerequisite: ME 211, ME 240, ME 250, preceded or accompanied by ME 382. I, II (4 credits)*

Principles of mechanical design; synthesis and selection of machine components. Design project. Three hours of lecture and one lab.

**ME 360. Modeling, Analysis and Control of Dynamic Systems**

*Prerequisite: ME 240. I, II (4 credits)*

Unified approach to abstracting real mechanical, fluid, and electrical systems into proper models in graphical and state equation form to meet engineering design and control system objectives. Introduction to system analysis (eigen values, time and frequency response) and linear feedback control. Synthesis and analysis by analytical and computer methods. Four lectures per week.

**ME 381. Manufacturing Processes**

*Prerequisite: ME 382. I, II (3 credits)*

Modeling and quantitative analysis of manufacturing processes used in industry to manufacture mechanical systems: machining, deformation, welding assembly, surface treatment, and solidification. Process costs and limits; influence of processes on the final mechanical properties of the product. Reconfigurable manufacturing. Three recitations.

**ME 382. Mechanical Behavior of Materials**

*Prerequisite: ME 211. I, II (4 credits)*

Material microstructures, dislocations and defects; processing and mechanical properties of metals, polymers, and composites; heat treatment of metals; elastic, plastic, and viscoelastic behavior of materials, strain hardening; fracture, fracture mechanics, fatigue and multiaxis loading; creep and stress relaxation; materials-related design issues, materials selection, corrosion and environmental degradation of materials.

**ME 395. Laboratory I**

*Prerequisite: Phys 240, Phys 241, ME 211, ME 235/ME 230, and ME 240; preceded or accompanied by ME 320/ME 330, and ME 382. I, II (4 credits)*

Weekly lectures and experiments designed to introduce the student to the basics of experimentation, instrumentation, data collection and analysis, error analysis, and reporting. Topics will include fluid mechanics, thermodynamics, mechancis, materials, and dynamical systems. Emphasis is placed on report writing and team-building skills.

**ME 400. Mechanical Engineering Analysis**

*ME 211, ME 240, Math 216. I (3 credits)*

Exact and approximate techniques for the analysis of problems in mechanical engineering including structures, vibrations, control systems, fluids, and design. Emphasis is on application.

**ME 401. (Mfg 402) Engineering Statistics for Manufacturing Systems**

*Prerequisite: senior or graduate standing. I (3 credits)*

Fundamentals of statistics. Independent t-test and paired t-test. Two-level factorial design. Fractional factorial designs. Matrix algebra and canonical analysis. Regression analysis (Least Squares Method). Response surface methodology. Probability. Binomial and Poisson distributions. Single sampling plan. Statistical process control (SPC). Taguchi methods. Introductory time series analysis and Defect Preventive Quality Control.

**ME 404. Coherent Optical Measurement Techniques**

*Prerequisite: senior or graduate standing. I (3 credits)*

Modern optical techniques using lasers in measurements of mechanical phenomena. Introduction to the nature of laser light and Fourier optics; use of holography and laser speckle as measurement techniques; laser doppler velocimetry.

**ME 412. Advanced Strength of Materials**

*Prerequisite: ME 311. I (3 credits)*

Review of energy methods, Betti's reciprocal theorem; elastic, thermoelastic and elastoplastic analysis of axisymmetric thick cylinders and rotating discs; bending of rectangular and circular plates, including asymmetric problems; beams on elastic foundations; axisymmetric bending of cylindrical shells; torsion of prismatic bars.

**ME 420. Fluid Mechanics II**

*Prerequisite: ME 320 or ME 330. II (3 credits)*

Control volume and streamline analysis for steady and unsteady flows. Incompressible and compressible flow. Hydraulic systems. Design of components. Losses and efficiency. Applications to centrifugal and axial flow machinery, e.g., fans, pumps, and torque converters.

**ME 424 (EECS 415). Engineering Acoustics**

*Math 216 and EECS 230 or Physics 240. II (3 credits)*

Vibrating systems; acoustic wave equation; plane and spherical waves in fluid media; reflection and transmission at interfaces; propagation in lossy media; radiation and reception of acoustic waves; pipes, cavities, and waveguides; resonators and filters; noise; selected topics in physiological, environmental and architectural acoustics.

**ME 432. Combustion**

*Prerequisite: ME 336, preceded or accompanied by ME 330. II (3 credits)*

Introduction to combustion processes; combustion thermodynamics, reaction kinetics and combustion transport. Chain reactions, ignition, quenching, and flammability limits, detonations, deflagrations, and flame stability. Introduction to turbulent premixed combustion. Applications in IC engines, furnaces, gas turbines, and rocket engines.

**ME 437. Applied Energy Conversion**

*Prerequisites: ME 230 and Math 216. I (3 credits)*

Quantitative treatment of energy resources, conversion processes, and energy economics. Consideration of fuel supplies, thermodynamics, environmental impact, capital and operating costs. Emphasis is placed on issues of climate change and the role of energy usage. In-depth analysis of automobiles to examine the potential of efficiency improvement and fuel change.

**ME 438. Internal Combustion Engines**

*Prerequisite: Preceded or accompanied by ME 336 or permission of instructor. I (4 credits)*

Analytical approach to the engineering problem and performance analysis of internal combustion engines. Study of thermodynamics, combustion, heat transfer, friction and other factors affecting engine power, efficiency, and emissions. Design and operating characteristics of different types of engines. Computer assignments. Engine laboratories.

**ME 440. Intermediate Dynamics and Vibrations**

*Prerequisite: ME 240. I, II, IIIa (4 credits)*

Newton/Euler and Lagrangian formulations for three-dimensional motion of particles and rigid bodies. Linear free and forced responses of one and two degree of freedom systems and simple continuous systems. Applications to engineering systems involving vibration isolation, rotating imbalance and vibration absorption.

**ME 450. Design and Manufacturing III**

*Prerequisite: ME 350, ME 360. I, II, IIIa (4 credits)*

A mechanical engineering design project by which the student is exposed to the design process from concept through analysis to layout and report. Projects are proposed from the different areas of study within mechanical engineering and reflect the expertise of instructing faculty. Two hours of lecture and two laboratories.

**ME 451 (Mfg 453). Properties of Advanced Materials for Design Engineers**
*Prerequisite: ME 382. II (3 credits)*
Mechanical behavior and environmental degradation of polymeric-, metal-, and ceramic-matrix composites; manufacturability of advanced engineering materials; use of composite materials in novel engineering designs.

**ME 452 (Mfg 452). Design for Manufacturability**
*Prerequisite: ME 350. II (3 credits)*
Conceptual design. Design for economical production, Taguchi methods, design for assembly; case studies. Product design using advanced polymeric materials and composites; part consolidation, snap-fit assemblies; novel applications. Design projects.

**ME 454. (Mfg 454) Computer Aided Mechanical Design**
*Prerequisite: Eng 101, ME 360. II (3 credits)*
Introduction to the use of the digital computer as a tool in engineering design and analysis of mechanical components and systems. Simulation of static, kinematic and dynamic behavior. Optimal synthesis and selection of elements. Discussion and use of associated numerical methods and application software. Individual projects.

**ME 456 (BiomedE 456). Tissue Mechanics**
*Prerequisite: ME 211, ME 240. II (3 credits)*
Definition of biological tissue and orthopaedic device mechanics including elastic, viscoelastic and non-linear elastic behavior. Emphasis on structure function relationships. Overview of tissue adaptation and the interaction between tissue mechanics and physiology.

**ME 458. Automotive Engineering**
*Prerequisite: ME 350. I, II (3 credits)*
Emphasizes systems approach to automotive design. Specific topics include automotive structures, suspension steering, brakes, and driveline. Basic vehicle dynamics in the performance and handling modes are discussed. A semester team-based design project is required.

**ME 461. Automatic Control**
*Prerequisite: ME 360. I (3 credits)*
Feedback control design and analysis for linear dynamic systems with emphasis on mechanical engineering applications; transient and frequency response; stability; system performance; control modes; state space techniques; digital control systems.

**ME 463 (EECS 463) (Mfg 464). Modern Control Systems Design**
*Prerequisite: EECS 460 or ME 461 or Aero 471. I, II (4 credits)*
The class is organized into teams of four to five students. Each team must select, plan, and complete a design project within the general theme of automatic control systems. The project accounts for approximately 75% of the course grade. Lectures will cover state space analysis techniques, system ID basics, and state space feedback design methods.

**ME 471. Computational Heat Transfer**
*Prerequisite: ME 330. II (3 credits)*
Enclosure and gas radiation. Parallel flow and boundary layer convection. Variable property and odd geometry conduction. Technological applications. Individual term projects. Use of elementary spectral, similarity, local similarity, local (finite) difference and global difference (finite element) solution techniques.

**ME 476 (BiomedE 476). Thermal-Fluid Sciences in Bioengineering**
*Prerequisite: ME 330. I (3 credits)*
Dynamics, measurements and simulation of vascular pressure and flow in health and disease, microcirculation, design of prosthetic flow-regulation devices, cellular energetics and body metabolism, thermal modeling and measurements, cell hyperthermia and hypothermia, design of blood heat exchangers, thermal probes, cryoprobes, prosthetic mass transfer devices, medical visualization and medical image processing.

**ME 482 (Mfg 492). Machining Processes**
*Prerequisite: senior standing. II (4 credits)*
Mechanics of 2-D and Basic 3-D cutting. Industrially-applicable, mechanistic force models for practical processes including turning, facing, boring, face milling, end milling, and drilling. Surface generation and wear-based economic models. Motivation for and methods of applying developed models in simultaneous engineering. Three hours lecture and one two-hour laboratory.

**ME 487 (Mfg 488). Welding**
*Prerequisite: ME 382. I (3 credits)*
Study of the mechanism of surface bonding, welding metallurgy, effect of rate of heat input on resulting microstructures, residual stresses and distortion, economics and capabilities of the various processes.

**ME 490. Experimental Research in Mechanical Engineering**
*Prerequisite: senior standing. I, II, IIIa, IIIb (3 credits)*
Individual or group experimental or theoretical research in the area of mechanical engineering. A topic in mechanical engineering under the direction of a member of the department. The student will submit a final report. Two four-hour laboratories per week. For undergraduates only.

**ME 491. Independent Study**
*Prerequisite: ME 490, permission of instructor; mandatory pass/fail. I, II, IIIa, IIIb (1-3 credits)*
Individual or group experimental or theoretical research in the area of mechanical engineering. A topic in mechanical engineering under the direction of a member of the department. The student will submit a final report. Two four-hour laboratories per week. For undergraduates only.

**ME 495. Laboratory II**
*Prerequisite: ME 360, ME 395, preceded or accompanied by ME 350. Recommend that ME 450 not be elected concurrently. I, II (4 credits)*
Weekly lectures and extended experimental projects designed to demonstrate experimental and analytical methods as applied to complex mechanical systems. Topics will include controls, heat transfer, fluid mechanics, thermodynamics, mechanics, materials, and dynamical systems. Emphasis on laboratory report writing, oral presentations, and team-building skills, and the design of experiments.

**ME 499. Special Topics in Mechanical Engineering**
*Prerequisite: permission of instructor. I, II, IIIa, IIIb (to be arranged)*
Selected topics pertinent to mechanical engineering.

**ME 501. Analytical Methods in Mechanics**
*Prerequisite: ME 211, ME 240, Math 216. I (3 credits)*
An introduction to the notation and techniques of vectors, tensors, and matrices as they apply to mechanics. Emphasis is on physical motivation of definitions and operations, and on their application to problems in mechanics. Extensive use is made of examples from mechanics.

**ME 502. Methods of Differential Equations in Mechanics**
*Math 454. II (3 credits)*
Applications of differential equation methods of particular use in mechanics. Boundary value and eigenvalue problems are particularly stressed for linear and nonlinear elasticity, analytical dynamics, vibration of structures, wave propagation, fluid mechanics, and other applied mechanic topics.

**ME 503. Mathematical Methods in Applied Mechanics**
*Prerequisite: one 500-level course in mechanics. I (3 credits)*
Matrix methods applied to the stiffness matrix, vibration analysis, and hydrodynamic stability. Solution of integral equations by collocation, variational methods, successive approximations; applications to elasticity, plates, slow viscous flow, and inviscid flow. Finite difference and finite increment methods; application to wave propagation, structural stability, plasticity, free-surface flows and wakes.

**ME 504. Principles and Applications of Variational Methods**
*Prerequisite: ME 440. I (3 credits)*
Fundamental processes of the calculus of variations; derivation of the Euler-Lagrange equations; proof of the fundamental lemma; applications of the direct method; Lagrange multipliers; "natural" boundary conditions; variable end points; Hamilton's canonical equation of motion; Hamilton-Jacobi equations. Descriptions of fields by variational principles. Applications to mechanics. Approximate methods.

**ME 505. Finite Element Methods in Mechanical Engineering and Applied Mechanics**
*Prerequisite: ME 501, ME 311, ME 320, and ME 370 or ME 330. I, II (3 credits)*
Theoretical and computational aspects of finite element methods. Examples from areas of thermal diffusion, potential/irrotational flows, lubrication, structural mechanics, design of machine components, linear elasticity, and Navier-Stokes flows problems. Program development and modification are expected as well as learning the use of existing codes.

**ME 506 (BiomedE 506). Computational Modeling of Biological Tissues**
*I, II (3 credits)*
Biological tissues have multiple scales and can adapt to their physical environment. This course focuses on visualization and modeling of tissue physics and adaptation. Examples include electrical conductivity of heart muscle and mechanics of hard and soft tissues. Homogenization theory is used for multiple scale modeling.

**ME 507. Approximate Methods in Mechanical Engineering**
*Prerequisite: senior standing. II (3 credits)*
Orthogonal and nonorthogonal expansions. Matrix algebra and algebraic eigenvalue problems. Finite difference formulation and solution. Integral and variational approaches to finite element formulation. Solution by electronic calculator and digital computer. Application to conduction, convection, radiation heat transfer, and fluid and solid mechanics.

**ME 508. Product Liability**
*Prerequisite: senior or graduate standing. I (3 credits)*
Introduction and background to areas of law that affect engineering practice with main emphasis on product liability. Additional topics include torts, law and economics, engineering ethics and professional responsibility. The "socratic" method of instruction is used in conjunction with relevant case law.

**ME 509. Patents, Trademarks, Copyrights**
*Prerequisite: senior or graduate standing. II (3 credits)*
The course surveys the area of intellectual property law for engineers. Topics include: 1) patents: requirements, statutory bars, infringement, remedies; 2) trademarks: registrability requirements, scope of rights, abandonment, remedies; 3) copyrights: requirements, scope of rights, fair use doctrine, remedies. Unfair competition and public access policy issues are also covered.

**ME 511. Theory of Solid Continua**
*Prerequisite: ME 211, Math 450. I (3 credits)*
The general theory of a continuous medium. Kinematics of large motions and deformations; stress tensors; conservation of mass, momentum and energy; constitutive equations for elasticity, viscoelasticity and plasticity; applications to simple boundary value problems.

**ME 512. Theory of Elasticity**
*Prerequisite: ME 412, ME 511. II (3 credits)*
Stress, strain and displacement, equilibrium and compatibility. Use of airy stress function in rectangular and polar coordinates, asymptotic fields at discontinuities, forces and dislocations, contact and crack problems, rotating and accelerating bodies. Galerkin and Papcovich-Neuber solutions, singular solutions, spherical harmonics. Thermoelasticity. Axisymmetric contact and crack problem. Axisymmetric torsion.

**ME 514. Nonlinear Fracture Mechanics**
*Prerequisite: ME 412. II (3 credits)*
Elements of solid mechanics, historical development of fracture mechanics, energy release rate of cracked solids, linear elastic fracture mechanics, and elastic-plastic fracture mechanics.

**ME 515. Contact Mechanics**
*Prerequisite: ME 311 or ME 350. I alternate and odd years (3 credits)*
Hertzian elastic contact; elastic-plastic behavior under repeated loading; shakedown. Friction; transmission of frictional tractions in rolling; fretting; normal and oblique impact. Dynamic loading. Surface durability in rolling. Surface roughness effects. Conduction of heat and electricity across interfaces. Thermal and thermoelastic effects in sliding and static contact.

**ME 516. Mechanics of Thin Films and Layered Materials**
*Prerequisite: ME 311 or graduate standing. I alternate years (3 credits)*
Stresses and deformations in layered materials; energy-release rates and delamination; fracture mechanics of layered materials; spalling; interfacial fracture mechanics; mixed-mode fracture; buckling-driven delamination; cracking of thin films; effects of plasticity on fracture; stress-relaxation mechanisms in multi-layered materials; adhesion and fracture tests.

**ME 517. Mechanics of Polymers I**
*Prerequisite: ME 511 or permission of instructor. II (3 credits)*
Constitutive equation for linear small strain viscoelastic response; constant rate and sinusoidal responses; time and frequency dependent material properties; energy dissipation; structural applications including axial loading, bending, torsion; three dimensional response, thermo-viscoelasticity, correspondence principle, Laplace transform and numerical solution methods.

**ME 518 (Mfg 518). Composite Materials: Mechanics, Manufacturing, and Design**
*Prerequisite: senior or graduate standing. II alternate years (3 credits)*
Composite materials, including naturally occurring substances such as wood and bone, and engineered materials from concrete to carbon-fiber reinforced epoxies. Development of micromechanical models for a variety of constitutive laws. Link between processing and as-manufactured properties through coupled fluid and structural analyses.

**ME 519. Theory of Plasticity I**
*Prerequisite: ME 511. II (3 credits)*
Fundamentals of plasticity; stress-strain relations, yield criteria and the general behavior of metals and nonmetals beyond proportional limit in the light of experimental evidence. Various approximate theories with emphasis on the theory of plastic flow. Application to problems of bending, torsion, plane strain and plane stress, technological problems.

**ME 520. Advanced Fluid Mechanics I**
*Prerequisite: ME 330. I, II (3 credits)*
Fundamental concepts and methods of fluid mechanics; inviscid flow and Bernoulli theorems; potential flow and its application; Navier-Stokes equations and constitutive theory; exact solutions of the Navier-Stokes equations; boundary layer theory; integral momentum methods; introduction to turbulence.

**ME 521. Advanced Fluid Mechanics II**
*Prerequisite: ME 520. II (3 credits)*
Viscous flow fundamentals; vorticity dynamics; solution of the Navier-Stokes equations in their approximate forms; thin shear layers and free surface flows; hydrodynamic stability and transition to turbulence; fundamental concepts of turbulence; the turbulent boundary layer; introduction to turbulence modeling.

**ME 523 (Aero 523). Computational Fluid Dynamics I**
*Prerequisite: preceded or accompanied by Aero 520 or ME 520. I (3 credits)*

Physical and mathematical foundations of computational fluid mechanics with emphasis on applications. Solution methods for model equations and the Euler and the Navier-Stokes equations. The finite volume formulation of the equations. Classification of partial differential equations and solution techniques. Truncation errors, stability, conservation, and monotonicity. Computer projects and homework.

### ME 524. Advanced Engineering Acoustics
*Prerequisite: ME 424, (EECS 415). I (3 credits)*

Derivation of the acoustic wave equation and development of solution techniques. Transmission and reflection from solids, plates and impedance boundaries. Radiation and scattering from non-simple geometries. Green's functions; boundary element and finite element methods. Sound in ducts and enclosures. Introduction to structural-acoustic coupling. Automotive and other applications considered.

### ME 527. Multiphase Flow
*Prerequisite: ME 520. II (3 credits)*

Selected topics in multiphase flow including nucleation and cavitation, dynamics of stationary and translating particles and bubbles, basic equations of homogeneous two-phase gas/liquid, gas/solid, and vapor/liquid flows, kinematics and acoustics of bubbly flows, instabilities and shock waves in bubbly flows, stratified, annular, and granular flow.

### ME 532. Advanced Combustion
*Prerequisite: ME 432 or equivalent. II (3 credits)*

Advanced treatment of fundamental combustion processes. Conservation equations for reacting gas mixtures. The structure of one-dimensional diffusion and premixed flames; introduction to activation energy asymptotics. Two-dimensional Burke-Schumann flames and boundary layer combustion. Flame instabilities and flame stretch; turbulent combustion.

### ME 534. Advanced Internal Combustion Engines
*Prerequisite: ME 438. II (3 credits)*

Modern analytical approach to the design and performance analysis of advanced internal combustion engines. Study of thermodynamics, fluid flow, combustion, heat transfer, and other factors affecting the design, operating and emissions characteristics of different engine types. Application of course techniques to engine research projects.

### ME 535. Thermodynamics III
*Prerequisite: ME 336. I (3 credits)*

Definitions and scope of thermodynamics; first and second laws. Maxwell's relations. Clapeyron relation, equation of state, thermodynamics of chemical reactions, availability.

### ME 540 (Aero 540). Intermediate Dynamics
*Prerequisite: ME 240. I (3 credits)*

Newton/Euler and Lagrangian formulations for three dimensional motion of particles and rigid bodies. Principles of dynamics applied to various rigid-body and multi-body dynamics problems that arise in aerospace and mechanical engineering.

### ME 541. Mechanical Vibrations
*Prerequisite: ME 441. I (3 credits)*

Time and frequency domain mathematical techniques for linear system vibrations. Equations of motion of discrete nonconservative systems. Vibration of multi-degree-of-freedom systems. Small oscillation theory. Free vibration eigenvalue problem. Undamped system response. Viscously damped systems. Vibration of continuous systems. Modes of vibration of bars, beams, membranes, plates.

### ME 542. Vehicle Dynamics
*Prerequisite: ME 440. II (3 credits)*

Dynamics of the motor vehicle. Static and dynamic properties of the pneumatic tire. Mechanical models of single and double-track vehicles enabling prediction of their response to control forces/moments and external disturbances. Directional response and stability in small disturbance maneuvers. The closed-loop driving process. Behavior of the motor vehicle in large perturbation maneuvers. Ride phenomena treated as a random process.

### ME 543. Analytical and Computational Dynamics I
*Prerequisite: ME 440. I (3 credits)*

Modern analytical rigid body dynamics equation formulation and computational solution techniques applied to mechanical multibody systems. Kinematics of motion generalized coordinates and speeds, analytical and computational determination of inertia properties, generalized forces, Gibb's function, Routhian, Kanes's equations, Hamilton's principle, Lagrange's equations holonomic and nonholonomic constraints, constraint processing, computational simulation.

### ME 551 (Mfg 560). Mechanisms Design
*Prerequisite: ME 350. II (3 credits)*

Basic concepts. Type synthesis - creative design of mechanisms; graph theory. Precision-point Burmester theory for dimensional synthesis of linkages. Applications. Cam and follower system synthesis. Joint force analysis and dynamic analysis formulations. Analytical synthesis of programmable and compliant mechanisms. Use of software for synthesis and analysis. Design projects.

### ME 552 (Mfg 552). Electromechanical System Design
*Prerequisite: EECS 210 or equivalent. I (3 credits)*

Design of electromechanical systems with emphasis placed on the integration of mechanical and electrical principles. Topics include: electromechanical device design: generators/alternators, electrical motors, measurement/sensing devices; digital control: microprocessors, AD/DA converters, data transmission and acquisition; electromechanical system design: mixed domain modeling, real time control and mechatronic systems.

### ME 553 (Mfg 553). Microelectromechanical Systems
*Prerequisite: senior or graduate standing. II alternate years (3 credits)*

Basic integrated circuit (IC) manufacturing processes; electronics devices fundamentals; microelectromechanical systems fabrications including surface micromachining, bulk micromachining, LIGA and others. Introduction to microactuators and microsensors such as micromotors, grippers, accelerometers and pressure sensors. Mechanical and electrical issues in micromachining. IC CAD tools to design microelectromechanical structures using MCNC MUMPs service. Design projects.

### ME 554 (Mfg 554). Computer Aided Design Methods
*Prerequisite: ME 454, (Mfg 454) or ME 501. I (3 credits)*

Generalized mathematical modeling of engineering systems, methods of solution and simulation languages. Analysis methods in design; load, deformation, stress and finite element considerations; nonlinear programming. Computational geometry; definition and generation of curves and surfaces. Computer graphics; transformations; clipping and windowing; graphics systems; data structures; command languages; display processors.

### ME 555 (Mfg 555). Design Optimization
*Prerequisite: Math 451 and Math 217 or equivalent. II (3 credits)*

Mathematical modeling of engineering design problems for optimization. Boundedness and monotonicity analysis of models. Differential optimization theory and selected numerical algorithms for continuous nonlinear models. Emphasis on the interaction between proper modeling and computation. Students propose design term projects from various disciplines and apply course methodology to optimize designs.

### ME 556 (Mfg 556). Fatigue in Mechanical Design
*Prerequisite: 382 or equivalent. I (3 credits)*

A broad treatment of stress, strain, and strength with reference to engineering design and analysis. Major emphasis is placed on the analytical and experimental determination of stresses in relationship to the fatigue strength properties of machine and structural components. Also considered are deflection, post-yield behavior, residual stresses, temperature and corrosion effects.

**ME 557 (Mfg 557). Materials in Manufacturing and Design**

*Prerequisite: senior or graduate standing. I (3 credits)*

Material selection on the basis of cost, strength, formability and machinability. Advanced strength analysis of heat-treated and cold-formed parts including axial, bending, shear and cyclic deformation. Correlations of functional specifications and process capabilities. Problems in redesign for productability and reliability.

**ME 558 (Mfg 558). Discrete Design Optimization**

*Prerequisite: senior or graduate standing. I alternate years (3 credits)*

Fundamentals of discrete optimization for engineering design problems. Mathematical modeling of engineering design problems as discrete optimization problems, integer programming, dynamic programming, graph search algorithms, and introduction to NP completeness. A term project emphasizes applications to realistic engineering design problems.

**ME 559 (Mfg 559). Smart Materials and Structures**

*Prerequisite: EECS 210 or equivalent. I alternate years (3 credits)*

This course will cover theoretical aspects of smart materials, sensors and actuator technologies. It will also cover design, modeling and manufacturing issues involved in integrating smart materials and components with control capabilities to engineering smart structures.

**ME 560 (Mfg 562). Modeling Dynamic Systems**

*Prerequisite: ME 360. I (3 credits)*

A unified approach to the modeling, analysis and simulation of energetic dynamic systems. Emphasis on analytical and graphical descriptions of state-determined systems using Bond Graph language. Analysis using interactive computer simulation programs. Applications to the control and design of dynamic systems such as robots, machine tools and artificial limbs.

**ME 561 (Aero 571) (EECS 561). Design of Digital Control Systems**

*Prerequisite: EECS 460 or Aero 471 or ME 461. I, II (4 credits)*

Sampling and data reconstruction. Z-transforms and state variable descriptions of discrete-time systems. Modeling and identification. Analysis and design using root locus, frequency response, and state space techniques. Linear quadratic optimal control and state estimation. Quantization and other nonlinearities. Computer simulations and laboratory implementation of real-time control systems.

**ME 562. Dynamic Behavior of Thermal-Fluid Processes**

*Prerequisite: ME 330. II alternate years (3 credits)*

Principles of transport processes and automatic control. Techniques for dynamic analysis; dynamic behavior of lumped- and distributed-parameter systems, nonlinear systems, and time-varying systems; measurement of response; plant dynamics. Experimental demonstration for dynamic behavior and feedback control of several thermal and fluid systems.

**ME 563 (IOE 565) (Mfg 561). Time Series Modeling, Analysis, Forecasting**

*Prerequisite: IOE 366 or ME 401. I (3 credits)*

Time series modeling, analysis, forecasting, and control, identifying parametric time series, autovariance, spectra, Green's function, trend and seasonality. Examples from manufacturing, quality control, ergonomics, inventory, and management.

**ME 564 (Aero 550) (EECS 560). Linear Systems Theory**

*Prerequisite: graduate standing. I (4 credits)*

Linear spaces and linear operators. Bases, subspaces, eigenvalues and eigenvectors, canonical forms. Linear differential and difference equations. Mathematical representations: state equations, transfer functions, impulse response, matrix fraction and polynomial descriptions. System-theoretic concepts: causality, controllability, observability, realizations, canonical decomposition, stability.

**ME 567 (EECS 567) (Mfg 567). Introduction to Robotics: Theory and Practice**

*Prerequisite: EECS 380. II (3 credits)*

Introduction to robots considered as electro-mechanical computational systems performing work on the physical world. Data structures representing kinematics and dynamics of rigid body motions and forces and controllers for achieving them. Emphasis on building and programming real robotic systems and on representing the work they are to perform.

**ME 568. Vehicle Control Systems**

*Prerequisite: ME 461 or equivalent. I (3 credits)*

Design and analysis of vehicle control systems such as cruise control, traction control, active suspensions and advanced vehicle control systems for Intelligent Vehicle-Highway Systems (IVHS). Human factor considerations such as driver interfaces. This course may be used as part of the IVHS certification program.

**ME 571. Conduction Heat Transfer**

*Prerequisite: ME 330 or ME 370. II (3 credits)*

Lumped, differential, and integral formulations of conduction. Product solutions in terms of orthogonal functions or approximate profiles. Periodic conduction, computational conduction: finite difference versus finite element. Technological applications.

**ME 572. Convection Heat Transfer**

*Prerequisite: ME 330 or ME 370. II (3 credits)*

Differential and integral formulations of convection. Parallel and nearly parallel laminar (boundary layer) flows. Similarity solutions. Periodic convection. Computational convection. Instability and turbulence. Kinetic and thermal scales and spectra. Flow prediction. Heat transfer prediction. Multiple scale dimensional analysis. Technological applications.

**ME 573. Radiative Heat Transfer**

*Prerequisite: ME 330 or ME 370. I (3 credits)*

Electromagnetic, optical and quantum aspects of radiative equilibrium. Enclosure radiation including spatial, specular, and spectral distributions. Gas radiation including boundary affected thin gas and thick gas approximations. Averaged and spectral properties. Technological applications.

**ME 574. Phase Change Dynamics**

*Prerequisite: ME 336; ME 330 or ME 370. II (3 credits)*

Heat and mass transfer and fluid dynamics of phase change and two-phase flow. Basic laws, mechanisms and correlations for evaporation, boiling, condensation and pressure drop. Applications in areas of power plant boilers and condensers (conventional and nuclear), internal combustion engines (carburetion, diesel injection), freeze drying, bubble lift pumps, humidification/ dehumidification.

**ME 575. Heat Transfer in Porous Media**

*Prerequisite: ME 370 or equivalent. I (3 credits)*

Heat transfer and fluid flow in porous media are examined based on conservation principles. Local volume-averaging is developed and applied to conduction, convection, mass transfer, radiation, and two-phase flows. Several single-phase and two-phase problems are examined.

**ME 580 (Mfg 580). Rheology and Fracture**

*Prerequisite: ME 382. I (3 credits)*

Mechanisms of deformation, cohesion, and fracture of matter. Unified approach to the atomic-scale origins of plastic, viscous, viscoelastic, elastic, and anelastic behavior. The influences of time and temperature on behavior. Stress field of edge and screw dislocations, dislocation interactions, and cross slip. Ductile, creep, brittle, and fatigue failure mechanisms.

**ME 581 (Mfg 581). Friction and Wear**

*Prerequisite: background in materials and mechanics desirable. II (3 credits)*

The nature of solid surfaces, contact between solid surfaces, rolling friction, sliding friction, and surface heating due to sliding; wear and other types of surface attrition are considered with reference to practical combinations of sliding materials, effect of absorbed gases, surface contaminants and other lubricants on friction, adhesion, and wear; tire and brake performance.

**ME 582 (Mfg 582) (MSE 523). Metal-Forming Plasticity**
*Prerequisite: ME 211. II (3 credits)*
Elastic and plastic stress-strain relations; yield criteria and flow rules; analyses of various plastic forming operations. Effects of hardening and friction, temperature, strain rate, and anisotropy.

**ME 583 (IOE 583) (Mfg 583) (EECS 566). Scientific Basis for Reconfigurable Manufacturing**
*Prerequisite: Graduate standing or permission of instructor. II alternate years (3 credits)*
Principles of reconfigurable manufacturing systems (RMS). Students will be introduced to fundamental theories applicable to RMS synthesis and analysis. Concepts of customization, integratability, modularity, diagnosability, and convertability. Reconfiguration design theory, life-cycle economics, open-architecture principles, controller configuration, system reliability, multi-sensor monitoring, and stream of variations. Term projects.

**ME 584 (Mfg 584). Control of Machining Systems**
*Prerequisite: ME 461 or equivalent. II (3 credits)*
Advanced control and sensing methodologies for machining processes: milling, turning, drilling, grinding and laser cutting: machine tool structure; CNC programming; drive components; trajectory interpolators; selection of control parameters; software compensation and adaptive control. The design process of a comprehensive machining system. (Two-hour lecture and two-hour lab per week.)

**ME 585 (Mfg 585). Machining Dynamics and Mechanics**
*Prerequisite: graduate standing or permission of instructor. I even years (3 credits)*
Dynamic cutting process models and process stability issues. Advanced cutting process mechanics and modeling including cutting process damping, thermal energy and cutting temperature, and wear evolution. Single and multi-DOF stability analysis techniques, stability margins and stability charts. Modeling approximations for industrial applications.

**ME 587 (Mfg 587). Reconfigurable Agile Manufacturing**
*Prerequisite: one 500-level manufacturing or design class. II (3 credits)*
Product-process-market modeling. Principles of mass production. Agility in product design. Agility in manufacturing processes. Flexible line boring. Optimal batch size. System reliability. Product quality. CAD/CAM and CNC. Agility in marketing and delivery. Virtual organizations. Agile scheduling. Using agile strategies in product development.

**ME 588 (IOE 588) (Mfg 588). Assembly Modeling for Design and Manufacturing**
*Prerequisites: ME 381 and ME 401 or equivalent. I alternate years (3 credits)*
Assembly on product and process. Assembly representation. Assembly sequence. Datum flow chain. Geometric Dimensioning & Tolerencing. Tolerance analysis. Tolerance synthesis. Robust design. Fixturing. Joint design and joining methods. Stream of variation. Auto body assembly case studies.

**ME 589 (Mfg 589). Failure Analysis Case Studies**
*Prerequisite: preceded or accompanied by ME 350. II (3 credits)*
Detailed case study of a variety of service failures in engineering structures such as vehicles, medical implants, hoisting equipment, machinery, and consumer products such as ladders, mowers, and tools. Procedures for analysis include applications of optical and electron microscopy; load history, dynamics, and stress analysis; indentation hardness analysis; accident investigation and reconstruction techniques; specifications and standards; fracture mechanics. The expert's role in product liability litigation.

**ME 590. Study or Research in Selected Mechanical Engineering Topics**
*Prerequisite: graduate standing; permission of the instructor who will guide the work; mandatory satisfactory/unsatisfactory. I, II, III, IIIa, IIIb (3 credits)*
Individual or group study, design, or laboratory research in a field of interest to the student. Topics may be chosen from any of the areas of mechanical engineering. The student will submit a report on the project and give an oral presentation to a panel of faculty members at the close of the term.

**ME 591. Automotive Engineering Seminar I**
*Prerequisite: graduate standing. I (1 credit)*
A series of invited speakers from industry, academia, and government will present seminars on various aspects of automotive engineering. Speakers will emphasize systems engineering, design and manufacturing, team building practices, business and management issues, and other topics which would broaden the student's perspective. Term paper required.

**ME 592. Automotive Engineering Seminar II**
*Prerequisite: graduate standing; mandatory satisfactory/unsatisfactory. II (1 credit)*
A series of invited speakers from industry, academia, and government will present seminars on various aspects of automotive engineering. Speakers will emphasize systems engineering, design and manufacturing, team building practices, business and management issues, and other topics which would broaden the student's perspective. Term paper required.

**ME 593. Automotive Engineering Project**
*Prerequisite: ME 591, ME 592 or permission of instructor. III (4 credits)*
Students will carry out a project in interdisciplinary teams, and where possible, in conjunction with an internship held during the summer with an industrial or government sponsor. An ME faculty member will follow the progress and serve as an advisor to the project teams.

**ME 595. Master's Thesis Proposal**
*Prerequisite: graduate standing in Mechanical Engineering. I, II, III, IIIa, IIIb (3 credits); (Not for credit until 6 hrs of ME 695 is satisfactorily completed.)*
A course devoted to literature search, analysis, design of experiments, and other related matters prior to completion of a master's degree thesis. A thesis proposal clearly delineating the proposed research and including the above items is required at the conclusion of the course.

**ME 599. Special Topics in Mechanical Engineering**
*Prerequisite: permission of instructor I, II, IIIa, IIIb (to be arranged)*
Selected topics pertinent to mechanical engineering.

**ME 605. Advanced Finite Element Methods in Mechanics**
*Prerequisite: ME 505 or CEE 510, (NA 512). II (3 credits)*
Recent developments in finite element methods; mixed, hybrid, mixed-hybrid, reduced integration penalty, singular, boundary integral elements. Emphasis on the methodology for developing elements by using calculus of variations. Applications selected from various branches of solid and fluid mechanics.

**ME 617. Mechanics of Polymers II**
*Prerequisite: ME 511, ME 517, (MacroSE 517), or permission of instructor. I alternate years (3 credits)*
Selected advanced topics in the mechanics of polymeric solids and fluids, including nonlinear elasticity, nonlinear viscoelastic solids, viscoplasticity in amorphous and crystalline polymer solids, constitutive models and associated flow properties for polymer fluids, temperature dependence and solidification, applications.

**ME 619. Theory of Plasticity II**

*Prerequisite: ME 519. II (3 credits)*

Plastic theory for materials with isotropic hardening, kinematic hardening, and time dependence. Theories based on crystal slip; variational theorems; range of validity of total deformation theories. Theory of generalized stresses applied to circular plates; behavior at finite deflection; limit analysis of shells. Plane stress, plane strain, and axial symmetry. Plastic response to impact loads. Minimum weight design.

**ME 622. Inviscid Fluids**

*Prerequisite: ME 520. II (3 credits)*

Vorticity theorems of Helmholtz and Kelvin. Potential Flow; the complex potential; flow around bodies. Conformal mapping and free streamline theory. Rotational flow; Stability, Kelvin-Helmholtz and Rayleigh-Taylor instabilities. Motion of point vortices and vortex regions. Chaotic vortex motions. Vortex filaments and vortex sheets.

**ME 623. Hydrodynamic Stability**

*Prerequisite: ME 520. I (3 credits)*

An introduction to the theory of hydrodynamic stability with applications to stability of thermal flows, rotating and curved flows, wallbounded and free shear flows. Development of the asymptotic theory of the Orr-Sommerfeld equation. Review of the fundamental concepts and current work in nonlinear theory of hydrodynamic stability.

**ME 624. Turbulent Flow**

*Prerequisite: ME 520. I (3 credits)*

Fundamentals of turbulent flows; the basic equations and the characteristic scales, statistical description of turbulence. Review of experimental results on the statistics and structure of turbulent flows. Methods for calculation of turbulent flows; the problem of closure, semi-empirical, phenomenological and analytical theories of turbulence, large-eddy and direct simulations of turbulence.

**ME 625. Nonhomogeneous Fluids**

*Prerequisite: ME 520. I, II (3 credits)*

Motion of fluids of variable density and entropy in gravitational field, including the phenomenon of blocking and selective withdrawal; waves of small finite amplitudes, including waves in the lee of mountains; stability of stratified flows; flow of Nonhomogeneous fluids in porous media. Analogy with rotating fluids.

**ME 626. Perturbation Methods for Fluids**

*Prerequisite: ME 520. II (3 credits)*

Application of asymptotic methods to fluid mechanics, with special emphasis on the method of matched expansions. Regular perturbation solutions; suppression of secular terms; method of multiple scales; boundary layer and low Reynolds number flows by inner and outer expansions; phenomena in rotating flows. Applications to computational fluid mechanics.

**ME 627 (NA 627). Wave Motion in Fluids**

*Prerequisite: ME 520 or NA 520 or equivalent. I (3 credits)*

Surface waves in liquids; group velocity and dispersion; water waves created by and wave resistance to a moving body; Korteweg de Vries equation; conoidal and solitary waves in water; wave reflection and diffraction; shallow-water waves by the method of characteristics; statistical approach and spectral analysis; wave generation.

**ME 631. Statistical Thermodynamics**

*Prerequisite: ME 230 or ME 336. II (3 credits)*

Introduction to statistical methods for evaluating thermodynamic and transport properties. Elements of quantum mechanics, statistical mechanics, and kinetic theory, as applied to engineering thermodynamics.

**ME 635. Thermodynamics IV**

*Prerequisite: ME 535. II (3 credits)*

Discussion of thermodynamic systems including surface phenomena, external fields, and relativistic effects. Study of complex equilibrium calculations including effect of heterogeneous reactions and real substance behavior. Introduction to the thermo-dynamics of irreversible processes with applications to heat and mass transfer, relaxation phenomena and chemical reactions.

**ME 641. Advanced Vibrations of Structures**

*Prerequisite: ME 541. II (3 credits)*

Energy formulation for nonconservative gyroscopic systems. Spectral methods for free and forced vibrations. Eigenvalue and boundary value problems. Non self-adjoint systems. Variational methods of approximation: Bubnov-Galerkin. Perturbation theory for the eigenvalue problem. Dynamics of rotating systems. Dynamics of constrained dynamical systems.

**ME 643. Analytical and Computational Dynamics II**

*Prerequisite: ME 543. II alternate years (3 credits)*

Kinematical and dynamical equation formulation for rigid and flexible mechanical multi-body systems undergoing large overall motion and small elastic deformation. Energy principles, higher and lower pair joint parameterizations, space and dense equation formulation and solution techniques, numerical integration, generalized impulse and momentum, collisions, and computational elastodynamics. Course project.

**ME 645. Wave Propagation in Elastic Solids**

*Prerequisite: ME 541. II alternate years (3 credits)*

Elastodynamic equations, isotropic and anisotropic materials; vector/scalar potentials, reflection and transmission at interfaces, mode conversion, surface waves, Rayleigh-Lamb equation. Green's tensor; variational, Galerkin and Hamilton's equations. Kirchhoff-Love and Reissner-Mindlin kinematic hypotheses for beam, plate and shell theories. Fourier and Laplace transform, modal and state-vector solution techniques.

**ME 646 (BiomedE 646). Mechanics of Human Movement**

*Prerequisite: ME 540, (Aero 540) or ME 543, or equivalent. II alternate years (3 credits)*

Dynamics of muscle and tendon, models of muscle contraction. Kinematics and dynamics of the human body, methods for generating equations of motion. Mechanics of proprioceptors and other sensors. Analysis of human movement, including gait, running, and balance. Computer simulations and discussion of experimental measurement techniques.

**ME 648. Nonlinear Oscillations and Stability of Mechanical Systems**

*Prerequisite: ME 541. II (3 credits)*

Large amplitude mechanical vibrations; phase-plane analysis and stability; global stability, theorems of Liapunov and Chetayev; asymptotic and perturbation methods of Lindstedt-Poincare, multiple scales, Krylov-Bogoliubov-Mitropolsky; external excitation, primary and secondary resonances; parametric excitation, Mathieu/Hill equations, Floquet theory; multi-degree of freedom systems and modal interaction.

**ME 649 (Aero 615) (CEE 617). Random Vibrations**

*Prerequisite: Math 425 or equivalent, CEE 513 or ME 541, or Aero 543 or equivalent. II alternate years (3 credits)*

Introduction to concepts of random vibration with applications in civil, mechanical, and aerospace engineering. Topics include: characterization of random processes and random fields, calculus of random processes, applications of random vibrations to linear dynamical systems, brief discussion on applications to nonlinear dynamical systems.

**ME 661. Adaptive Control Systems**

*Prerequisite: ME 561. I (3 credits)*

Introduction to control of systems with undetermined or time varying parameters. Theory and application of self-tuning and model reference adaptive control for continuous and discrete-time deterministic systems. Model based methods for estimation and control, stability of nonlinear systems, adaptation laws, and design and application of adaptive control systems.

**ME 662 (Aero 672) (EECS 662). Advanced Nonlinear Control**
*Prerequisite: EECS 562 or ME 548. I (3 credits)*
Geometric and algebraic approaches to the analysis and design of nonlinear control systems. Nonlinear controllability and observability, feedback stabilization and linearization, asymptotic observers, tracking problems, trajectory generation, zero dynamics and inverse systems, singular perturbations, and vibrational control.

**ME 663. Estimation of Stochastic Signals and Systems**
*Prerequisite: ME 563 or IOE 565 or equivalent. I (3 credits)*
Estimation and prediction methods for vector stochastic signals and systems. Topics include characteristics of stochastic signals and systems; principles of estimation theory; linear regression models; description of signals and systems within a time series frame-work; prediction, prediction-error, and correlation-type estimation methods; recursive estimation methods; asymptotic properties; model validation.

**ME 672. Turbulent Transport of Momentum, Heat and Mass**
*Prerequisite: ME 572. I (3 credits)*
Introduction to laminar flow stability. Statistical and phenomenological theories of turbulence. Turbulent transport of momentum, heat and mass in steady and unsteady internal, boundary layer, and free flows. Skin friction, heat and mass transfer coefficients. Discussion of experimental results.

**ME 695. Master's Thesis Research**
*Prerequisite: ME 595; mandatory satisfactory/unsatisfactory. I, II, IIIa, IIIb (3 credits)*
Student must elect 2 terms of 3 hrs/term. No credit without ME 595 Student is required to present a seminar at the conclusion of the second election as well as prepare a written thesis.

**ME 699. Advanced Special Topics in Mechanical Engineering**
*Prerequisite: permission of instructor. I, II, IIIa, IIIb (to be arranged)*
Advanced selected topics pertinent to mechanical engineering.

**ME 790. Mechanical Sciences Seminar**
*Prerequisite: candidate status in the mechanical sciences. I (1 credit)*
Every Ph.D. student in the field of mechanical sciences is requested to present a one-hour seminar about his/her research, and lead a one-hour follow-up discussion. Active participation in the discussions that follow all presentations is also required for a grade. In addition, each student will participate as a panelist in a panel discussion of the future trends in his/her field. Graded S-U.

**ME 990. Dissertation/Pre-Candidate**
*I, II, III (1-8 credits); IIIa, IIIb (1-4 credits)*
Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**ME 995. Dissertation/Candidate**
*Prerequisite: Graduate School authorization for admission as a doctoral candidate. I, II, III (8 credits); IIIa, IIIb (4 credits)*
Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

## Mechanical Engineering Faculty

A. Galip Ulsoy, Ph.D., *William Clay Ford Professor of Manufacturing and Chair*
Steven Ceccio, Ph.D., *Associate Professor and Associate Chair of Mechanical Engineering*

### Professors

Vedat S. Arpaci, Sc.D.
Dennis M. Assanis, Ph.D., *Arthur F. Thurnau Professor*
Arvind Atreya, Ph.D.
James R. Barber, Ph.D.
Michael Chen, Ph.D.
Debasish Dutta, Ph.D.; *also Director, Interdisciplinary Professional Programs; Director, Program In Manufacturing*
Steven Goldstein, Ph.D.
Elijah Kannatey-Asibu, Jr., Ph.D.
Massoud Kaviany, Ph.D.
Noboru Kikuchi, Ph.D.
Yoram Koren, Ph.D., *Paul G. Goebel Professor of Engineering; also Director of NSF Engineering Research Center for Reconfigurable Machining Systems*
Sridhar Kota, Ph.D.
Jyotirmoy Mazumder, Ph.D., D.I.C., *Robert H. Lurie Professor of Engineering; also Materials Science and Engineering*
Jun Ni, Ph.D.; also *Director of S.M. Wu Manufacturing Research Center*
Jwo Pan, Ph.D.
Panos E. Papalambros, Ph.D., *Donald C. Graham Professor of Engineering; also Director, Automotive Research Center*
Noel Perkins, Ph.D.
Christophe Pierre, Ph.D.
William W. Schultz, Ph.D
Richard A. Scott, Ph.D.
Jeffrey L. Stein, Ph.D., P.E.
Michael Thouless, Ph.D.; *also Materials Science and Engineering*
Alan S. Wineman, Ph.D.; *Arthur F. Thurnau Professor; also Macromolecular Science and Engineering*
Wei-Hsuin Yang, Ph.D.

### Professors Emeritus

Herbert H. Alvord, M.S.E.
Jay A. Bolt, M.S. (M.E.), P.E.
John A. Clark, Sc.D.; *also Production Engineering*
Samuel K. Clark, Ph.D., P.E.

Maria A. Comninou, Ph.D.
Joseph Datsko, M.S.E.
Walter R. Debler, Ph.D., P.E.
John H. Enns, Ph.D.
David Kniseley Felbeck, Sc.D., P.E.
William Graebel, Ph.D.
Robert L. Hess, Ph.D.
Edward R. Lady, Ph.D., P.E.
Kenneth C. Ludema, Ph.D.
Herman Merte, Jr., Ph.D.
Donald J. Patterson, Ph.D., P.E.
John R. Pearson, M.Sc. (M.E.)
Leland J. Quackenbush, M.S.E. (M.E.)
Albert B. Schultz, Ph.D., *Vennema Professor of Mechanical Engineering*
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Richard E. Sonntag, Ph.D.
John E. Taylor, Ph.D.; *also Aerospace Engineering*
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### Adjunct Professor
Thomas D. Gillespie, Ph.D.

### Associate Professors
Rayhaneh Akhavan, Ph.D.
Ellen Arruda, Ph.D.; *also Macromolecular Science and Engineering*
Claus Borgnakke, Ph.D.
David R. Dowling, Ph.D.
Karl Grosh,Ph.D.
Shixin Hu, Ph.D.
Gregory M. Hulbert, Ph.D.
Bruce H. Karnopp, Ph.D.
Arthur D. Kuo, Ph.D.
Huei Peng, Ph.D.
Ann Marie Sastry, Ph.D.
Volker Sick, Ph.D.
Anna G. Stefanopoulous, Ph.D.

### Joint Associate Professor
Scott Hollister, Ph.D.

### Associate Professors Emeritus
Kurt C. Binder, B.S.E. (M.E.), M.B.A., *Engineering Graphics*
David E. Cole, Ph.D.
Donald C. Douglas, B.S. (M.E.), *Engineering Graphics*
Robert H. Hoisington, M.S., *Engineering Graphics*
Robert B. Keller, Ph.D.
Raymond C. Scott, M.S. (Ed.), *Engineering Graphics*
John G. Young, B.S.E. (M.E.)

### Assistant Professors
Diann E. Brei, Ph.D.
Suman Das, Ph.D.
Krishna Garikipati, Ph.D.
R. Brent Gillespie, Ph.D.
Hong Geun Im, Ph.D.
Katsuo Kurabayashi, Ph.D.
Jonathan Luntz, Ph.D.
Kazuhiro Saitou, Ph.D.
Steven J. Skerlos, Ph.D.
Dawn Tilbury, Ph.D.
Margaret Wooldridge, Ph.D.

### Lecturers
Donald M. Geister, M.S.E.; *also Aerospace Engineering*

### Research Scientists
James Ashton-Miller, Ph.D.; *also Institute of Gerontology*
Johann Borenstein, D.Sc.

### Joint Research Scientist
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### Associate Research Scientists
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Loucas Louca
Mostafa Mehrabi
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## Mechanical Engineering Contact Information
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# NAVAL ARCHITECTURE AND MARINE ENGINEERING

*Program Advisor*
*Associate Professor D.G. Karr*
*236B Naval Architecture and Marine Engineering Building*
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## Engineering for the Marine Environment

More than 70 percent of our planet is covered by water. Engineering for the marine environment covers the design and production of all types of systems to operate successfully in this often harsh and demanding environment. In addition to traditional **naval architecture and marine engineering,** instruction is offered in **offshore engineering, coastal engineering,** and **marine environmental engineering**. Recent graduates are active in design and research related to offshore oil and gas exploration and production platforms. Others are involved in overcoming water-borne pollution transport in the Great Lakes and the oceans, and coastal erosion predictions, as well as the design of traditional ships, submersibles, high-speed vessels and recreational craft. A number of our alumni have leading roles in the design of America's Cup racing yachts.

Since the design of modern marine systems encompasses many engineering fields, graduates of this department are called upon to handle diverse professional responsibilities; therefore, the program includes study in the fundamentals of the physical sciences and mathematics as well as a broad range of engineering aspects that constitute design for the marine environment. To provide the appropriate educational breadth, it is also desirable that as many courses in the humanities and social sciences be elected as can be accommodated. It is recognized that the undergraduate program cannot, in the time available, treat all important aspects of engineering for the marine environment that may be desired by the student; therefore, graduate work is encouraged.

Ship and offshore platform analysis and design require knowledge of hull geometry, vessel arrangements, hydrostatic stability, structures, resistance, propulsion, maneuvering, and seakeeping. Other areas of concern are the economic aspects of design and operation, production, model testing, propeller and control theory, vibration problems, and piping and electrical system analysis and design.

The undergraduate degree program is arranged to give the student a broad engineering mechanics education by requiring basic courses in the areas of structural mechanics, hydrodynamics, marine power systems, and marine dynamics. These courses cover engineering fundamentals and their application to the design and construction of marine vehicles and systems. Courses in marine structures deal with the design and analysis of marine vehicles and platforms including static strength, fatigue, dynamic response, safety, and production. Resistance, maneuvering, and seakeeping characteristics of bodies in the marine environment are the subject matter for courses in marine hydrodynamics. Marine power systems involve all the mechanical systems on a marine vehicle with particular emphasis on the selection and arrangement of the main propulsion system. In marine dynamics, the student studies the vibrations of marine structures and engines and the rigid body responses of the vessel to wind and waves. Through the use of technical and free electives, students may decide to focus their education in areas such as:

- Marine Structures
- Ship Production and Management
- Sailing Yachts
- High Speed Craft
- Marine Environmental Fluid Mechanics
- Marine Power Systems

An integration of the material covered in earlier courses takes place in the two-semester, final design sequence. In the first course of this sequence, the student works on a class design project using state-of-the-art computer-aided design tools. In the second semester, the students form design teams and work on projects of their choosing. Recent final design projects included a Volvo Around the World racing yacht, high-speed ferry boats, an escort tug, a Coast Guard offshore cutter, a sport fisherman, a large cruise ship, a small deep-submergence submarine, harbor design and a mega yacht.

The department works closely with the marine industry and is able to assist graduates in obtaining positions in the field. The department is in constant touch with the country's marine design offices, shipyards, ship operators, government agencies, and other organizations concerned with ocean development. A summer internship program allows students to work in the marine field and receive academic credit. Academic credit is earned by successful completion of a job-related project; the final written report is formally presented to faculty and students the following semester.

Students who meet the academic requirements of both departments may earn an additional B.S.E. degree in another engineering discipline, or in combined programs with other engineering departments. The combined programs allow substantial substitution of courses required in one regular program for those required in the other, and typically can be completed in one extra term.

This program is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

## Our Mission, Goals, Objectives and Outcomes for Undergraduate Education

### Mission

To be a world leader in the education of naval architects, marine and ocean engineers in the application of engineering principles in the marine environment by:

- Providing the leading bachelor's program in naval architecture and marine engineering, with emphasis on the design, manufacture, and management of marine vehicles, structures, and systems;
- Providing the leading graduate education and research program in engineering for the marine environment; one which spans a broad range of inquiry;
- Providing leadership and service to the state, national and international marine community.

### Goals

- To recruit, educate, and support excellent, diverse students and prepare them for a life-long career of engineering leadership in the marine related industries, government service, and academia.
- To have the leading undergraduate program in the world in Naval Architecture and Marine Engineering; one which provides a rigorous and effective preparation for a life-long career of engineering leadership.

### Objectives

- Prepare engineers for professional practice in the design and manufacture of vehicles to operate in the marine environment. Primary emphasis is on the scientific, engineering, and design aspects of ships, small boats, and craft, and also submersibles, platforms, and other marine systems. The program also emphasizes the ability to work effectively in teams and culminates with a major team design experience.
- Prepare students for professional practice in the marine industries, for further graduate study, and for life-long learning.
- To serve the people of Michigan and the world through preeminence in creating, communicating, preserving and applying knowledge, art, and academic values, and in developing leaders and citizens who will challenge the present and enrich the future.

### Outcomes

The outcomes we desire are that graduates of the Naval Architecture and Marine Engineering Program demonstrate:

- An ability to apply knowledge of mathematics, science, and engineering within naval architecture and marine engineering;
- An ability to formulate engineering problems and develop practical solutions;
- An ability to design products and processes applicable to naval architecture and marine engineering;
- An ability to design, conduct, analyze, and interpret the results of engineering experiments;
- An ability to work effectively in diverse teams and provide leadership to teams and organizations;
- An ability for effective oral, graphic, and written communication;
- A broad education necessary to understand the impact of engineering decisions in a global/societal/economic/environmental context;
- An understanding of professional and ethical responsibility;
- A recognition of the need for and an ability to engage in life-long learning;
- A broad education necessary to contribute effectively beyond their professional careers;
- A sense of responsibility to make a contribution to society;
- An ability to apply probability and statistical methods to naval architecture and marine engineering problems;
- An ability to apply basic knowledge in fluid mechanics, dynamics, structural mechanics, material properties, hydrostatics, and energy/propulsion systems in the context of marine vehicles;

• A familiarity and experience with instrumentation appropriate to naval architecture and marine engineering including experiment design, data collection, data analysis, and formal laboratory report writing;
• An understanding of the organization, methods and techniques of marine system manufacture and the use of concurrent marine design;
• An understanding of and experience in marine system conceptual and preliminary design using industrial capability design software, including a team design experience with formal written and oral presentation.

## Facilities

The department operates the Marine Hydrodynamics Laboratory (MHL) located on Central Campus. The laboratory houses a 110 x 6.7 x 3.2 meter towing tank, a low turbulence-free surface water channel, a gravity-capillary water wave facility, a 35-meter-long gravity wave tank, and a propeller tunnel for student use. The laboratory is equipped with appropriate shops and state-of-the-art instrumentation, much of which was developed in-house. Undergraduate students are required to take at least one laboratory course that uses the model basin. The MHL also hires students on a part-time basis to help with ongoing research.

The department provides the Undergraduate Marine Design Laboratory (UMDL) to support student design work in sophomore through senior classes. Teams of seniors work in this laboratory to develop and present their final design projects. The laboratory contains 15 team work areas, each with a Windows workstation, small drawing layout table, and work desk. This laboratory also contains major Michigan-developed and industrial ship design software needed in the design activities. The laboratory also supports digitizing, scanning, and printing needs.

The department also has an Ocean Engineering Laboratory and a Virtual Reality Laboratory. The Ocean Engineering Laboratory (OEL) is involved in full-scale field measurements such as beach erosion, thermal fronts and pollution transport on the Great Lakes, and active remote sensing of the ocean surface from satellites and aircraft. In addition, the OEL is the home of the University's underwater Remote Operated Vehicle for Education and Research (M-ROVER). M-ROVER is used for submerged vehicle/dynamics studies in the undergraduate curriculum and for exploration and research of the Great Lakes and the oceans.

The Virtual Reality Laboratory (VRL) is a leading university facility that investigates the use of immersive display technologies in a variety of applications, especially in virtual prototyping of marine and other designs and in the simulation of manufacturing processes. The VRL is equipped with state-of-the-art graphics computers as well as with Head Mounted Display devices, BOOM devices, data gloves, motion sensors and other related technologies.

## Dual Degrees

For students with special interests, dual degree programs leading to two bachelor's degrees are available. Favorite second degree areas of concentration among naval architecture and marine engineering students are aerospace engineering and mechanical engineering. Combined degrees with other departments can also be arranged. As early as possible, students interested in such dual degree programs should consult with the program advisors in both programs to work out optimum combinations of courses.

## Sample Schedule B.S.E. Naval Architecture and Marine Engineering

| | Credit Hours | Terms 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| **Subjects required by all programs (52 hrs.)** | | | | | | | | | |
| Mathematics 115, 116, 215, and 216 | 16 | 4 | 4 | 4 | 4 | - | - | - | - |
| Engr 100, Intro to Engr | 4 | 4 | - | - | - | - | - | - | - |
| Engr 101, Intro to Computers | 4 | - | 4 | - | - | - | - | - | - |
| [1]Chemistry 125 and 130 or Chemistry 210 and 211 | (5) 4 | 4 | - | - | - | - | - | - | - |
| [2]Physics 140 with Lab 141; 240 with Lab 241 | (10) 8 | - | 4 | 4 | - | - | - | - | - |
| Humanities and Social Sciences | 16 | 4 | 4 | - | - | - | - | 4 | 4 |
| [3]**Advanced Mathematics (3 or 4 hrs.)** | 3 or 4 | - | - | - | - | 4 | - | - | - |
| **Related Technical Core Subjects (12 hrs.)** | | | | | | | | | |
| ME 211, Intro to Solid Mechanics | 4 | - | - | 4 | - | - | - | - | - |
| ME 240, Intro to Dynamics | 4 | - | - | - | 4 | - | - | - | - |
| ME 230, Thermal Sciences I | 4 | - | - | - | 4 | - | - | - | - |
| **Program Subjects (40 hrs.)** | | | | | | | | | |
| NA 270, Marine Design | 4 | - | - | 4 | - | - | - | - | - |
| NA 276, Marine Systems Manufacturing | 2 | - | - | - | 2 | - | - | - | - |
| NA 277, Intro to Probal and Statistics w/ Marine Appls | 2 | - | - | - | 2 | - | - | - | - |
| NA 310, Marine Structures I | 4 | - | - | - | - | 4 | - | - | - |
| NA 320, Marine Hydrodynamics I | 4 | - | - | - | - | 4 | - | - | - |
| NA 321, Marine Hydrodynamics II | 4 | - | - | - | - | - | 4 | - | - |
| NA 330, Marine Power Systems I | 4 | - | - | - | - | 4 | - | - | - |
| NA 340, Marine Dynamics I | 4 | - | - | - | - | - | 4 | - | - |
| NA 391, Marine Engr Laboratory | 4 | - | - | - | - | - | 4 | - | - |
| NA 470, Foundations of Ship Design | 4 | - | - | - | - | - | - | 4 | - |
| NA 475, Marine Design Team Project | 4 | - | - | - | - | - | - | - | 4 |
| **Technical Electives (8 hrs.)** | 8 | - | - | - | - | - | - | 4 | 4 |
| *Choose two from the following list. At least one must come from the first four on the list.* | | | | | | | | | |
| NA 410, Marine Structures II | | | | | | | | | |
| NA 420, Environmental Ocean Dynamics | | | | | | | | | |
| NA 430, Marine Power Systems II | | | | | | | | | |
| NA 440, Marine Dynamics II | | | | | | | | | |
| NA 401 Small Craft Design | | | | | | | | | |
| NA 403 Sailing Craft Design Principles | | | | | | | | | |
| NA 455 Environmental Nearshore Dynamics | | | | | | | | | |
| NA 460, Marine Production Engineering, Planning and Control | | | | | | | | | |
| **Unrestricted Electives (12 hrs.)** | 12 | - | - | - | - | - | 4 | 4 | 4 |
| **Total** | 128 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |

Candidates for the Bachelor of Science degree in Engineering (Naval Architecture and Marine Engineering)—(B.S.E. Nav. Arch. & Marine E.)—must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

In the fourth year, students are required to select two four-credit technical electives from a prescribed list. These electives allow students to focus their education in specific areas. Example focus areas and possible courses are as follows:

Marine Structures:
NA 410 and NA 440

Marine Environmental Fluid Mechanics:
NA 420 and NA 455

Marine Manufacturing:
NA 410 and NA 460

High Speed Craft Design:
NA 401 and NA 430 or NA 440

Marine Power Systems:
NA 430 and NA 401 or NA 410

Sailing Yachts:
NA 403 and NA 410, NA 430, or NA 440

These and other combinations of free and technical electives should be selected in consultation with the Undergraduate Program Advisor. Students are strongly encouraged to review the possible options prior to their senior year.

**Notes:**

[1]Chemistry: 125, 130 or 210, 211 will count for 5 total credits, 1 of which will be applied according to individual program directives.

[2]Physics: 140, 141; 240, 241 will count for 10 total credits, 2 of which will be applied according to individual program directives.

[3]A list of approved courses is available from Program Advisor.

## Naval Architecture and Marine Engineering Course Listings

Course descriptions are found also on the College of Engineering web site at http://courses.engin.umich.edu/

### NA 102 (NS 201). Introduction to Ship Systems

*Prerequisite: none. II (3 credits) (Not open for credit to students in NAME.)*

Types, structures, and purposes of ships. Ship compartmentation, propulsion systems, auxiliary power systems, interior communications, and ship control. Elements of ship design to achieve safe operations, and ship stability characteristics. Not open for credit to students in Naval Architecture and Marine Engineering.

### NA 270. Marine Design

*Prerequisite: none. I, II (4 credits)*

Introduction to the marine industries, ships, and platforms. Engineering economics as applied in marine design decision making. Overview of preliminary ship design with brief team design project. Hydrostatics, stability, and trim of ships, boats, and marine platforms.

### NA 276. Introduction to Marine Manufacturing

*Prerequisite: preceded by or taken concurrently with NA 270. offered first half of term II (2 credits)*

Overview of the marine industry including equipment types and components. Shipbuilding and offshore equipment manufacturing methods as they relate to all aspects of naval architecture and marine engineering.

### NA 277. Introduction to Probability and Statistics with Marine Applications

*Prerequisite: preceded by or taken concurrently with NA 270. II (2 credits)*

Introduction to shipping and shipbuilding markets and competition. Introduction to probability theory and statistics, with marine applications.

### NA 310. Marine Structures I

*Prerequisite: ME 211, NA 270. I (4 credits)*

Structural analysis of ship hulls and offshore structures. Loading, material and fabrication considerations. Hull primary bending and midship section analysis. Framing systems. Secondary and tertiary stresses in stiffened plate components. Energy methods. Introduction to Finite Element Analysis. Failure theories for buckling; combined stress states; brittle fracture and fatigue.

### NA 320. Marine Hydrodynamics I

*Prerequisite: ME 211 or ME 240, or permission of instructor. I (4 credits)*

Concepts and basic equations of marine hydrodynamics. Similitude and dimensional analysis, basic equations in integral form, continuity, and Navier-Stokes equations. Ideal fluid flow, Euler's equations, Bernoulli equation, free surface boundary value problems. Laminar and turbulent flows in pipes and around bodies.

### NA 321. Marine Hydrodynamics II

*Prerequisite: NA 320. II (4 credits)*

Ideal and viscous fluid theory applied to marine systems. Ship resistance components. Resistance prediction from model testing and standard series. Two-dimensional and three-dimensional airfoil theory. Propeller geometry, design and matching. Hull-propeller interaction, propeller charts, powering prediction. Unsteady marine hydrodynamics: wave loads, seakeeping and transport of pollutants.

### NA 330. Marine Power Systems I

*Prerequisite: ME 230; Corequisite: NA 320. I (4 credits)*

Diesel engines, steam turbines, and gas turbines as marine prime movers.

Cycles, ratings, matching to loads. Electrical and mechanical transmission of power to marine loads. Energy conservation by means of bottoming cycles. Principles of fluid system design. Characteristics of electrical generators, motors, and distribution systems.

**NA 340. Marine Dynamics I**

*Corequisites: NA 277, NA 321, ME 240. II (4 credits)*

Structural vibration; one and multi-degree of freedom models. Forced steady state response. Fourier series; definition and application to frequency response. Introduction to random processes and applications in linear systems. Rigid body motion of floating structures. Sea wave excitation. Hydrodynamic added mass and damping; anti-roll tanks. Ship maneuvering; directional stability and steady turning.

**NA 391. Marine Engineering Laboratory**

*Prerequisite: none; Corequisites: NA 321, NA 340. II (4 credits)*

Instruction in laboratory techniques and instrumentation. Use of computers in data analysis. Technical report writing. Investigation of fluid concepts, hydroelasticity, marine dynamics, propeller forces, wave mechanics, ship hydrodynamics, and extrapolation of model tests to full scale.

**NA 401. Small Craft Design**

*Prerequisite: preceded or accompanied by NA 321 and NA 340. II (4 credits)*

Hydrodynamics of small high-speed craft including planing hulls, air cushion vehicles, surface effect ships, and catamarans. Theoretical and empirical methods for resistance propulsion and attitude prediction. Nonlinear dynamics and stability of high-speed marine vehicles. Effect of hull form on resistance and dynamic performance. Structural design considerations including bottom plating strength and frame loading. Discussion of various types of framing. Material choices.

**NA 403. Sailing Craft Design Principles**

*Prerequisite: preceded or accompanied by NA 321. I (3 credits)*

Forces and moments acting on a sailing yacht. Speed polar diagrams. Two- and three-dimensional airfoil theory. Application to keel and rudder design. Yacht model testing. Delft Standard Series for prediction of hydrodynamic performance. Aerodynamics of yacht sails. Sail force coefficients. Velocity Prediction Program. Rigging design and analysis. Yacht racing rules.

**NA 410 (Mfg 410). Marine Structures II**

*Prerequisite: NA 310. I (4 credits)*

Structural modeling and analysis techniques applied to ship and marine structure components. Equilibrium and energy methods applied to elastic beam theory; static bending, torsion and buckling. Shear flow and warping of multi-cell cross sections. Stiffened and composite plates. Plastic analysis of beams. Thick walled pressure vessels. Course project using finite element analysis.

**NA 420 (AOSS 420). Environmental Ocean Dynamics**

*Prerequisites: NA 320 or AOSS 305 or CEE 325. I (4 credits)*

Physical conditions and physical processes of the oceans; integration of observations into comprehensive descriptions and explanations of oceanic phenomena. Emphasis on wave and current prediction, optical and acoustical properties of sea water, currents, tides, waves and pollutant transport.

**NA 421. Ship Model Testing**

*Prerequisite: undergraduates only and permission of instructor. I, II, IIIa (to be arranged)*

Individual or team project, experimental work, research or directed study of selected advanced topics in ship model testing.

**NA 430. Marine Power Systems II**

*Prerequisite: NA 330 and NA 340. II (4 credits)*

Integrated treatment of the statics and dynamics of marine power transmission systems: alignment; lubrication; propeller excitation, added mass, and damping; lateral, axial, and torsional vibrations. Characteristics of electrical generators, motors, and distribution systems with emphasis on marine ship service and propulsion systems. Circuit analysis and circuit protection.

**NA 440. Marine Dynamics II**

*Prerequisite: NA 321, NA 340. II (4 credits)*

Dynamic analysis in a fluid environment. Rayleigh's principle for continuous systems. Equations of motion for ship rigid body dynamics. Wave excitation. Response Amplitude Operator (RAO). Random processes and probability. Motion in irregular seas. Introduction to time series analysis.

**NA 455. Environmental Nearshore Dynamics**

*Prerequisite: NA 320. II (4 credits)*

Shallow water waves and currents are investigated in nearshore processes including tides and long-term sea-level changes, longshore current and prediction of sediment and pollutant transport. Beach response to these processes is examined; coastal structures and effects on the nearshore environmentally conscious coastal design is emphasized. Interpretation of aerial photography is investigated.

**NA 460 (Mfg 460). Ship Production Engineering, Planning and Control**

*Prerequisite: NA 270, NA 276, NA 277. I (4 credits)*

Application of production engineering and operations management to the production of complex marine systems, such as ships, offshore structures, and yachts. Applicability of various manufacturing and operations management philosophies, production engineering, planning and scheduling, performance measurement, and control to the operation of ship and boat yards.

**NA 469 (AOSS 469). Underwater Operations**

*Prerequisite: permission of instructor. II (3 credits)*

Survey of manned undersea activities in oceanography and ocean engineering. The tools of underwater operations: decompression chambers, habitats, submarines, diving apparatus; pertinent design criteria and applications as based on human hyperbaric physiology and performance. Topics in research diving for engineering and oceanographic studies.

**NA 470 (Mfg 470). Foundations of Ship Design**

*Prerequisite: NA 321, NA 340. Corequisites: NA 310 and NA 330. I (4 credits)*

Organization of ship design. Preliminary design methods for sizing and form; powering, maneuvering, and seakeeping estimation; arranging; propulsion; structural systhesis; and safety and environmental risk of ships. Extensive use of design computer environment. Given owner's requirements, students individually create and report the conceptual/preliminary design for a displacement ship.

**NA 475. Marine Design Team Project**

*Prerequisite: NA 470. II (4 credits)*

Small teams of up to 4 students create, develop, and document original marine designs to contract design level. Projects typically involve a ship, yacht, submersible, or offshore system. Involves extensive project planning and weekly progress reporting. Extensive written and oral presentation of the project. Significant design CAD effort.

**NA 477 (Eng 477). Principles of Virtual Reality**

*Prerequisite: senior standing or permission of instructor. I (4 credits)*

Enabling technologies (display systems, motion trackers, interactive devices, others), applications, human factors and perception, computer graphics and geometric modeling principles, creation of virtual environments, existing tools, special topics. Interdisciplinary group projects will develop VR applications using the facilities in the Media Union. http://www-VRL.umich.edu/Eng477/

**NA 490. Directed Study, Research and Special Problems**

*Prerequisite: undergraduate only and permission. I, II, IIIa (to be arranged)*

Individual or team project, experimental work or study of selected topics in naval architecture or marine engineering. Intended primarily for students with senior standing.

**NA 500. Engineering Analysis in the Marine Environment**
*Prerequisite: graduate standing. I (4 credits)*
Formulation of hydrodynamic, rigid body dynamics, and structural problems in the marine environment. Multiple scales, problem decoupling. Direct, energy, and stochastic modeling methods. Solution methods: linear systems, linear stochastic systems, linear ODE and PDE boundary and initial value problems, stability concepts, perturbation methods, dominant balance in nonlinear differential equations. Applications in ship motions, viscous flows, vibrations, structures, elasticity, structural dynamics, stochastic loading.

**NA 510. Marine Structural Mechanics**
*Prerequisite: NA 500. II (4 credits)*
Failure modes encountered in ship and offshore structures. Von Karman plate equations. Geometric and material nonlinear analyses of beams and stiffened plates. Calculus of variations. Effective width and breadth of stiffened plates. Introduction to structural reliability theory with applications to marine structural design.

**NA 511. Special Topics in Ship Structure**
*Prerequisite: prior arrangement with instructor. (to be arranged)*
Individual or team project, experimental work, research or directed study of selected advanced topics in ship structure. Primarily for graduate students.

**NA 512 (CEE 510). Finite Element Methods in Solid and Structural Mechanics**
*Prerequisite: graduate standing. II (3 credits)*
Basic equations of three dimensional elasticity. Derivation of relevant variational principles. Finite element approximation. Convergence requirements. Isoparametric elements in two and three dimensions. Implementational considerations. Locking phenomena. Problems involving non-linear material behavior.

**NA 518. Strength Reliability of Ship and Offshore Structures**
*Prerequisite: NA 410, Aero 452. I (3 credits)*
Stress versus strength analysis. Deterministic stress analysis, safety factor approach. Random nature of loads, geometry material and construction. Random variables and random functions. Reliability of structures described by one or more random variables. Introduction to random vibration of discrete and continuous structural systems.

**NA 520. Wave Loads on Ships and Offshore Structures**
*Prerequisite: NA 500. II (4 credits)*
Computation of wave loads on marine vehicles and offshore structures including resistance, diffraction, viscous and radiation forces. Linear theory using panel methods and Green functions. Forces on cylindrical bodies. Morison's Equation. Nonlinear computation using desingularized method for inviscid flow and Reynold's averaged Navier-Stokes equation (RANS) for viscous flow.

**NA 521. Directed Study and Research in Marine Hydrodynamics**
*Prerequisite: permission of instructor. (to be arranged)*
Individual or team project, experimental work, research or directed study of selected advanced topics in marine hydrodynamics. Primarily for graduate students.

**NA 522. Experimental Marine Engineering**
*Prerequisite: NA 410 and NA 440 or third-term graduate standing. IIIa (3 credits)*
Advanced experiments in mechanics, vibrations, dynamics, and hydrodynamics illustrating concepts of 400 and introductory 500 level NA courses. Typical experiments include full scale experiments using Remote Operated Vehicle; vessel dynamic stability; offshore tower strength and vibrations; high speed planing; Tension Leg Platform hydrodynamic damping.

**NA 528 (AOSS 528). Remote Sensing of Ocean Dynamics**
*Prerequisite: NA 420 (AOSS 420) or permission of instructor. II (3 credits)*
The dynamics of ocean wave motion, both surface and internal waves, and ocean circulation are explored utilizing active and passive remote sensing techniques. Emphasis is placed upon the synoptic perspective of ocean dynamics provided by remote sensing which is not obtainable by conventional means.

**NA 540. Marine Dynamics III**
*Prerequisite: NA 340 or equivalent, preceded or accompanied by NA 500. I (4 credits)*
Fundamental analysis of marine dynamical systems. Normal mode analysis. Matrix representation of frequency domain seakeeping equations. Properties of linear gravity waves. Wave forces on marine structures. Linear and nonlinear time domain seakeeping, and maneuvering simulations. Nonlinear stability and bifurcation theory applied to mooring and capsizing. Shock mitigation.

**NA 550 (AOSS 550). Offshore Engineering Analysis II**
*Prerequisite: NA 420 (AOSS 420). II (3 credits)*
Design and analysis requirements of off-shore facilities. Derivation of hydrodynamic loads on rigid bodies. Loads on long rigid and flexible cylinders. Viscous forces on cylinders, experimental data, Morison's equation, Stokes wave theories. Shallow water waves. Selection of appropriate wave theory. Diffraction of waves by currents. Hydrodynamic loads on risers, cables, pipelines and TLP's.

**NA 561 (Mfg 573). Marine Product Modeling**
*Prerequisite: NA 570. II (3 credits)*
Fundamental aspects of marine product modeling, data exchange, and visualization. Simulation Based Design. Introduction to activity modeling and information modeling. Overview of Object Oriented Programming. Geometric modeling of solids and surfaces. Simulation and visualization. Virtual prototyping.

**NA 562 (Mfg 563). Concurrent Marine Design Management**
*Prerequisite: B.S. in Engineering. I (3 credits)*
Combination capstone and management development course to provide students the opportunity to apply basic naval architectural and related engineering knowledge to a real life business situation and to apply newly gained management skills. Management and organization concepts, theories and processes will be presented in the context of the marine industry.

**NA 570 (Mfg 572). Advanced Marine Design**
*Prerequisite: graduate standing required. II (4 credits)*
Organization of marine product development; concurrent marine design. Shipbuilding policy and build strategy development. Group behaviors; leadership and facilitation of design teams. General theories and approaches to design. Conceptual design of ships and offshore projects. Nonlinear programming, multicriteria optimization, and genetic algorithms applied to marine design. Graduate standing required.

**NA 571 (Mfg 571). Ship Design Project**
*Prerequisite: prior arrangement with instructor. I, II, IIIa (to be arranged)*
Individual (or team) project, experimental work, research or directed study of selected advanced topics in ship design. Primarily for graduate students.

**NA 575 (Mfg 575). Computer-Aided Marine Design Project**
*Prerequisite: none. I, II, IIIa, IIIb, III (2-6 credits), (to be arranged)*
Development of computer-aided design tools. Projects consisting of formulation, design, programming, testing, and documentation of programs for marine design and constructional use.

***NA 579. Concurrent Marine Design Team Project***
*Prerequisite: NA 460, NA 570, and NA 580. III (4-6 credits)*
Industrial related team project for Master's of Engineering Concurrent Marine Design degree program. Student teams will conduct concurrent design project for and in conjunction with industrial or government customer.

**NA 580 (Mfg 578). Optimization, Market Forecast and Management of Marine Systems**

*Prerequisite: NA 500. I (4 credits)*

Optimization methods (linear, integer, nonlinear, sequential) concepts and applications in the operations of marine systems. Forecasting methods (ARMA, Fuzzy sets, Neural nets) concepts and applications to shipping and shipbuilding decisions. Economics of merchant shipbuilding and ship scrapping. Elements of maritime management: risk and utility theory. Deployment optimization.

**NA 582 (Mfg 579). Reliability and Safety of Marine Systems**

*Prerequisite: EECS 401 or Math 425 or Stat 412. II (3 credits)*

Brief review of probability, statistics, trade-off analysis, and elements of financial management. Thorough presentation of the methods and techniques of reliability analysis. Marine reliability, availability, maintenance, replacement, and repair decisions. Safety and risk analysis. FMEA, fault-tree and event-tree analysis. Marine applications.

**NA 590. Reading and Seminar**

*Prerequisite: permission. I, II, IIIa, IIIb (to be arranged)*

A graduate level individual study and seminar. Topic and scope to be arranged by discussion with instructor.

**NA 592. Master's Thesis**

*Prerequisite: graduate standing. I, II, III, IIIa, IIIb (1-6 credits)*

To be elected by Naval Architecture and Marine Engineering students pursuing the master's thesis option. May be taken more than once up to a total of 6 credit hours.

**NA 615. Special Topics in Ship Structure Analysis II**

*Prerequisite: NA 510, prior arrangement with instructor. I, II (to be arranged)*

Advances in specific areas of ship structure analysis as revealed by recent research. Lectures, discussions, and assigned readings.

**NA 620. Computational Fluid Dynamics for Ship Design**

*Prerequisite: NA 500. I alternate years (3 credits)*

Development of the necessary skills for the hydrodynamic design of hull shapes based on available Computational Fluid Dynamic (CFD) tools. Topics: Potential Flows (Deeply submerged, Free-surface treatment, Status of CFD solvers), Viscous flows (Basics, Turbulence modeling, Grid generation, Discretization, Numerical techniques, Free-surface, Status of CFD solvers), Design methodologies (Strategies for Wave Resistance, Viscous flows, Total resistance and Optimization work).

**NA 625. Special Topics in Marine Hydrodynamics**

*Prerequisite: permission. I, II (to be arranged)*

Advances in specific areas of marine hydrodynamics as revealed by recent research.

**NA 627 (ME 627). Wave Motion in Fluids**

*Prerequisite: ME 520 or NA 520 or equivalent. I (3 credits)*

Surface waves in liquids; group velocity and dispersion; water waves created by and wave resistance to a moving body; Korteweg-deVries equation; conoidal and solitary waves in water; wave reflection and diffraction; shallow-water waves by the method of characteristics; statistical approach and spectral analysis; wave generation.

**NA 635. Special Topics in Marine Engineering**

*Prerequisite: permission. I, II (to be arranged)*

Advances in specific areas of marine engineering as revealed by recent research. Lectures, discussions, and assigned readings.

**NA 644. Numerical Methods for Vibro-Acoustic Modeling of Complex Systems**

*Prerequisite: NA 340 or ME 440. II alternate years (3 credits)*

Theoretical development, numerical formulation, and practical modeling aspects of the Statistical Energy Analysis (SEA) and the Energy Finite Element Analysis (EFEA). Numerical evaluation of vibration and acoustic characteristics of complex structural/acoustic systems, such as ship structure, airframe, or trimmed car body.

**NA 650. Dynamics of Offshore Facilities**

*Prerequisite: NA 410, NA 440. II (3 credits)*

Dynamics and stability of single point mooring systems. Marine cable statics and dynamics. Dynamics and stability of multilegged mooring systems. Dynamics and stability of towing systems. Dynamics of offshore towers. Structural redesign. Correlation of finite element model and physical structure. Dynamics and stability of marine risers; bundles of risers. Statics and dynamics of pipelines.

**NA 655. Special Topics in Offshore Engineering**

*Prerequisite: NA 410, NA 440, NA 550 or NA 650. II (to be arranged)*

Advances in specific areas of offshore engineering as revealed by recent research. Lectures by doctoral students. Projects and presentations by M.S. students. Discussion, assigned readings.

**NA 685. Special Topics in Marine Systems**

*Prerequisite: permission of instructor; mandatory pass/fail. I, II (to be arranged)*

Advances in specific areas of marine systems engineering as revealed by recent research. Lectures, discussions, and assigned readings.

**NA 792. Professional Degree Thesis**

*I, II, III (2-8 credits); IIIa, IIIb (1-6 credits)*

**NA 990. Dissertation/Pre-Candidate**

*I, II, III (2-8 credits); IIIa, IIIb (1-4 credits)*

Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**NA 995. Dissertation/Candidate**

*Prerequisite: Graduate School authorization for admission as a doctoral candidate. I, II, III (8 credits); IIIa, IIIb (4 credits)*

Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

## Naval Architecture and Marine Engineering Faculty

Michael M. Bernitsas, Ph.D., *Professor and Chair*

### Professors

Robert F. Beck, Ph.D., *Graduate Program Chair*
Guy A. Meadows, Ph.D., *also Atmospheric, Oceanic and Space Science*
Michael G. Parsons, Ph.D., *Arthur F. Thurnau Professor*
Armin W. Troesch, Ph.D., P.E.

### Professors Emeritus

Harry Benford, B.S.E.
Howard M. Bunch, M.B.A., C.M.A., *Transportation Management*
Amelio M. D'Arcangelo, M.S.
Movses J. Kaldjian, Ph.D.; *also Civil and Environmental Engineering*
John B. Woodward, Ph.D.
Raymond A. Yagle, M.S.E.

### Adjunct Professor

Stephen Brandt, Ph.D.

### Associate Professors

Dale G. Karr, Ph.D., P.E.
Anastassios N. Perakis, S.M. (M.B.A.), Ph.D.
Marc Perlin, Ph.D.
Nickolas Vlahopoulos, Ph.D.

### Adjunct Associate Professors

Klaus-Peter Beier, Dr. Ing.
Thomas Lamb, M.B.A., P.E.
Zissimos P. Mourelatos, Ph.D.

### Assistant Professors

Ana Sirviente, Ph.D.
H. Tuba Özken-Haller, Ph.D.

### Adjunct Lecturers

Brant R. Savander, Ph.D.
Mark H. Spicknall, M.B.A.

### Research Scientist

David R. Lyzenga, Ph.D.

### Associate Research Scientist

David T. Walker, Ph.D.

### Adjunct Associate Research Scientist

H. Bruce Bongiorni, M.B.A.

### Adjunct Assistant Research Scientist

Basem Alzahabi, Ph.D.

## Naval Architecture and Marine Engineering Contact Information

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# NUCLEAR ENGINEERING AND RADIOLOGICAL SCIENCES

*Program Advisor*
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Nuclear engineering and radiological sciences are concerned with the direct technological use of atomic and subatomic particles. These applications have become an inseparable part of much of modern technological life: smoke detectors, nuclear power reactors, nondestructive evaluation of turbine blades, hardening of artificial hip joints, treatment of radioactive waste, medical CT and PET imaging, treatment of cancer using radiotherapy —all of these rely on the direct manipulation and measurements of parts of atoms or their emitted energy. These are the kinds of technologies that nuclear engineering and radiological sciences encompasses.

The Undergraduate Program in Nuclear Engineering and Radiological Sciences is divided into two tracks (the nuclear engineering track and the radiological science track) both leading to the Bachelor of Science in Engineering degree—B.S.E.(N.E.R.S.).

## Nuclear Engineering

The nuclear engineering track is intended for students interested in nuclear power and nuclear reactors. Students following this track are generally interested in:

- Neutron transport and reactor physics: how neutrons move through matter and how to manipulate them.
- Nuclear reactor systems and safety: the technological systems that support nuclear electric generating stations, and the safety issues that surround them.

## Radiological Sciences

Generally speaking, the radiological science track is designed for students who are interested in the applications of radiation and other fundamental atomic and subatomic particles. Students pursuing this track are generally interested in:

- Radiological health engineering: the use of engineering principles to protect human health in radiation environments.
- Medical uses of radiation: the use of radiation (x-rays, positrons, gamma rays) and nuclear properties (magnetic resonance) to image structures and processes in the human body, and to treat cancer and other diseases
- Radiation measurements: the use of radiation measurement, and the detection of radiation in industrial and medical settings.
- Ion and plasma materials processing: the use of ions to modify or process materials.
- Radioactive waste engineering: the study of the treatment and storage of radioactive waste

Students interested in Biomedical Engineering should consider the radiological sciences track as one with sufficient flexibility to ready them for their graduate studies. The program is designed to provide a basic common core, and then allow a wide range of choices, from Nuclear Engineering and Radiological Sciences, other College of Engineering departments, the School of Public Health, and the University of Michigan Hospitals so that students can develop their interests.

Students in either track learn the fundamentals of modern physics and the fundamentals of radiation measurement on which these nuclear and radiation technologies are based. In the senior year the tracks branch apart into more specialized courses and design studies.

The program, leading to the B.S.E. (Nuclear Engineering and Radiological Sciences), is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

## Research Opportunities and Scholarships

Programs have been established in the Nuclear Engineering and Radiological Sciences Department which allow students to interact with faculty and graduate students on different research projects. These include the Fermi Scholar Program specifically for first- and second-year students and the Research Opportunity Program for junior- and senior-level students. In addition to the research opportunities, scholarships are also available for all levels (first-year through completion of a B.S.E.) for those students interested in this program of study.

## Our Mission, Goals, Objectives and Outcomes for Undergraduate Education

### *Mission*

To provide a superior education for engineers and scientists in nuclear engineering and radiological sciences and to develop future leaders in industry, government, and education.

### *Goals*

The program provides students with:

• skills and tools necessary for industrial, medical, and environmental applications of nuclear processes and radiation;

• insights and skills that will prepare them to be leaders in research and the practice of nuclear engineering and radiological sciences.

### *Objectives*

Graduates of the program will:

• learn to perform the analysis and measurements related to radiation interactions with matter;

• gain experience in engineering practice for beneficial applications of nuclear processes and radiation;

• be prepared with sufficient breadth and depth to successfully pursue graduate studies;

• develop multi-disciplinary, team-work, life-long learning, and communications skills.

### *Outcomes*

Graduates of the program will have:

• an ability to apply mathematics, engineering, and science, including atomic and nuclear physics, to the study of radiation interactions with matter and nuclear processes;

• an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice;

• an ability to formulate engineering problems and develop practical solutions;

• an ability to design products and processes applicable to nuclear engineering and radiological sciences;

• an ability to design, conduct, analyze, and interpret the results of engineering experiments, including characteristic attributes of nuclear processes and radiation;

• an ability to work effectively in diverse teams and provide leadership to teams and organizations;

• an ability for effective oral, graphic, and written communication;

• a broad education necessary to understand the impact of engineering decisions and biological effects of radiation in a societal and environmental context;

• an understanding of professional and ethical responsibility;

• a recognition of the need for and an ability to engage in life-long learning;

• a knowledge of contemporary issues;

• an ability to work professionally in one or more areas related to: nuclear power systems, plasma science and applications, radiation effects in materials and radiation-enhanced materials processing, nuclear measurement and instrumentation, radiological health engineering, and radiotherapy, nuclear medicine and radiological imaging.

## Facilities

The Department of Nuclear Engineering and Radiological Sciences occupies the Mortimer E. Cooley Building, which contains departmental offices, faculty offices, classrooms, and several of the labs listed below. Other laboratories of the department are housed in the Phoenix Memorial Laboratory and the Naval Architecture and Marine Engineering (NAME) Building. The Department of Nuclear Engineering and Radiological Sciences has a number of special facilities and laboratories that allow students to get hands-on experience with systems that manipulate matter at a fundamental level. These include:

Ford Nuclear Reactor
Glow Discharge Laboratory
High Temperature Corrosion Laboratory
Intense Energy Beam Interaction Laboratory
Materials Preparation Laboratory
Metastable Materials Laboratory
Michigan Ion Beam Laboratory
Nuclear Imaging and Measurements Laboratory
Radiation Detection Laboratory
Radioactive Waste Management Laboratory
Radiological Health Engineering Laboratory
Semiconductor Materials Radiological Technologies Laboratory

# Sample Schedule B.S.E. Nuclear Engineering and Radiological Sciences

| | Credit Hours | Terms 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| **Subjects required by all programs (52 hrs.)** | | | | | | | | | |
| Mathematics 115, 116, 215, and 216 | 16 | 4 | 4 | 4 | 4 | - | - | - | - |
| Engr 100, Intro to Engr. | 4 | 4 | - | - | - | - | - | - | - |
| Engr 101, Intro to Computers | 4 | - | 4 | - | - | - | - | - | - |
| [1]Chemistry 125 and 130 or Chemistry 210 and 211 | (5) 4 | 4 | - | - | - | - | - | - | - |
| [2]Physics 140 with Lab 141; 240 with Lab 241 | (10) 8 | - | 4 | 4 | - | - | - | - | - |
| Humanities and Social Sciences | 16 | 4 | 4 | - | 4 | 4 | - | - | - |
| **Advanced Mathematics (4 hrs.)** | | | | | | | | | |
| Math 450, Adv Math for Eng 1 | 4 | - | - | - | - | 4 | - | - | - |
| **Related Technical Subjects (20 hrs.)** | | | | | | | | | |
| MSE 250, Princ of Eng Materials | 4 | - | - | 4 | - | - | - | - | - |
| CEE 211, Statics and Dynamics | 4 | - | - | - | 4 | - | - | - | - |
| EECS 210, Elec Eng 1 | 4 | - | - | - | - | 4 | - | - | - |
| CEE 325, Fluid Mechanics | 4 | - | - | - | - | - | 4 | - | - |
| ME 235, Thermodynamics I | 4 | - | - | - | - | - | 4 | - | - |
| **Program Subjects (36 hrs.)** | | | | | | | | | |
| NERS 211, Intr to Nuclear Eng and Rad Sci | 4 | - | - | - | 4 | - | - | - | - |
| NERS 311, Ele of Nuc Eng and Rad Sci I | 4 | - | - | - | - | 4 | - | - | - |
| NERS 312, Ele of Nuc Eng and Rad Sci II | 4 | - | - | - | - | - | 4 | - | - |
| NERS 315, Nuclear Instr Lab | 4 | - | - | - | - | - | 4 | - | - |
| NERS 441, Nuclear Reactor Theory I or NERS 484, Rad Hlth Eng Fundamentals | 4 | - | - | - | - | - | - | 4 | - |
| [3]Laboratory Course (above NERS 315) | 4 | - | - | - | - | - | - | - | 4 |
| [4]Design Course | 4 | - | - | - | - | - | - | - | 4 |
| NERS Electives | 8 | - | - | - | - | - | - | 4 | 4 |
| **Technical Electives (4 hrs.)** | 4 | - | - | - | - | - | - | 4 | - |
| **Unrestricted Electives (12 hrs.)** | 12 | - | - | 4 | - | - | - | 4 | 4 |
| **Total** | 128 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |

Candidates for the Bachelor of Science degree in Engineering (Nuclear Engineering and Radiological Sciences)—B.S.E. (N.E.R.S.)—must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

**Notes:**

[1]Chemistry: 125, 130 or 210, 211 will count for 5 total credits, 1 of which will be applied according to individual program directives; for students who have advanced placement credit for freshman chemistry, a 100-level or above biology course may be used to fulfill this requirement.

[2]Physics: 140, 141; 240, 241 will count for 10 total credits, 2 of which will be applied according to individual program directives.

[3]Laboratory Course (above NERS 315) select one from the following: NERS 445, 425, 575. (NERS 575 with Program Advisor's consent.)

[4]Design Course select one: NERS 442, 554.

## Nuclear Engineering and Radiological Sciences Course Listings

Course descriptions are found also on the College of Engineering web site at http://courses.engin.umich.edu/

### NERS 100. Radiation and the Environment

*Prerequisite: none. I, II (2 credits)*

Sources of natural and human-made radiation (including radioactivity and electromagnetic radiation) and its effect on the environment. The course will include examples of applications of radiation such as nuclear power, nuclear medicine, food irradiation, radon, and electronmagnetic fields. Discussions of societal issues concerning radiation. Class participation in demonstrations.

### NERS 211. Introduction to Nuclear Engineering and Radiological Sciences

*Prerequisite: preceded or accompanied by Math 216. II (4 credits)*

This course will discuss different forms of energy, the history of nuclear energy, the fundamentals of fission and fusion nuclear power, radiological health applications, and electromagnetic radiation in the environment. Current topics in the media such as radon, radioactive waste, and nuclear proliferation will also be covered.

### NERS 311. Elements of Nuclear Engineering and Radiological Sciences I

*Prerequisite: NERS 211, Physics 240, preceded or accompanied by Math 450. I (4 credits)*

Photons, electrons, neutrons, and protons. Particle and wave properties of radiation. Introduction to quantum mechanics and special relativity. Properties and structure of atoms and nuclei. Introduction to interactions of radiation with matter.

### NERS 312. Elements of Nuclear Engineering and Radiological Sciences II

*Prerequisite: NERS 311. II (4 credits)*

Production and use of nuclear radiation. Alpha-, beta- and gamma-decay of nuclei. Neutrons. Nuclear Reactions. Elementary radiation interactions and transport.

### NERS 315. Nuclear Instrumentation Laboratory

*Prerequisite: preceded or accompanied by NERS 312. II (4 credits)*

An introduction to the devices and techniques most common in nuclear measurements. Topics include the principles of operation of gas-filled, solid state, and scintillation detectors for charged particle, gamma ray, and neutron radiations. Techniques of pulse shaping, counting, and analysis for radiation spectroscopy. Timing and coincidence measurements.

### NERS 400. Elements of Nuclear Energy

*Prerequisite: junior standing. I, II (2 credits) (7-week course)*

Ideas and concepts important to the development of nuclear energy for peaceful purposes — intended for those in fields other than nuclear engineering. History of the nuclear energy program, elementary nuclear physics, fission and fusion reactors, radiological health physics, and nuclear medicine.

### NERS 421. Nuclear Engineering Materials

*Prerequisite: MSE 250, NERS 312. I (2 credits) (7-week course)*

An introduction to materials used in nuclear systems and radiation effects in materials (metals, ceramics, semiconductors, organics) due to neutrons, charged particles, electrons and photons.

### NERS 425. Application of Radiation

*Prerequisite: NERS 312. II (4 credits)*

Applications of radiation interaction with matter using various forms (neutrons, ions, electrons, photons) of radiation, including activation analysis, neutron radiography, nuclear reaction analysis, Rutherford backscattering analysis, proton-induced x-ray emission, plasma-solid interactions and wave-solid interactions. Lectures and laboratory.

**NERS 441. Nuclear Reactor Theory I**

*Prerequisite: NERS 312, Math 450. I (4 credits)*

An introduction to the theory of nuclear fission reactors including neutron transport theory, the $P_1$ approximation, diffusion theory, criticality calculations, reactor kinetics, neutron slowing down theory, and numerical solution of the diffusion equation.

**NERS 442. Nuclear Power Reactors**

*Prerequisite: NERS 441, CEE 325. II (4 credits)*

Analysis of nuclear fission power systems including an introduction to nuclear reactor design, reactivity control, steady-state thermal-hydraulics and reactivity feedback, fuel cycle analysis and fuel management, environmental impact and plant siting, and transient analysis of nuclear systems. A semester-long design project of the student's choice.

**NERS 445. Nuclear Reactor Laboratory**

*Prerequisite: NERS 315, NERS 441. II, IIIa (4 credits)*

Measurements of nuclear reactor performance: activation methods, rod worth, critical loading, power and flux distributions, void and temperature coefficients of reactivity, xenon transient, diffusion length, pulsed neutrons.

**NERS 462. Reactor Safety Analysis**

*Prerequisite: preceded or accompanied by NERS 441. I (2 credits) (7-week course)*

Analysis of those design and operational features of nuclear reactor systems that are relevant to safety. Reactor containment, engineered safety features, transient behavior and accident analysis for representative reactor types. NRC regulations and procedures. Typical reactor safety analyses.

**NERS 471. Introduction to Plasmas**

*Prerequisite: preceded or accompanied by Physics 240 or equivalent. I (4 credits)*

Single particle orbits in electric and magnetic fields, moments of Boltzmann equation and introduction to fluid theory. Wave phenomena in plasmas. Diffusion of plasma in electric and magnetic fields. Analysis of laboratory plasmas and magnetic confinement devices. Introduction to plasma kinetic theory. Engineering applications of plasmas.

**NERS 472. Fusion Reactor Technology**

*Prerequisite: NERS 471. II (2 credits) (7-week course)*

Study of technological topics relevant to the engineering feasibility of fusion reactors as power sources. Energy and particle balances in fusion reactors; neutronics and tritium breeding, various approaches to plasma heating, heat removal and environmental aspects.

**NERS 481. (BiomedE 481) Engineering Principles of Radiation Imaging**

*Prerequisite: none. II (2 credits) (7-week course)*

Analytic description of radiation production, transport and detection in radiation imaging systems. Measurements methods for image quality and statistical performance of observers. Systems for radiographic and radioisotope imaging, including film/screen, storage phosphor, and electronic radiography, fluoroscopy, computed tomography, Anger camera, and PET systems. Emphasis on impact of random process on observer detection.

**NERS 482. (BiomedE 482) Fundamentals of Ultrasonics with Medical Applications**

*Prerequisite: EECS 230 II (2 credits) (7-week course)*

Basic principles; waves, propagation, impedance, reflection, transmission, attenuation, power levels. Generation of ultrasonic waves; transducers, focusing, Fraunhofer and Fresnel zones. Instrumentation; display methods, Doppler techniques, signal processing. Medical applications will be emphasized.

**NERS 484. (BiomedE 484) Radiological Health Engineering Fundamentals**

*Prerequisite: NERS 312 or equivalent or permission of instructor. I (4 credits)*

Fundamental physics behind radiological health engineering and topics in quantitative radiation protection. Radiation quantities and measurement, regulations and enforcement, external and internal dose estimation, radiation biology, radioactive waste issues, radon gas, emergencies, and wide variety of radiation sources from health physics perspective.

**NERS 490. Special Topics in Nuclear Engineering**

*Prerequisite: permission of instructor. (to be arranged)*

Selected topics offered at the senior or first-year graduate level. The subject matter may change from term to term.

**NERS 499. Research in Nuclear Engineering**

*Prerequisite: permission of instructor. (1-3 credits)*

Individual or group research in a field of interest to the student under the direction of a faculty member of the Nuclear Engineering and Radiological Sciences department.

**NERS 511. Quantum Mechanics in Neutron-Nuclear Reactions**

*Prerequisite: NERS 312, Math 450. II (3 credits)*

An introduction to quantum mechanics with applications to nuclear science and nuclear engineering. Topics covered include the Schroedinger equation and neutron-wave equations, neutron absorption, neutron scattering, details of neutron-nuclear reactions, cross sections, the Breit-Wigner formula, neutron diffraction, nuclear fission, transuranic elements, the deuteron problem, masers, and lasers.

**NERS 512. Interaction of Radiation and Matter**

*Prerequisite: NERS 511. II (3 credits)*

Classical and quantum-mechanical analysis of the processes by which radiation interacts with matter. Review of nuclear structure and properties. Nuclear models. Nuclei as sources of radiation. Interaction of electromagnetic radiation with matter. Interaction of charged particles with matter. Radiative collisions and theory of bremsstrahlung. Interaction of neutrons with matter. Interaction mechanisms and cross sections are developed.

**NERS 515. Nuclear Measurements Laboratory**

*Prerequisite: permission of instructor. I (4 credits)*

Principles of nuclear radiation detectors and their use in radiation instrumentation sys-tems. Characteristics of important devices with applications in nuclear science. Gamma ray spectroscopy, fast and thermal neutron detection, charged particle measurements, pulse analysis, nuclear event timing, and recent development in nuclear instrumentation.

**NERS 518. Advanced Radiation Measurements and Imaging**

*Prerequisite: NERS 315 or NERS 515. I alternate years (2 credits)*

Detection and imaging of ionizing radiation that builds on a basic course in radiation measurements. Topics include statistical limits on energy and spatial resolution, analog and digital pulse processing, pulse shape analysis and discrimination, position sensing techniques, application of Ramo theorem for calculating induced charge, and the use of statistical methods in data analysis. Specific devices used as examples of evolving technology include newly-developed scintillators and wave-shifters, optical sensors, gas-filled imaging and spectroscopic detectors, semiconductor spectrometers from wide bandgap materials, gamma ray/neutron imaging systems, and cryogenic spectrometers.

**NERS 521. Radiation Effects in Nuclear Materials**

*Prerequisite: permission of instructor. I (3 credits)*

Radiation effects in crystalline solids; defect production, spike phenomena, displacement cascades, interatomic potentials, channeling, focusing, slowing down. Radiation effects on mechanical behavior of reactor components; creep, hardening, fracture, fatigue. Applications to pressure vessel steels, in-core components, and fusion reactor wall materials.

**NERS 522. Nuclear Fuels**

*Prerequisite: permission of instructor. II alternate years (3 credits)*

Nuclear reactor fuels and the fuel cycle; mining, processing, isotope separation and fabrication. Fuel/clad behavior; radiation damage, thermal response, densification, swelling, fission gas release, burnup, clad corrosion, design and modeling. Spent fuel; characterization, performance, reprocessing, disposal.

**NERS 531. Nuclear Waste Management**

*Prerequisite: senior standing. II (3 credits)*

Based on the nuclear fuel cycle, this course will review the origin, composition, form and volumes of waste generated by commercial reactors and defense programs. The scientific and engineering basis for near-field and far-field containment in a geologic repository will be reviewed in the context of performance assessment methodologies.

**NERS 543. Nuclear Reactor Theory II**

*Prerequisite: NERS 441 or equivalent. I (3 credits)*

A continuation of NERS 441 including neutron resonance absorption and thermalization, perturbation and variational methods, flux synthesis. Analytic and numerical solutions of the neutron transport equation including the $S_n$ and $B_n$ methods, collision probabilities and Monte Carlo methods.

**NERS 551. Nuclear Reactor Kinetics**

*Prerequisite: preceded or accompanied by NERS 441. II (2 credits) (7-week course)*

Derivation and solution of point reactor kinetic equations. Concept of reactivity, inhour equations and reactor transfer function. Linear stability analysis of reactors. Reactivity feedback and nonlinear kinetics. Space-dependent reactor kinetics and xenon oscillations. Introduction to reactor noise analysis.

**NERS 554. Radiation Shielding**

*Prerequisite: NERS 441 or NERS 484. II (4 credits)*

The design of radiation shields, including neutrons, photons and charged particles. Dosimetric quantities, detector response functions, materials selection, and energy deposition in shields. Techniques for dose estimation including buildup factors, neutron removal cross-sections and Monte Carlo.

**NERS 561. Nuclear Core Design and Analysis I**

*Prerequisite: NERS 441. II (3 credits)*

Analytical investigation of areas of special importance to the design of nuclear reactors. Includes development, evaluation, and application of models for the neutronic, thermal-hydraulic, and economic behavior of both thermal and fast reactors. Typical problems arising in both design and operation of nuclear reactors are considered. This course includes extensive use of digital computers.

**NERS 562. Nuclear Core Design and Analysis II**

*Prerequisite: NERS 561. IIIa (3 credits)*

Continuation of subject matter covered under NERS 561 with emphasis on applications of analytical models to the solution of current problems in reactor technology.

**NERS 571. Intermediate Plasma Physics I**

*Prerequisite: NERS 471 or Physics 405. I (3 credits)*

Single particle motion, collision, and transport; plasma stability from orbital considerations; Vlasov and Liouville equations; Landau damping; kinetic modes and their reconstruction from fluid description; electrostatic and electromagnetic waves, cutoff and resonance.

**NERS 572. (Appl Phys 672) Intermediate Plasma Physics II**

*Prerequisite: NERS 571. II (3 credits)*

Waves in non-uniform plasmas, magnetic shear; absorption, reflection, and tunneling gradient-driven micro-instabilities; BGK mode and nonlinear Landau damping; macroscopic instabilities and their stabilization; non-ideal MHD effects.

**NERS 575 (EECS 519). Plasma Generation and Diagnostics Laboratory**

*Prerequisite: preceded or accompanied by a course covering electromagnetism. II (4 credits)*

Laboratory techniques for plasma ionization and diagnosis relevant to plasma processing, propulsion, vacuum electronics, and fusion. Plasma generation techniques includes: high voltage-DC, radio frequency, and e-beam discharges. Diagnostics include: Langmuir probes, microwave cavity perturbation, microwave interferometry, laser schlieren, and optical emission spectroscopy. Plasma parameters measured are: electron/ion density and electron temperature.

**NERS 576. Charged Particle Accelerators and Beams**

*Prerequisite: Physics 240 or EECS 331. I alternate years. (3 credits)*

Principles and technology of electrostatic and electrodynamic accelerators, magnetic and electrostatic focusing, transient analysis of pulsed accelerators. Generation of intense electron and ion beams. Dynamics, stability, and beam transport in vacuum, neutral and ionized gases. Intense beams as drivers for inertial confinement and for high power coherent radiation.

**NERS 577. Plasma Spectroscopy**

*Prerequisite: introductory courses in plasma and quantum mechanics. I alternate years (3 credits)*

Basic theory of atomic and molecular spectroscopy and its application to plasma diagnostics. Atomic structure and resulting spectra, electronic (including vibrational and rotational) structure of molecules and the resulting spectra, the absorption and emission of radiation and the shape and width of spectral lines. Use of atomic and molecular spectra as a means of diagnosing temperatures, densities and the chemistry of plasmas.

**NERS 578 (EECS 517). Physical Processes in Plasmas**

*Prerequisites: EECS 330. II even years (3 credits)*

Plasma physics applied to electrical gas discharges used for material processing. Gas kinetics; atomic collisions; transport coefficients; drift and diffusion; sheaths; Boltzmann distribution function calculation; plasma simulation; plasma diagnostics by particle probes, spectroscopy, and electromagnetic waves; analysis of commonly used plasma tools for materials processing.

**NERS 580 (BiomedE 580). Computation Projects in Radiation Imaging**

*Prerequisite: preceded or accompanied by NERS 481 II (1 credit)*

Computational projects illustrate principles of radiation imaging from NERS 481(BiomedE 481). Students will model the performance of radiation systems as a function of design variables. Results will be in the form of computer displayed images. Students will evaluate results using observer experiments. Series of weekly projects are integrated to describe the performance of imaging systems.

**NERS 582 (BiomedE 582). Medical Radiological Health Engineering**

*Prerequisite: NERS 484 (BiomedE 484) or permission of instructor. II (3 credits)*

This course covers the fundamental approaches to radiation protection in radiology, nuclear medicine, radiotherapy, and research environments at medical facilities. Topics presented include health effects, radiation dosimetry and dose estimation, quality control of imaging equipment, regulations, licensing, and health physics program design.

**NERS 583. Applied Radiation Dose Assessment**

*Prerequisite: EIH 670 or equivalent. II (4 credit)*

Principles and methods of protection against radiation hazards, with emphasis on occupational and other environmental aspects. Dosimetry, personnel protection, instruments and special health physics techniques and problems. Lectures and laboratory.

**NERS 585 (EHS 672). Radiological Assessment and Risk Evaluation**

*Prerequisite: Graduate status, EIH 583 and EIH 670 or permission of instructor. I (3 credits)*

Evaluation of the significance of uses of nuclear energy in relation to environmental processes and radiation exposure consequences. Consideration of biological accumulation, movement of radionuclides in the environment, pathway analysis, environmental dosimetry, and risk evaluation. Examination of cohorts exposed to high levels of ionizing radiation for the determination of carcinogenic and genetic risk. Introduction to risk estimation methods, dose-response models, projection models, life tables and hormesis.

**NERS 586 (EHS 686). Radiological Health Seminar**

*Prerequisite: Permission of academic and research advisors. I, II (1 credit)*

Special topics of importance in the control of radiation hazards. For students and workers in radiological health, nuclear science and nuclear engineering. May be elected more than once.

**NERS 587 (EHS 587). Internal Radiation Dose Assessment**

*Prerequisite: Grad status, EIH 670 or Ners 484 or permission of instructor. II (3 credits)*

Determination of radiation doses due to internal deposition of radioactive materials in the human body. Intake and deposition models of radioactive materials via inhalation or oral ingestion with particular emphasis on internationally accepted models for lungs, GI tract, and bone. Concepts of Annual Limit of Intake to meet risk based standards. Derive Air Concentrations, submersion exposure, retention models, and bioassay principles for determining intake and retention of radionuclides. Lectures and problem sessions.

**NERS 588. Radiological Health Engineering Practicum**

*Prerequisite: permission of instructor; mandatory satisfactory/unsatisfactory. I, II, III, IIIa, IIIb (1-2 credits)*

Individuals intern at a medical or industrial facility. Students concentrate on a specific radiological health engineering problem and participate in broader facility activities. Assignments are arranged by agreement among the student, staff member, and facility personnel. This course may be repeated for up to 12 credit hours.

**NERS 589. Radiological Health Engineering Project**

*Prerequisite: permission of instructor. I, II, III, IIIa, IIIb (1-2 credits)*

Group investigations on a topic involving Radiological Health Engineering. Specific topics will be selected upon mutual agreement between students and a staff member, and should be of practical significance to medical, nuclear, or radiation protection industry. This course may be repeated for up to 12 credit hours.

**NERS 590. Special Topics in Nuclear Engineering II**

*Prerequisite: permission of instructor. (to be arranged)*

Selected advanced topics such as neutron and reactor physics, reactor core design, and reactor engineering. The subject matter will change from term to term.

**NERS 599. Master's Project**

*Prerequisite: permission of instructor I, II, III, and IIIa or IIIb (1-3 credits)*

Individual or group investigations in a particular field or on a problem of special interest to the student. The course content will be arranged at the beginning of each term by mutual agreement between the student and a staff member. This course may be repeated for up to 6 credit hours.

**NERS 622 (Mfg 622) (MSE 622). Ion Beam Modification and Analysis of Materials**

*Prerequisite: NERS 421, NERS 521 or MSE 351 or permission of instructor. II alternate years (3 credits)*

Ion-solid interactions, ion beam mixing, compositional changes, phase changes, micro-structural changes; alteration of physical and mechanical properties such as corrosion, wear, fatigue, hardness; ion beam analysis techniques such as RBS, NRA, PIXE, ion channeling, ion microprobe; accelerator system design and operation as it relates to implantation and analysis.

**NERS 644. Transport Theory**

*Prerequisite: Math 555. I (3 credits)*

Mathematical study of linear transport equations with particular application to neutron transport, plasma physics, photon transport, electron conduction in solids, and rarefied gas dynamics; one-speed transport theory; Wiener-Hopf and singular eigen function methods; time-dependent transport processes; numerical methods including spherical harmonics, discrete ordinates, and Monte Carlo techniques; non-linear transport phenomena.

**NERS 671. Theory of Plasma Confinement in Fusion Systems I**

*Prerequisite: NERS 572. I alternate years (3 credits)*

Study of the equilibrium, stability, and transport of plasma in controlled fusion devices. Topics include MHD equilibrium for circular and non-circular cross section plasmas; magneto-hydrodynamic and micro-instabilities; classical and anomalous diffusion of particles and energy, and scaling laws.

**NERS 672. Theory of Plasma Confinement in Fusion Systems II**

*Prerequisite: NERS 671. II alternate years (3 credits)*

Study of the equilibrium, stability, and transport of plasma in controlled fusion devices. Topics include MHD equilibrium for circular and non-circular cross section plasmas; magneto-hydrodynamic and micro-instabilities; classical and anomalous diffusion of particles and energy, and scaling laws.

**NERS 673. Electrons and Coherent Radiation**

*Prerequisite: NERS 471 or Physics 405. II (3 credits)*

Collective interactions between electrons and surrounding structure studied. Emphasis given to generation of high power coherent microwave and millimeter waves. Devices include: cyclotron resonance maser, free electron laser, peniotron, orbitron, relativistic klystron, and crossed-field geometry. Interactions between electron beam and wakefields analyzed.

**NERS 674 (Appl Phys 674). High Intensity Laser-Plasma Interactions**

*Prerequisite: NERS 471, NERS 571 or permission of instructor. I (3 credits)*

Coupling of intense electromagnetic radiation to electrons and collective modes in time-dependent and equilibrium plasmas, ranging from underdense to solid-density. Theory, numerical models and experiments in laser fusion, x-ray lasers, novel electron accelerators and nonlinear optics.

**NERS 799. Special Projects**

*(1-6 credits)*

Individual or group investigations in a particular field or on a problem of special interest to the student. The project will be arranged at the beginning of the term by mutual agreement between the student and a staff member.

**NERS 990. Dissertation/Pre-Candidate**

*Prerequisite: I, II, III (2-8 credits); IIIa, IIIb (1-4 credits)*

Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**NERS 995. Dissertation/Candidate**

*Prerequisite: Graduate School authorization for admission as a doctoral candidate I, II, III (8 credits); IIIa, IIIb (4 credits)*

Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

## Nuclear and Radiological Sciences Engineering Faculty

John C. Lee, Ph.D., *Professor and Chair*

### Professor

Alex Bielajew, Ph.D.
James J. Duderstadt, Ph.D.; *also University Professor of Science and Engineering; also U-M President Emeritus*
Rodney C. Ewing, Ph.D.
Ronald F. Fleming, Ph.D.
Ronald M. Gilgenbach, Ph.D.
Kimberlee J. Kearfott, Sc.D.
Edward W. Larsen, Ph.D.
Y. Y. Lau, Ph.D.
William R. Martin, Ph.D.
Gary S. Was, Sc.D.

### Professor Emeritus

A. Ziya Akcasu, Ph.D.; *also Macromolecular Science and Engineering*
Terry Kammash, Ph.D.
William Kerr, Ph.D.
John S. King, Ph.D.
Glenn F. Knoll, Ph.D.
Dietrich H. Vincent, Dr. Rer. Nat.

### Associate Professor

Michael Atzmon, Ph.D.
Mary L. Brake, Ph.D.
James P. Holloway, Ph.D.
Donald P. Umstadter, Ph.D., *also Electrical Engineering and Computer Science*
David K. Wehe, Ph.D.

### Adjunct Associate Professor

Michael J. Flynn, Ph.D.
Roger E. Stoller, Ph.D.

### Assistant Professor

Zhong He, Ph.D.

### Associate Research Scientist

Lumin Wang, Ph.D.

### Assistant Research Scientist

Douglas S. McGregor, Ph.D.

## Nuclear Engineering and Radiological Sciences Contact Information

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*Engineering Division*
*Professor Gary D. Herrin*
*Assistant Dean for Students*
*1011 Lurie Engineering Center*
*(734) 647-7106*

*Program Assistant*
*Wanda Dobberstein*
*1422 Lurie Engineering Center*
*(734) 647-7114*

## Engineering Division Courses

**Important Note:** Eng 211, 212, 214, 241, 242, 266, 267, 431, 432, 433, and 434 are not open to College of Engineering students. These courses are open to Focus Hope students who are pursuing a Bachelor of Engineering Technology degree. The effort is part of the Greenfield Coalition for New Manufacturing Education.

**ENG 100. Introduction to Engineering**
*Prerequisite: Students must have passed English Composition Board assessment or equivalent. I, II (4 credits)*
Focused team projects dealing with technical, economic, safety, environmental, and social aspects of a real-world engineering problem. Written, oral, and visual communication required within the engineering profession; reporting on the team engineering projects. The role of the engineer in society; engineering ethics. Organization and skills for effective teams.

**ENG 101. Introduction to Computers and Programming**
*Prerequisite: Prior or concurrent enrollment in Math 115 or equivalent. I, II (4 credits)*
Algorithms and programming in C++ and Matlab, computing as a tool in engineering, introduction to the organization of digital computers.

**ENG 195. Selected Topics in Engineering**
*(to be arranged)*

**ENG 280. Undergraduate Research**
*Prerequisite: Permission of Instructor. I, II, IIIa, IIIb (1-4 credits)*
This course offers research experience to first- and second-year Engineering students in an area of mutual interest to the student and to a faculty member within the College of Engineering. For each hour of credit, it is expected that the student will work three hours per week. The grade for the course will be based on a final project/report evaluated by the faculty sponsor and participation in other required UROP activities, including bimonthly research group meetings and submission of a journal chronicling the research experience.

**ENG 303 (CEE 303). Computational Methods for Engineers and Scientists**
*Prerequisite: Eng 101, Math 216. ( Required for some programs; see you advisor) I, II (4 credits)*
Applications of numerical methods to infrastructure and environmental problems. Development of mathematical models and computer programs using a compiled language (FORTRAN). Formulation and solution of initial and boundary-value problems with emphasis on structural analysis, fluid flow, and transport of contaminants. Lecture, recitation and computation.

**ENG 371 (Math 371). Numerical Methods for Engineers and Scientists**
*Prerequisite: Eng 101 and Math 216, 256, 286 or 316. I, II (3 credits)*
This is a survey course of the basic numerical methods which are used to solve scientific problems. In addition, concepts such as accuracy, stability and efficiency are discussed. The course provides an introduction to MATLAB, an interactive program for numerical linear algebra as well as practice in computer programming.

**ENG 390. Special Topics in Engineering**
*Prerequisite: permission of instructor. (to be arranged)*
Individual or group study of 300-level, undergraduate topics of current interest.

**ENG 400. Engineering Cooperative Education**
*Prerequisite: permission of program director. I, II, III (no credit)*
Off-campus work under the auspice of the cooperative education program. Engineering work experience in government or industry.

**ENG 401 (Mfg 401). Total Quality Management**
*Prerequisite: none. I, II (3 credits)*
The technical and management aspects of total quality management. Topics include voice of the customer, metrics, cross-functional teams, and the systems aspects. Examples from engineering and business operations such as dimensional tolerancing, quality function deployment, process control, simultaneous engineering, lean production, purchasing, inventory control, and scheduling systems.

**ENG 403. Scientific Visualization**
*Prerequisite: upper division or graduate standing. I (3 credits)*
Introduces engineering and science students to scientific visualization principles of data display. Use of color to encode quantitative information. Display of 2- and 3-D scalar and vector data. Interactive computer techniques emphasized. Extensive hands-on practice. Project or research paper required.

**ENG 477 (NA 477). Principles of Virtual Reality**
*Prerequisite: senior standing or permission of instructor. I (4 credits)*
Enabling technologies (display systems, motion trackers, interactive devices, others), applications, human factors and perception, computer graphics and geometric modeling principles, creation of virtual environments, existing tools, special topics. Interdisciplinary group projects will develop VR applications using the facilities in the Media Union.

**ENG 490 (Mfg 490). Special Topics in Engineering**
*Prerequisite: none. (to be arranged)*
Individual or group study of topics of current interest selected by the faculty.

**ENG 580 (ChE 580). Teaching Engineering**
*Prerequisite: graduate standing. II alternate years (3 credits)*
Aimed at doctoral students from all engineering disciplines interested in teaching. Topics include educational philosophies, educational objectives, learning styles, collaborative and active learning, creativity, testing and grading, ABET requirements, gender and racial issues. Participants prepare materials for a course of their choice, including course objectives, syllabus, homework, exams, mini-lecture.

**ENG 590. International Experience in Engineering**
*Prerequisite: seniors and grad students of engineering only. I, II, III, IIIa, IIIb (2-8 credits)*
This independent study course covers selected research areas in engineering. The topic and research plan must be approved by the instructor. A student is expected to participate in the planning of the course, visit a foreign research institution, participate in a research project (analytical and/or experimental), and write a report. The course may continue for more than one semester.

**ENG 996. Responsible Research Practices**
*II (1-2 credits)*
The Research Responsibility Program introduces concepts and policies relat-

ing the responsible practice of research. It does not provide opportunities for students to put what they are learning into practice in a scholarly context. The course is designed to provide the opportunity to apply what students are learning to the scholarly analysis of an issue that raises questions about responsible research practices. Attendance required.

## Focus Hope Courses

**ENG 211. Manufacturing Processes I**
*I, II (1 credit)*
An introduction into the issues of product quality and tolerances. Manufacturing processes for casting and how the various methods influence secondary operations such as machining and metal framing processes.

**ENG 212. Manufacturing Processes II**
*I, II (1 credit)*
An introduction into manufacturing joining processes which include various types of welding, brazing and soldering. A study of the heat flow in the work piece, weld microstructure and weld discontinuities.

**ENG 214. Introduction to Engineering Mechanics**
*I, II (1 credit)*
This course introduces the student to vibrations of mechanical systems and to the basic concepts of engineering structural analysis.

**Engineering 241. Manufacturing Planning I**
*I, II (1 credit)*
An introduction into manufacturing economics, basic concepts of direct and indirect costs, and time value of money. A study of basic optimization tools, such as linear programming used to model manufacturing optimization problems. Candidates will learn about inventory control, the tradeoffs involved in holding inventory, the different types of inventory in manufacturing processes, and basic models in inventory control to determine the optimal amount of inventory in the system.

**ENG 242. Manufacturing Planning II**
*I, II (1 credit)*
A study of material requirements planning, basic dynamics of material requirements planning, the basic lot sizing techniques used in MRP, and the difference between MRP and other release control techniques such as kanban.

**ENG 266. Manufacturing Statistical Methods I**
*Prerequisite: college algebra. I, II (2 credits)*
Multimedia instruction in the use of statistical methods in manufacturing. Topics are problem-solving tools, descriptive statistics, data collection, control charts, process capability and tolerancing systems. Statistical computer packages will be used and field studies will be required.

**ENG 267. Manufacturing Statistical Methods II**
*Prerequisite: Eng 266. I, II (1 credit)*
Multimedia instruction in the use of statistical methods in manufacturing. Topics are hypothesis testing and regression analysis. Statistical computer packages will be used and field studies will be required.

**ENG 431. Basic Principles and Creative Design**
*I, II, III (Greenfield Coalition Credit only)*
Basic principles of Mechanisms design. Degrees of freedom, instant centers and mechanical advantage; compliant mechanisms. Type synthesis and creative design.

**ENG 432. Synthesis of Linkages**
*I, II, III (Greenfield Coalition Credit only)*
Dimensional synthesis. Linkages motion, path and function generation; 2, 3, and 4 precision points. Computer aided synthesis of mechanisms using LINCAGES.

**ENG 433. Transmission System Components**
*I, II, III (Greenfield Coalition Credit only)*
Machine forces torques and power. Share with module 5 GCF 322. Fluid power actuators and components. Clutch, coupling, torque limiting, gears and braking devices. Cam design (Module 3; GCF 322)

**ENG 434. Production Machinery**
*I, II, III (Greenfield Coalition Credit only)*
Work transfer subsystem design. Transfer machinery, part feeders, orientors, etc. Design of machining centers. Design of stamping presses..

## Engineering Division Contact Information

Engineering Division
(Division 258: Subject = ENGR)
1422 Lurie Engineering Center
(734) 647-7114

# Study Abroad Course listings

**Study Abroad 200. Non-UM**
Students who choose to enroll in a non-UM sponsored study abroad program will register for the study abroad semester using this course number.

**Study Abroad 301. Study Abroad at Imperial College, England**
Direct enrollment for one semester or an entire academic year at this elite engineering institution located in London. Requirements for admission: 3.6 GPA. Fall (September-December), Winter (January-March), Summer (April–June)

**Study Abroad 303. Study Abroad at University of New South Wales, Australia**
Up to 8 students per semester from the College may directly enroll in this relatively new but very popular study abroad destination institution of 25,000 students. Students may attend either the Fall (July-December) or Winter (February-June) semesters.

**Study Abroad 305. Study Abroad at Adelaide University, Australia**
The 4th best university in Australia is located in the capital of South Australia, a city of 1 million. 14,000 students attend Adelaide University. UM students directly enroll for Winter semester (February-June) or Fall semester (July-November).

**Study Abroad 306. Study Abroad at University of Melbourne, Australia**
Students can directly enroll at this institution of 30,000 students for a semester or academic year. Melbourne is Australia's second oldest and leading research university. Winter semester (March-June) or Fall semester (July-November).

**Study Abroad 307. Study Abroad at Monash University, Australia**
Engineering courses are on Caulfield campus (student population: 9,000), located in Melbourne. Monash emphasizes global education and has campuses in Malaysia and South Africa. Students directly enroll for either one semester or an academic year at Monash. Winter semester (February-June) or Fall semester (July-October).

**Study Abroad 308. Study Abroad at University of Queensland, Australia**
The University of Queensland is one of only three Australian members of the elite Universitas 21 — a global alliance of 20 universities committed to quality enhancement through international benchmarking. The engineering campus is located in St. Lucia Queensland, on the Brisbane river. Students can directly enroll for a semester or an academic year. Fall semester (July-November), Winter semester (March-June)

**Study Abroad 309. Study Abroad at University of Bristol, England**
Direct enrollment for a semester, an academic year, or spring is possible at

this institution in the largest city in southwest England, near the Welsh border. Bristol is a large financial center, where the University is an integral part of the city. Student population at Bristol is 12000. Fall semester (October-December), Winter semester (January-June).

**Study Abroad 310. Study Abroad at University of Manchester, England**
Direct enrollment for a semester or an academic year is possible. The University is home to 18000 students and located midway between the English Channel and Scotland. Manchester has a strong engineering program, but also provides flexibility in course offerings for students interested in arts and humanities. Fall semester (September-January), Winter semester (February-June)

**Study Abroad 311. Study Abroad at Middlesex University, England**
Students can directly enroll at this multi-campus university of 20,000 students in north London that emphasizes hands-on experience and contact with industry. Enrollment for a semester, academic year or a summer is possible. Academically supervised internships are also possible during the summer term. Fall semester (September-January), Winter semester (February-June), Summer semester (July-August).

**Study Abroad 312. Study Abroad at Technical University of Denmark (DTU), Denmark**
Semester, academic year, and summer programs are possible at DTU, one of northern Europe's largest education and research institutions of technology and engineering. DTU has 9,500 students, researchers, faculty and staff and is located just north of Copenhagen. One third of DTU courses (including over 350 upper level courses) are taught in English. Fall semester (September-January), Winter semester (February-July).

**Study Abroad 313. Study Abroad at Rheinisch Westfaelische Technische Hochschule Aachen, Germany**
This exchange program for either a semester or academic year allows students with at least two years of college-level German to directly enroll in classes at Aachen, a university of 33,000 students located central to all of western Europe. Students interested in laser technology can take part in an internship doing research at Aachen's Fraunhofer Resource Center and RWTH's Institute for Laser technology. Fall semester (October-February), Winter semester (April-July)

**Study Abroad 314. Study Abroad at Nagoya University, Japan**
Students pay UM tuition and attend the Nagoya University Program for Academic Excellence (NUPACE) as an exchange student. NUPACE combines Japanese-language curriculum and cultural studies with courses in your major with the possibility of independent research. All classes except language classes are in English. Fall semester ( October-March), Spring Semester (April-September).

**Study Abroad 315. Study Abroad at École Nationale Supérieure de Techniques Avancées (ENSTA), France**
Students with at least two years of college-level French can directly enroll in classes at this engineering institution of 500 students located in Paris. ENSTA is one of the leading French 'Grandes Écoles' which trains highly qualified engineers with a global knowledge and emphasizes practical training through internships with industry. Students may study for one semester or an entire year.

**Study Abroad 317. Study at Delft University of Technology, Netherlands**
Two exchange students with a command of the Dutch language (at least 2 years of college-level Dutch) can participate in this exchange program for a semester or a year. Delft University of Technology is the oldest, largest, and most comprehensive technical university in the Netherlands, with over 13,000 students. Fall semester (September-December), Winter semester (April-July)

**Study Abroad 318. Study at Hong Kong University of Science and Technology, Hong Kong**
Two exchange students per semester may directly enroll in one of the region's premier technological institutions with state-of-the-art laboratories, innovative teaching methods, a high-speed fiber-optic campus network, and an information-age library. Many courses are taught in English. Fall semester (September-December), winter semester (February-May)

**Study Abroad 319. Study at Eindhoven Institute of Technology, Netherlands**
Students with a strong command of Dutch may enroll directly at this exchange partner institution of 6,000 students for either a semester or a year. For students interested in industrial operations engineering and manufacturing, the fall semester offers English-language courses focusing on manufacturing, production, and business, in addition to Dutch language courses. Fall semester (September-December), Winter semester (January-April)

**Study Abroad 320. Study at Technical University of Berlin, Germany**
Students pay UM tuition to become an exchange student for a semester or year at this revered institution which enjoys the oldest partnership with the College. Located in the capitol of Germany, Berlin is rich with political and historical beauty in addition to its cultural diversity. Competence in German is essential; at least two years of College-level German are required in order to directly enroll at the University, which is home to 29,000 students. Fall semester (October-February), Winter semester (April-July).

**Study Abroad 321. Study through Global Engineering Education Exchange Consortium**
As an exchange participant in the GE3 consortium for either a semester or a year, students can either seek English-speaking programs or native language programs in a host of institutions in Germany, Austria, France, Spain, Mexico, and other countries. Students apply for the individual programs directly through the GE3 consortium and are matched up with at least one of the host institutions listed on their application. Scholarships for GE3 participants are available to help subsidize the cost of the program.

## Study Abroad

### Study Abroad Contact Information

Study Abroad
(Division 290: Subject = ENGINSA)
International Programs in Engineering
245 Chrysler Center
(734) 647-7026
http://www.engin.umich.edu/services/oip/

## Technical Communication Course Listings

The following courses provide senior-year and graduate students with intensive training in communication.

**TechComm 215. Technical Communication for Electrical and Computer Engineering**
*Prerequisite: Engineering 100, Corequisite: EECS 215. I, II (1 credit)*
Professional communication to the general public, managers, and other professionals about electrical and computer engineering ideas. Functional, physical and visual/diagrammatic description. Report writing about circuits, signals, and systems, including description and analysis. Job letters and resumes.

**TechComm 281. Technical Communication for Computer Science and Engineering**
*Prerequisite: Engineering 100, Corequisite: EECS 281. I, II (1 credit)*
Introduction to professional communication for computer scientists and engineers. Communication to managers and programmers about data structures, algorithms, and programs. Coding conventions and documentation. Functional and visual/diagrammatic descriptions. Letters of transmittal and reports on software systems. Job letters and resumes.

**TechComm 311. Report Preparation for Electronic Circuits Laboratory**
*Corequisite: EECS 311. I, II (1 credit)*
Introduction to audiences in organizations and to professional writing situations in electrical engineering. Report writing for electronic circuits laboratory work, including experiments, analysis, and design. Report structure and formatting. Design of the heading, foreward, summary, procedure, results, discussion, and appendices. Design of visuals. Editing for readability and emphasis.

**TechComm 373. Report Preparation for Microprocessor Systems Laboratory**
*Corequisite: EECS 373. I, II (1 credit)*
Introduction to audiences in organizations and to professional writing situations in computer engineering. Report writing for microprocessor systems laboratory work, including experiments, analysis, and design. Report structure and formatting. Design of the heading, foreward, summary, procedure, results, discussion, and appendices. Design of visuals. Editing for readability and emphasis.

**TechComm 400. Information and Communication Resources**
*I, II (1 credit)*
Overview of information resources in printed, electronic, and verbal form; use of the information research process to explore communication among scientists and engineers.

**TechComm 450. Web Page and Site Design**
*Prerequisite: junior or senior standing. I, II (4 credits)*
Students will learn both practical skills and theoretical principles necessary to design effective WWW pages and sites. Practical skills include HTML, tools for creating Web pages, graphics, scripting, animation, and multimedia. Theory includes information design, visual design, and theoretical principles. Students will both design and analyze Web sites.

**TechComm 475. Directed Study**
*Prerequisite: permission of instructor. I, II, IIIa, IIIb (to be arranged)*
Conferences and tutorial sessions for students with special interests. May be taken for 1-4 credit hours as arranged by the instructor.

**TechComm 486. Design of Computer Documentation**
*Prerequisite: senior or graduate standing. I, II (3 credits)*
Principles, methods, and skill development for effective computer documentation and related professional communication. Documentation coverage includes current techniques of audience, task, and content analysis; principles of effective document organization; and training in clear technical writing. Professional communication coverage includes preparation of effective memos, reports, and oral presentations.

**TechComm 490. Technical Information Resources and Research**
*I (3 credits)*
Description and demonstration of all forms of technical information resources now available to engineers. Access to a wide variety of sources and systems, with primary emphasis on on-line networks, and use of conferencing and database systems.

**TechComm 494. Professional Communication for Electrical & Computer Engineers**
*Corequisite: EECS Senior Design Course. I, II (2 credits)*
Development of the communication skills required of electrical and computer engineers and managers. Focus on (1) the design and writing of proposals reports and documentation that address the needs of diverse organizational audiences adn (2) the preparation and delivery of organizational oral presentations and briefings. Writing and speaking about design projects in terms that will satisfy both specialists and non-specialists.

**TechComm 496. Advanced Technical Communication for Electrical Engineering, Computer Science, and Computer Engineering**
*Corequisite: Senior Design Course. I, II (2 credits)*
Advanced technical communication for EECS. Design and writing of user and task analyses, requirements documents, proposals, reports, documentation, and web design for design projects, all aimed at diverse organizational audiences. Usability and performance test design and testing. Preparation and delivery of final oral presentation and written report on design.

**TechComm 497. Argument and Persuasion**
*Prerequisite: senior standing. (3 credits)*
Logical argument and its role in persuasive discourse, especially writing. The nature of a reasoned argument; the formulation and analysis of problems; and methods of selecting, arranging, writing, and editing information on the basis of the intended effect on a particular audience.

**TechComm 498. Technical and Professional Writing for Industry, Government, and Business**
*Prerequisite: senior or graduate standing. I, II, IIIa, IIIb (3 credits)*
Development of the communication skills required of engineers and managers in industry, government, and business. Focus on (1) the design and writing of reports and memoranda that address the needs of diverse organizational audiences and (2) the preparation and delivery of organizational oral presentations and briefings. Writing and speaking about design and research problems in terms that will satisfy both specialists and non-specialists. A series of short explanatory papers and speeches leading up to a final formal report and public lecture.

**TechComm 499. Scientific and Technical Communication**
*Prerequisite: permission of Technical Communication faculty. (elective credit only)*
Conferences and tutorial sessions that provide opportunities for students with special interests to work on a tutorial basis with a member of the Technical Communication faculty. These courses are not intended as substitutes for regularly scheduled courses. Students who wish to elect Directed Study must confer with an instructor about the pro-posed study. If the instructor agrees to accept the student for this study, the two prepare a contract and submit it for approval. Directed study contracts must be approved before the student may enroll. (Directed Study contract forms and additional information are available from the Technical Communication office.)

**TechComm 575. Directed Study**
*Prerequisite: permission of instructor. I, II, IIIa, IIIb (to be arranged)*
Conferences and tutorial sessions for students with special interests. May be taken for 1-4 credit hours as arranged by the instructor.

**TechComm 675. Directed Study**
*Prerequisite: graduate standing, permission of instructor. I, II, IIIa, IIIb (to be arranged)*
Conferences and tutorial sessions for students with special interests. May be taken for 1-4 credit hours as arranged by the instructor.

## Technical Communication Faculty

Leslie A. Olsen, Ph.D., *Professor*

### Professors Emeritus

J.C. Mathes, Ph.D.
Thomas M. Sawyer, Ph.D.
Dwight W. Stevenson, Ph.D.

### Associate Professors Emeritus

Peter R. Klaver, Ph.D.
Rudolf B. Schmerl, Ph.D.

### Adjunct Assistant Professors

Robert DiGiovanni, Ph.D.
Rodney Johnson, Ph.D.

### Lecturers

Marthalee S. Barton, Ph.D.
Jack Fishstrom, M.A.
Fred C. Ward, Jr., M.S.

### Additional Lecturers

Pauline Khan
Gilbert Oswald
Robert Sulewski
Deborah Van Hoewyk

### Technical Communication Contact Information

Technical Communication
(Division 291; Subject = TCHNCLCM)
301 Engineering Programs
(734) 764-1427
http://www.engin.umich.edu/dept/techcomm/

## Business Administration

Engineering undergraduate students interested in complementing their course work with business electives can consult with counselors in the Office of Admissions and Career Development, Room 2260, Business Administration. Business electives give students a deeper understanding of corporate and manufacturing issues. Engineering students interested in consulting, information systems development, and industrial and operations management are especially encouraged to consider electives in business.

The business courses below are of special interest to students enrolled in the undergraduate engineering curriculum. In the election of such courses, attention is called to the administrative rules of the University of Michigan Business School, which affect elections as follows:

No student shall elect courses in the School of Business Administration who does not have at least third-year standing (55 credit hours). This does not apply to Accounting 271 and 272, which are listed as sophomore-level courses in the accounting area of the Business School.

Juniors may elect courses numbered 300 to 399 inclusive, and seniors may elect courses numbered 300 to 499 inclusive, provided they have satisfied particular courses' prerequisites. Please note that some courses are restricted to BBA students, and some courses are restricted to BBA students only in specific terms. The course listing below gives the term(s) in which non-business students can elect a particular course.

Courses numbered 500 or above may be elected only by properly qualified graduate students and are closed to undergraduate students.

For descriptions of the following and other courses in the Business School, see the University of Michigan Business School's website at: https://mtrack.bus.umich.edu/coursemanagement/coursedescriptions.asp

### Accounting and Information Analysis

**A 271. Principles of Accounting**
*(Must have sophomore standing) I, II, IIIa (3 credits)*

**A 272. Principles of Accounting**
*(Must have sophomore standing) I, II, IIIa (3 credits)*

**A 471. Accounting Principles**
*I, II (3 credits)*

### Computer and Information Systems

**CIS 315. Expert Systems**
*I, II (3 credits)*

**CIS 345. Analysis of Business Systems**
*I (3 credits)*

### Finance

**F 300. Financial Management**
*II (3 credits)*

### Law, History, and Communication

**LHC 305. Legal Environment of Business**
*I, IIIa (3 credits)*

**LHC 306. Law of Enterprise Organization**
*II (3 credits)*

### Marketing

**M 300. Marketing Management**
*I, II, IIIa (3 credits)*

### Organizational Behavior and Human Resources Management

**OB 300. Behavioral Theory in Management**
*II (3 credits)*

**OB 315. Management of Personnel**
*I, II (3 credits)*

**OB 322. Management-Union Relations**
*II (3 credits)*

## College of Literature, Science, and the Arts

LS&A course descriptions may be found at the LS&A Web site: http://www.lsa.umich.edu/saa/publications/courseguide

### Biology

**(Subject = BIOLOGY)**

**100. Biology for Nonscientists.**
*Not open to those with Advanced Placement or "Departmental" credit in biology, nor to those concentrating in the biological sciences. I, II (4 credits)*

**101. Biology and Human Affairs.**
*I (4 credits)*

**102. Practical Botany.**
*II (4 credits)*

**103. Ecology: Principles and Applications.**
*I (4 credits)*

**105. Food.**
*I (3 credits)*

**107. Evolution of Life.**
*(4 credits)*

**108. Introduction to Animal Diversity.**
*II (4 credits)*

**109. Ecological Knowledge and Environmental Problem Solving.**
*II (3 credits)*

**110 (AOSS 171) (UC 110) (Geol. 171) (NR&E 110). Introduction to Global Change I.**
*I (4 credits)*

**118. AIDS and Other Health Crises.**
*(4 credits)*

**120. First-Year Seminar in Biology.**
*Only first-year students, including those with sophomore standing, may pre-register for First-Year Seminars. All others need permission of instructor. (3 credits)*

**124. Cells, Cancer, and Society.**
*II (3 credits)*

**130. Animal Behavior.**
*II (3 credits)*

**140. Genetics and Society.**
*I (4 credits)*

**162. Introductory Biology.**
*Prerequisite: Prior or concurrent enrollment in Chemistry 130. Biology 162 is not open to students who have completed Biol. 152, 154 or 195. I, II, IIIa. (5 credits)*

**200. Undergraduate Tutorial.**
*Prerequisite: Permission of faculty member in biology. (2 credits)*

**201. Introduction to Research in the Life Sciences.**
*Prerequisite: Grade of B+ or better in Biology 162 (or 152 or 154). I, II (1)*

**202. Topics in Biology.**
*Prerequisite: Biology 162 (or 152 and 154, or 195). (3 credits)*

**207. Introductory Microbiology.**
*Prerequisite: Biol. 162 (or 152). I (4 credits)*

**208. Embryology.**
*Prerequisite: Biology 162. I (3 credits)*

**215. Spring Flora of Michigan.**
*Prerequisite: Biol. 162 (or 152, 195), or 102. IIIa. (3 credits in the half-term)*

**222. From Message to Mind: An Introduction to Neurobiology.**
*Prerequisite: Biol. 162 (or 152-154 or 195). I, II (3 credits)*

**225 (325). Principles of Animal Physiology: Lecture.**
*Prerequisite: Biol. 162 and a year of chemistry. II (3 credits)*

**226 (326). Animal Physiology Laboratory.**
*Prerequisite: Concurrent enrollment in Biol. 225 (or prior enrollment in 325, with permission). Students who intend at a later date to take Biol. 225 will not be admitted to Biol. 226 without special permission. I, II (2 credits)*

**230. Introduction to Plant Biology.**
*Prerequisite: Biol. 162 (or 152 or 195). I (4 credits)*

**252. Chordate Anatomy and Phylogeny.**
*Prerequisite: Biol. 162 (or 152-154 or 195). I (4 credits)*

**255. Plant Diversity.**
*II (5 credits)*

**281. General Ecology.**
*Prerequisite: Biol. 162 (or 152 and 154) and a laboratory course in chemistry. (3 credits)*

**282. General Ecology Laboratory.**
*Prerequisite: Biol. 162 (or 152 and 154), a laboratory course in chemistry, and concurrent or prior enrollment in Biol. 281. (3 credits)*

**288. Animal Diversity.**
*Prerequisite: Biol. 162. (4 credits)*

**300. Undergraduate Research.**
*Prerequisite: Eight credits of biology and 3.0 grade point average in science; permission of faculty member in biology. I, II, III, IIIa, IIIb in Ann Arbor; IIIb at Biological Station. (1-3 credits)*

**301. Writing for Biologists.**
*Prerequisite: Biol. 162 (or 152-154 or 195), and completion of the introductory composition requirement. II (3 credits)*

**302. Teaching Experience for Undergraduates.**
*Prerequisite: Permission of instructor. I, II, IIIa, IIIb. (1-3 credits).*

**305. Genetics.**
*Prerequisite: Biol. 162 (or 152 or 195), and prior or concurrent enrollment in Chem. 210. I, II, IIIa. (4 credits)*

**306. Introductory Genetics Laboratory.**
*Prerequisite: Prior or concurrent enrollment in Biol. 305. I, II (3 credits)*

**307. Developmental Biology.**
*Prerequisite: Biol. 305. II (3 credits)*

**308. Developmental Biology Laboratory.**
*Prerequisite: Prior or concurrent enrollment in Biol. 307. II (3 credits)*

**310. Introductory Biochemistry.**
*Prerequisite: Biol. 162 (or 152 or 195); and organic chemistry. (4 credits)*

**311. Introductory Biochemistry.**
*Prerequisite: Biol. 162 (or 152 or 195); and organic chemistry. I, II, IIIa. (4 credits)*

**321 (209). Introductory Plant Physiology Lectures.**
*Prerequisite: Biol. 162 (or 152-154 or 195); college physics recommended. II (3 credits)*

**322 (210). Plant Physiology Laboratory.**
*Prerequisite: Prior or concurrent enrollment in Biol. 321. (3 credits)*

**324 (224). Biology of Cancer.**
*Prerequisite: Biol. 162. I (3 credits)*

**330. Biology of Birds.**
*Prerequisite: Two collegiate courses in biology. IIIb at the Biological Station (5 credits in the half-term)*

**341. Parasitology.**
*Prerequisite: Biol. 162 (or 152-154 or 195). I (4 credits)*

**355 (NR&E 337). Woody Plants I: Biology and Identification.**
*Prerequisite: Biol. 162 (or 152 or 195). I (4 credits)*

**375 (275). Introduction to Plant Development.**
*Prerequisite: Biol. 162. II (4 credits)*

**380. Oceanography: Marine Ecology.**
*Prerequisite: Biol. 162 (or 152-154 or 195), and at least one term of college chemistry or physics. I (3 credits)*

**381. General Ecology.**
*Prerequisite: Biol. 162 (or 152-154 or 195); and a laboratory course in chemistry. IIIa, IIIb at Biol. Station (6 in Ann Arbor; 5 at Biol. Station)*

**390. Evolution.**
*Prerequisite: Biol. 162 (or 152-154). I in Ann Arbor; IIIa at Biol. Station. (4; 5 in the half-term in Ann Arbor; 5 at Biol. Station)*

**400. Advanced Research.**
*Prerequisite: 12 credits of biology, 3.0 average in science, and permission of faculty member in biology. Also offered at the Biological Station during IIIb. (1-3 credits)*

**401. Advanced Topics in Biology.**
*Intended for senior concentrators. (3 credits)*

**405. Molecular Basis of Development.**
*Prerequisite: Biol. 162 (or 152-154) and 305. A course in molecular and developmental biology is helpful but not required. II (3 credits)*

**406. Molecular Genetics of Plant Development.**
*Prerequisite: Biochemistry (Biol. 310, 311, or Biol. Chem. 415), and Genetics (Biol. 305). I (3 credits)*

**407. Advanced Genetic Principles.**
*Prerequisite: Biol. 305 and Biol. 310, 311, or Biol. Chem. 415. I (3 credits)*

**411. Protein Structure and Function.**
*Prerequisite: Biol. 310, 311, or Biol. Chem. 415. I (3 credits)*

**412. Teaching Biochemistry by the Keller Plan.**
*Prerequisite: Biol. 311 and permission of instructor. I, II, IIIa. (3 credits)*

**413. Plant Molecular Biology Laboratory.**
*Prerequisite: Biol. 310 or 311, or Biol. Chem. 415; and Biol. 305. II (3 credits)*

**415. Plant Constituents and Their Functions.**
*Prerequisite: Biol. 162 (or 154) or 195 and one term of organic chemistry. I (alternate years). (3 credits)*

**418. Endocrinology.**
*Prerequisite: Biol. 162 , 225, and organic chemistry. I (3 credits)*

**419. Endocrinology Laboratory.**
*Prerequisite: Prior or concurrent enrollment in Biol. 418. II (3 credits)*

**422. Cellular and Molecular Neurobiology.**
*Prerequisite: Biol. 162 (or 152-154, or 195), one year of physics, prior or concurrent enrollment in biochemistry. I (3 credits)*

**423. Introduction to Research in Cellular and Molecular Neurobiology.**
*Prerequisite: Concurrent enrollment in Biol. 422; or completion of Biol. 222 or 422, and permission of instructor. I (3 credits)*

**425. Systems Neurobiology.**
*Prerequisite: Biol. 222, 225, or 422. II (3 credits)*

**426. Molecular Endocrinology.**
*Prerequisite: Biol. 310, 311, or Biol. Chem. 415; and Biol. 225 or 418. II (3 credits)*

**427. Molecular Biology.**
*Prerequisite: Biol. 305; and Biol. 310 or 311, or Biol. Chem. 415. I, II (4 credits)*

**428. Cell Biology.**
*Prerequisite: Biol. 305; and Biol. 310 or 311, or Biol. Chem. 415. I, II (4 credits)*

**429. Laboratory in Cell and Molecular Biology.**
*Prerequisite: Biol. 427 or 428, or concurrent enrollment in Biol. 428. II (3 credits)*

**430. Molecular Biology of Plants.**
*Prerequisite: Biol. 305; and 310 or 311, or Biol. Chem. 415. II (3 credits)*

**431. Ecology of Animal Parasites.**
*Prerequisite: Two laboratory courses in biology. IIIb at the Biological Station (5 credits)*

**433 (NR&E 433). Ornithology.**
*Prerequisite: Biol. 162. I (4 credits)*

**435. Intracellular Trafficking.**
*Prerequisite: Biol. 305, Biol. 310, 311, or Biol. Chem. 415, and Biol. 428. I (3 credits)*

**436 (336). Introductory Immunology.**
*Prerequisite: Biol. 305 and biochemistry (Biol. 310, 311, or Biol. Chem. 415). I (3 credits)*

**437. Biology of Invertebrates.**
*Prerequisite: Biol. 162 (or 152-154, or 195), or introductory geology and two additional natural science courses. II (alternate years) (5 credits)*

**438. Biology of Mollusks.**
*Prerequisite: Biol. 162. IIIb at the Biological Station (alternate years) (3 credits; 5 credits at the Biological Station)*

**440 (NR&E 422). Biology of Fishes.**
*Prerequisite: Biol. 162 and one additional biology course. I (3 credits)*

**441 (NR&E 423). The Biology of Fishes Laboratory.**
*Prerequisite: Biol. 162 and one additional biology course. (1 credit)*

**442. Biology of Insects.**
*Prerequisite: Any college-level biology course. I in Ann Arbor; IIIb at Biological Station. (alternate years in Ann Arbor). (5 credits)*

**444. Fish Behavior.**
*Prerequisite: Biol. 440. II (4 credits)*

**445 (Geology 445). Biogeography.**
*Prerequisite: Biol. 162 (or 152-154, or 195). Historical Geology (or equivalent) is recommended. (3 credits)*

**450. Biology of Amphibians and Reptiles.**
*Prerequisite: Biol. 162 (or 152-154, or 195). II (5 credits)*

**451 (NR&E 451). Biology of Mammals.**
*Prerequisite: Biol. 162 (or 152-154, or 195). I (alternate years) (4 credits)*

**453. Field Mammalogy.**
*Prerequisite: Two laboratory courses in biology. IIIb at the Biological Station. (alternate years) (5 credits in the half-term)*

**455. Ethnobotany.**
*Prerequisite: Two college-level courses in biology. III at the Biological Station (5 credits in the half-term)*

**457. Algae in Freshwater Ecosystems.**
*Prerequisite: Two laboratory courses in botany. IIIb at the Biological Station (5 credits in the half-term)*

**458. Biology of the Algae.**
*Prerequisite: Biol. 162 (or 152 or 195), or Biol. 255. I (alternate years) (5 credits)*

**459. Systematic Botany.**
*Prerequisite: Biol. 162 (or 152-154, or 195), or Biol. 255. I (4 credits)*

**461. Morphology and Evolution of Vascular Plants.**
*Prerequisite: Biol. 162 (or 154) or 255. I (alternate years) (5 credits)*

**468. Mushrooms and Molds: Biology and Use.**
*Prerequisite: Biol. 162 (or 154). II (alternate years) (5 credits)*

**469. Signal Transduction.**
*Prerequisite: Biology 427 or 428. (3 credits)*

**472. Plant-Animal Interactions.**
*Prerequisite: Biology 281 or equivalent. II (3 credits)*

**474. Wetlands Ecology.**
*Prerequisite: Two college-level courses in Biology, preferably one in Ecology. III at the Biological Station (5 credits in the half-term)*

**475. Conservation Biology and Ecosystem Management.**
*Prerequisite: Two courses in the biological sciences including ecology. III at the Biological Station (5 credits in the half-term)*

**476 (NR&E 476). Ecosystem Ecology.**
*Prerequisite: An ecology course in the department of Biology, or an ecology course approved by the instructor; and permission of instructor. II (3 credits)*

**477. Laboratory in Field Ecology.**
*Prerequisite: A course in ecology. I (5 credits)*

**478. Advanced Ecology.**
*Prerequisite: A general ecology course (Biol. 381 or equivalent). II (3 credits)*

**479. The Dynamics of Neotropical Rainforests.**
*Prerequisite: A course in ecology, fluency in Spanish, and permission of instructor. II in Nicaragua. (2 credits)*

**480. Computer-Aided Inferences in Evolution and Ecology.**
*Prerequisite: Senior natural science concentrator or graduate student. I (4 credits)*

**481. Population Dynamics and Ecology.**
*Prerequisite: A course in ecology. Calculus is strongly recommended. I (4 credits)*

**482. Limnology.**
*Prerequisite: Three laboratory courses in botany or zoology. IIIb at the Biological Station (5 credits in the half-term)*

**483. Limnology: Freshwater Ecology.**
*Prerequisite: Advanced undergraduate or graduate standing, with background in physics, chemistry, biology, or water-related sciences. II (3 credits)*

**484. Limnology Laboratory.**
*Prerequisite: Concurrent enrollment in Biol. 483. II (3 credits)*

**485 (Geol. 450) (NR&E 450) (NavArch 450). Aquatic Science Field Studies.**
*Prerequisite: Junior science or engineering concentrators. IIIa in Grand Haven, Michigan (6 credits in the half-term)*

**486. Biology and Ecology of Fish.**
*Prerequisite: Two laboratory courses in biology. IIIb at the Biological Station (alternate years) (5 credits in the half-term)*

**487 (NR&E 409) Ecology of Fishes.**
*Prerequisite: One course in ecology. II (Lectures: 3 credits; lectures and lab: 4 credits)*

**488. Microbial Ecology of Terrestrial Ecosystems.**
*Prerequisite: Biol. 162 (or 152). II (3 credits)*

**489 (NR&E 430). Soil Properties and Processes.**
*Prerequisite: Biol. 162 and chemistry. I (3 credits)*

**491. Principles of Phylogenetic Systematics.**
*Prerequisite: Biol. 162 (or 152-154, or 195). II (alternate years) (4 credits)*

**492. Behavioral Ecology.**
*Prerequisite: Biol. 162 (or 152-154, or 195), and one additional course in zoology. I in Ann Arbor; IIIb at the Biological Station (4 credits in Ann Arbor; 5 credits in the half-term; 5 credits at Biol. Station, which also includes Biol. 493)*

**496 (NR&E 425). Population Ecology.**
*Prerequisite: General ecology and NR&E 438; calculus recommended. II (4 credits)*

**497. Community Ecology.**
*Prerequisite: A course in ecology. II (3 credits)*

**498. The Ecology of Agroecosystems.**
*Prerequisite: A course in ecology. I (alternate years) (3 credits)*

**499. Dynamic Systems in Population and Community Ecology.**
*Prerequisite: A course in calculus and Biol. 481. I (alternate years) (3 credits)*

**513. Microbial Genetics.**
*Prerequisite: Genetics; and microbiology or biochemistry. II (3 credits)*

**514. Topics in Molecular Evolution.**
*Prerequisite: Biol. 305 and one upper-level course in either molecular or evolutionary biology, and permission of instructor. I (alternate years) (3 credits)*

**521. Bacterial Physiology II: Carbon Metabolism.**
*Prerequisite: Biol. 305, and Biol. 310 or 311 or Biol. Chem. 415. (1 credit)*

**522. Bacterial Physiology III: Nitrogen Metabolism.**
*Prerequisite: Biol. 305, and Biol 310, 311, or Biol. Chem 415. (1 credit)*

**525 (Chem. 525). Chemical Biology I**
*Prerequisite: Chemistry 451, 452, 461, and 463. (3 credits)*

**526 (Chem. 526). Chemical Biology II**
*Prerequisite: Biol. 525. Prior or concurrent enrollment in Chemistry 402 or equivalent. (3 credits)*

**532. Birds of the World.**
*Prerequisite: Sixteen credits of biology and permission of instructor. II (alternate years) (4 credits)*

**534. Developmental Neurobiology.**
*Prerequisite: Previous courses in neurobiology and development; and permission of instructor. I (alternate years) (3 credits)*

**541. Mammalian Reproductive Endocrinology.**
*Prerequisite: Biol. 310 or 311, or Biol. Chem. 415. II (4 credits)*

**556. Field Botany of Northern Michigan.**
*Prerequisite: A course in systematic botany (Biol. 459). IIIb at the Biological Station (5 credits in the half-term)*

**585. Ecology of Streams and Rivers.**
*Prerequisite: A previous or concurrent course in limnology, aquatic ecology, phycology, or aquatic invertebrates is recommended. IIIb at the Biological Station (5 credits in the half-term)*

**589. Mechanisms of Microbial Evolution.**
*Prerequisite: Biol. 305. II (3 credits)*

## Chemistry

**(Subject = CHEM)**

**105 (AOSS 105). Our Changing Atmospheres**
*I (3 credits)*

**108 (GS 130) (Physics 119). The Physical World**
*Prerequisite: high school algebra. I (Nat Sci) (4 credits)*

**120. First Year Seminar in Chemistry**
*(3 credits)*

**125. General and Inorganic Chemistry Laboratory**
*Prerequisite: to be elected by students who are eligible for, or enrolled in, Chem 130. I, II, IIIa (2 credits)*

**130. General Chemistry: Macroscopic Investigations and Reaction Principles**
*Prerequisites: three years of high school math or Math 105; one year of high school chemistry recommended. Placement by testing, or permission of Chemistry Department. Intended for students without AP credit in chemistry. I, II, IIIa (3 credits)*

**210. Structure and Reactivity I**
*Prerequisites: high school chemistry. Placement by examination during orientation or AP credit. To be taken with Chem 211. I, II, IIIa (4 credits)*

**211. Investigations in Chemistry**
*Prerequisite: to be taken with Chem 210. I, II, IIIa (1 credit)*

**215. Structure and Reactivity II**
*Prerequisites: Chem 210, Chem 211, concurrent enrollment in Chem 216. I, II, IIIa (3 credits)*

**216. Synthesis and Characterization of Organic Compounds**
*Prerequisites: Chem 210, Chem 211. Must be taken with Chem 215. I, II, IIIa (2 credits)*

**230. Physical Chemical Principles and Applications**
*Prerequisite: Chem 215 or permission of instructor. No credit for students who have completed or are enrolled in Chem 260. I, II, IIIa (3 credits)*

**241. Introduction to Chemical Analysis**
*Prerequisites: prior or concurrent enrollment in Chem 260. Note: This course is linked to Chemistry 242. Students must elect both Chemistry 241 (for 2 credits) and Chemistry 242 (for 2 credits). I, II (2 credits)*

**242. Introduction to Chemical Analysis Laboratory**
*Prerequisites: prior or concurrent enrollment in Chem 260. Note: This course is linked to Chemistry 241. Students must elect both Chemistry 241 (for 2 credits) and Chemistry 242 (for 2 credits). I, II (2 credits)*

**260. Chemical Principles**
*Prerequisites: Chem 215/216, Math 115, and prior or concurrent enrollment in Physics 140. No credit granted for students that have completed Chem 260. I, II, IIIa (3 credits)*

**261. Introduction to Quantum Chemistry**
*Prerequisites: Chem 215/216, Math 115, and prior or concurrent enrollment in Physics 140. This course is intended primarily for Chemical Engineering students who have completed ChemE 330. I, II, IIIa (1 credit)*

**302. Inorganic Chemistry: Principles of Structure, Reactivity, and Function**
*Prerequisites: Chem 260 (or 340). I, II (3 credits)*

**312. Synthesis and Characterization**
*Prerequisites: Chem 215, Chem 216. Prior or concurrent enrollment in Chem 302. I, II (2 credits)*

**402. Intermediate Inorganic Chemistry**
*Prerequisites: Chem 302, and 461/462 (or 469). I, II (3 credits)*

**417 (Physics 417). Dynamical Processes in Biophysics**
*Prerequisites: Math 216 or equivalent, and Physics 242 or Chem 463 (or 468). II (3 credits)*

**420. Intermediate Organic Chemistry**
*Prerequisites: Chem 215, Chem 216, or equivalents. II (3 credits)*

**436. Polymer Synthesis and Characterization**
*Prerequisite: Chem 241/242 or equivalent or permission of instructor. (3 credits) Lab*

**447. Physical Methods of Analysis**
*Prerequisites: Chem 260 and 241/242. I, II (3 credits)*

**451. Introduction to Biochemistry I**
*Prerequisites: Chem 215, Biol 152 or 195 and Math 115. No credit granted to those who have completed or are enrolled in Biology 311 or Biological Chemistry 415. I (4 credits)*

**452. Introduction to Biochemistry II**
*Prerequisite: Chem 451. II (4 credits)*

**461. Physical Chemistry I**
*Prerequisites: Chem 260, Physics 240, and Math 215. I, II (3 credits)*

**462. Computational Chemistry Laboratory**
*Prerequisites: Math 215 and prior or concurrent enrollment in Chem 461. I, II (1 credit)*

**463. Physical Chemistry II**
*Prerequisites: Chem 461/462. I, II (3 credits)*

**467 (AOSS 467) (Geol Sci 465). Biogeochemical Cycles**
*Prerequisites: Math 116, Chem 210, and Phys 240. I (3 credits)*

**480. Physical and Instrumental Chemistry**
*Prerequisites: Chem 447, Chem 461/462; and concurrent enrollment in Chem 463 or permission of instructor. I, II (3 credits)*

**485. Projects Laboratory**
*Prerequisite: Chem 480 or the equivalent. (2 credits)*

**535 (MacroSE 535). Physical Chemistry of Macromolecules**
*Prerequisite: Chem 463. I (3 credits)*

**536. Laboratory in Macromolecular Chemistry**
*Prerequisite: Chem 535 or Physics 418 or permission of instructor. I (alternate years) (2 credits)*

**538 (MacroSE 538). Organic Chemistry of Macromolecules**
*Prerequisites: Chem 215, Chem 216, and Chem 230 or Chem 241/242, 260. I (3 credits)*

**567 (AOSS 567). Chemical Kinetics**
*Prerequisite: Chem 461 or AOSS 479. I (3 credits)*

***Note:*** *Safety regulations forbid the wearing of contact lenses in the laboratory.*

## Economics

**(Subject = ECON)**

**101. Principles of Economics I**
*(4 credits)*

**102. Principles of Economics II**
*Prerequisite: Econ 101. (4 credits)*

**309. Experimental Economics**
*Prerequisite: Econ 101. Lab fee $30. (3 credits)*

**310. Money and Banking**
*Prerequisites: Econ 101, Econ 102. (3 credits)*

**320. Survey of Labor Economics**
*Prerequisites: Econ 101, Econ 102. (3 credits)*

**323. Economics and Gender**
*Prerequisites: Econ 101, Econ 102. (3 credits)*

**325. Inequality in the United States**
*Prerequisites: Econ 101, Econ 102. (3 credits)*

**330. Industrial Performance and Public Policy**
*Prerequisites: Econ 101, Econ 102. (3 credits)*

**340. International Economics**
*Prerequisites: Econ 101, Econ 102.. (3 credits)*

**357/CAAS 357. Economic History of African-Americans**
*(3 credits)*

**360. The Developing Economics**
*Prerequisites: Econ 101, Econ 102. No credit granted to those who have completed or are enrolled in Econ 461. (3 credits)*

**370 (NR&E 375). Natural Resource Economics**
*Prerequisites: Econ 101, Econ 102. No credit granted to those who have completed or are enrolled in Econ 471 or 472. (3 credits)*

**380. Public Finance**
*Prerequisites: Econ 101, Econ 102. Credit is not granted for Econ 380 concurrently with or after Econ 481 or Econ 482. (3 credits)*

**395. Topics in Economics and Economic Policy**
*Prerequisites: Econ 101, Econ 102. (3 credits)*

**398. Strategy and Equity**
*Prerequisites: Econ 101 or permission of instructor. (4 credits) (3 credits in the half-term)*

## Geological Sciences

**(Subject = GEOSCI)**

**100. Coral Reefs**
*(Nat Sci) Lecture (1 credit)*

**101. Waves and Beaches**
*No credit is granted to those who have completed, or are enrolled in, GS 276. (Nat Sci) Lecture (1 credit)*

**102. Energy from the Earth**
*Prerequisite: none; a course in elementary chemistry (high school or university) would be helpful. (Nat Sci) Lecture (1 credit)*

**103. Dinosaurs and Other Failures**
*No credit is granted to those who have completed, or are enrolled in, GS 273. (Nat Sci) Lecture (1 credit)*

**104. Ice Ages, Past and Future**
*No credit is granted to those who have completed, or are enrolled in, GS 275. (Nat Sci) Lecture (1 credit)*

**105. Continents Adrift**
*No credit is granted to those who have completed, or are enrolled in, GS 205 or GS 270. (Nat Sci) Lecture (1 credit)*

**106. Fossils, Primates, and Human Evolution**
*No credit is granted to those who have completed, or are enrolled in, GS 125. (Nat Sci) Lecture (1 credit)*

**107. Volcanoes and Earthquakes**
*No credit is granted to those who have completed, or are enrolled in, GS 205, GS 270, or GS 271. (Nat Sci) Lecture (1 credit)*

**110. The History of the Oceans**
*No credit is granted to those who have completed, or are enrolled in, GS 222. (Nat Sci) (1 credit)*

**111. Climate and Mankind**
*No credit is granted to those who have completed, or are enrolled in, GS 201 or GS 275. (Nat Sci) (1 credit)*

**113. Planets and Moons**
*No credit is granted to those who have completed, or are enrolled in, GS 204 or GS 278. (Nat Sci) (1 credit)*

**114. The Elements**
*Prerequisites: high school math, physics, and chemistry. (Nat Sci) (1 credit)*

**115. Geologic Time**
*No credit is granted to those who have completed, or are enrolled in, GS 135. (Nat Sci) Lecture (1 credit)*

**116. Introductory Geology in the Field**
*Reduced credit is granted for GS 116 to those with credit for an introductory course in geology (GS 117, GS 118, GS 119, GS 120, GS 205, or GS 206). At Camp Davis, Wyoming. IIIb (8 credits)*

**117. Introduction to Geology**
*No credit is granted to those who have completed, or are enrolled in, GS 116, GS 119, or GS 120. Those with credit for GS 205 may elect GS 117 for 4 credits. I, II (5 credits)*

**118. Introductory Geology Laboratory**
*No credit is granted to those with credit for an introductory course in geology (GS 116, GS 117, GS 121, GS-122, or GS 218). I, II (Nat Sci) (1 credit)*

**119. Introductory Geology Lectures**
*No credit is granted to those who have completed, or are enrolled in, GS 116, GS 117, or GS 120. No credit granted to those who have completed both GS 205 and GS 206. Those with credit for GS 205 may elect GS 119 for 3 credits. I, II (4 credits)*

**120. Geology of National Parks and Monuments**
*Credit is not granted for GS 120 to those with credit for an introductory course in geology (GS 116, GS 117, or GS 119). No credit granted to those who have completed both GS 205 and GS 206. II (4 credits)*

**124. (AOSS 124) (Environmental Studies 124). Environment, People, Resources**

**125. Evolution and Extinction**
*Those with credit for GS 106 may elect GS 125 for 2 credits. May not be included in a concentration plan in GS. II (3 credits)*

**130 (Chem 108) (Physics 119). The Physical World**
*Prerequisite: high school algebra. I (Nat Sci) (4 credits)*

**135. History of the Earth**
*No credit is granted to those who have completed, or are enrolled in, GS 269. Those with credit for GS 115 may elect GS 135 for 2 credits. II (Nat Sci) (3 credits)*

**140. Science and the Media**
*(Nat Sci) (3 credits)*

**141. How to Build a Habitable Planet**
*(Nat Sci) (3 credits)*

**142. From Stars to Stones**
*(Nat Sci) (3 credits)*

**145. Evolution of the Earth**
*No credit is granted to those who have completed, or are enrolled in, GS 135. Those with credit for GS 115 may elect 145 for 2 credits. (3 credits)*

**146. Plate Tectonics**
*No credit is granted to those who have completed three of GS 105, GS 107, and GS 205. Those with credit for one of GS 105 and GS 107 may elect GS 146 for 2 credits. Those with credits for GS 205, or for both GS 105 and GS 107, may elect GS 146 for 1 credit. (Nat Sci) (3 credits)*

**147. Natural Hazards**
*Those with credit for GS 107 or GS 205 may elect GS 147 for 2 credits. Those who have credit for both GS 107 and GS 205 may elect GS 147 for 1 credit. (3 credits)*

**148. Seminar: Environmental Geology**
*Prerequisite: high school math and science. No credit is given to those who have completed, or are enrolled in, GS 284. Those with credit for GS 109 may elect GS 148 for 2 credits. (3 credits)*

**149. Contemporary Dinosaurs**
*Those with credit for GS 103 may elect GS 149 for 2 credits. (3 credits)*

**150. Dinosaur Extinction and Other Controversies**
*(3 credits)*

**151. The Ice Ages: Past and Present**
*Those with credit for GS 104 may elect GS 151 for 2 credits. (Nat Sci) (3 credits)*

**152. Coastal Systems and Human Settlements**
*Those with credit for GS 101 may elect GS 152 for 152 for 2 credits. (Nat Sci) (3 credits)*

**153. Earthlike Planets**
*Prerequisite: high school math and science recommended. Those with credit for GS 113 may elect GS 153 for 2 credits. (Nat Sci) (3 credits)*

**155. Evolution of North America**
*No credit is granted to those who have completed, or are enrolled in, GS 411. (3 credits)*

**156. Coral Reef Dynamics**
*(Nat Sci) (3 credits)*

**157. History of Earth Science**
*(3 credits)*

**171 (AOSS 171) (UC 110) (Bio 110) (SNRE 110). Introduction to Global Change–Part I**
*(4 credits)*

**201. Introductory Geography: Water, Climate and Mankind**
*No credit is granted to those who have completed or are enrolled in GS 268. Those with credit for GS 111 may only elect GS 201 for 3 credits. I, II (Nat Sci) (4 credits)*

**204. The Planets: Their Geology and Climates**
*Prerequisites: High school mathematics through plane geometry and trigonometry. Those with credit for GS 113 may only elect GS 204 for 2 credits. (Nat Sci) (3 credits)*

**205. How the Earth Works: The Dynamic Planet**
*No credit is granted to those who have completed, or are enrolled in, GS 117, GS 119, or GS 270. No credit granted to those who have completed both GS 105 and GS 107. Those with credit for one of GS 105 and GS 107 may elect GS 205 for 1 credit. (Nat Sci) (2 credits)*

**206. How the Earth Works: The Water Cycle and the Environment**
*Those with credit for GS 109 may elect GS 206 for 1 credit. (Nat Sci) (2 credits)*

**207. How the Earth Works: A Hands on Experience**
*No credit granted to those who have completed or are enrolled in GS 116, GS 117, GS 118, or GS 120. (Nat Sci) (2 credits)*

**222. Introductory Oceanography**
*No credit granted to those with credit for AOSS 203. QR/2 (Nat Sci) (3 credits)*

**223. Introductory Oceanography, Laboratory**
*Concurrent enrollment in GS 222. QR/2 (Nat Sci) (1 credit)*

**231. Elements of Mineralogy**
*Prerequisite: prior or concurrent enrollment in Chem 125/130 or Chem 210/211. Those with credit for GS 232 may elect GS 231 for only 2 credits. I (Excl) (4 credits)*

**232. Earth Materials**
*Prerequisite: prior or concurrent enrollment in Chem 125/130 or 210/211. Those with credit for GS 231 may elect GS 232 for only*

**279. Ocean Resources**
*Prerequisites: high school match and science recommended. (Nat Sci) (3 credits)*

**280. Mineral Resources, Economics, and the Environment**
*No previous knowledge of geology is required for this course. I (4 credits)*

**284. Environmental Geology**
*No credit is granted to those who have completed, or are enrolled in, GS 272. Those with credit for GS 271 may elect GS 284 for 3 credits. Prerequisites: high school science and math recommended. (4 credits)*

**305. Sedimentary Geology**
*Prerequisite: an introductory geological sciences laboratory course or permission of the instructor. I (4 credits)*

**310. Igneous and Metamorphic Petrology**
*Prerequisites: GS 231 and either an introductory geological sciences course or GS 351 to be elected prior to, or concurrently with, GS 310. II (4 credits)*

**351. Structural Geology**
*Prerequisite: GS 305 or permission of instructor. II (4 credits)*

**411. Geology of Michigan**
*No credit to those who have completed or are enrolled in GS 283. (3 credits)*

**415. Introductory Economic Geology (Metals)**
*Prerequisites: GS 310, GS 351, or permission of instructor. I (4 credits)*

**416. Organismal Function and Evolution**
*Prerequisites: Biol 152 or Geol 418; Math 115; Physics 125. (4 credits)*

**417. Geology of the Great Lakes**
*Prerequisites: One college-level science course; permission of instructor. (2 credits)*

**418. Paleontology**
*Prerequisite: GS 117 or equivalent, or Biology 154 or 195. (3 credits)*

**419. Paleontology Lab**
*Prerequisite: prior or concurrent enrollment in GS 418. (1 credit)*

**420. Introductory Earth Physics**
*Prerequisite: Math 116. I (3 credits)*

**422. Principles of Geochemistry**
*Prerequisites: GS 231, GS 305, GS 310, Chem 125/130. II (3 credits)*

**425. Environmental Geochemistry**
*Prerequisite: introductory chemistry. (3 credits)*

**426. Quantum Geology**
*Prerequisite: Math. Through 216 or approval of instructor; one of mineralogy, petrology, solid-state chemistry, solid-state physics, or materials science, or approval of instructor. (3 credits)*

**427. Environmental and Technological Applications of Mineralogy**
*Prerequisite: Geology 231, 232 or comparable courses in solid-state chemistry, physics, materials science or permission of instructor. (3 credits)*

**430. Depositional Environments**
*Prerequisite: permission of instructor. (Excl) (3 credits)*

**437. Evolution of Vertebrates**
*Prerequisite: A course in general biology or historical geology. (4 credits)*

**438. Evolution of Primates**
*Prerequisite: Permission of instructor. (4 credits)*

**439. Fossil Record and Evolution of Mammals**
*Prerequisite: Permission of instructor. (4 credits)*

**440. Field Course in Geology**
*Prerequisites: elementary trigonometry, GS 310 and GS 351. At Camp Davis, Wyoming. IIIb (8 credits)*

**441. Field Course in Environmental Geology**
*Prerequisite: Geol 116, 117 or 119 or 205 and 206. (4 credits)*

**442. Earth Surface Processes and Soils**
*I (4 credits)*

**449. Marine Geology**
*Prerequisites: GS 222, GS 223 or introductory physical geology. II (3 credits)*

**450 (Biol 485) (NA 450) (NR&E 450). Aquatic Science Field Studies**
*Prerequisite: Junior science or engineering concentrators. Those with credit for GS 223 may only elect GS450 for 5 credits.*

**451. Introductory Earth Structure**
*Prerequisite: Permission of instructor. (3 credits)*

**455. Determinative Methods in Mineralogical and Inorganic Materials**
*Prerequisites: one term of elementary chemistry and physics. II (4 credits)*

**465. Biogeochemical Cycles**
*Prerequisites: Math 116, Chem 210 and Physics 240. (3 credits)*

**467. Stratigraphy**
*Prerequisites: GS 305, GS 310, GS 351. I (3 credits)*

**473. Fundamentals of Organic Geochemistry**
*Prerequisite: GS 305 or Chem 226. (3 credits)*

**477. Hydrogeology**
*Prerequisites: basic chemistry, physics, calculus (e.g., Math 115,*

*Math 116; Physics 140, Physics 141; Chem 125, Chem 130). (3 credits)*

**478. Aqueous Geochemistry**
*Prerequisite: Chem 365 or the equivalent. (3 credits)*

**479. Marine Geochemistry**
*Prerequisite: Chem 125/130 or the equivalent. (3 credits)*

**480 (AOSS 480). The Planets: Composition, Structure, and Evolution**
*Prerequisites: Math 216, Physics 240, Chem 130. I (3 credits)*

**483. Geophysics: Seismology**
*Prerequisites: Math 215 at least concurrently, Physics 240, or permission of instructor. II (4 credits)*

**484. Geophysics: Physical Fields of the Earth**
*Prerequisites: Math 216 at least concurrently, Physics 240, or permission of instructor. II (4 credits)*

**486. Geodynamics**
*Prerequisites: GS 420 and prior or concurrent election of Math 215, Physics 240, or permission of instructor. (3 credits)*

**488. Physical Fields Laboratory**
*(1 credit)*

## Mathematics

**(Subject = MATH)**

**105. Data, Functions, and Graphs**
*Prerequisite: three years of high school mathematics. See LS&A Bulletin. (4 credits)*

**110. Pre-calculus (self-study)**
*Prerequisite: three years of high school mathematics and permission of Math 115 instructor. See LS&A Bulletin. (2 credits)*

**115. Calculus I**
*Prerequisite: four years high school mathematics. Credit usually is granted for only one course from among Math 112, Math 115, Math 185, and Math 295. (4 credits)*

**116. Calculus II**
*Prerequisite: Math 115. Credit is granted for only one course from among Math 116, Math 119, Math 156, Math 186, and Math 296. (4 credits)*

**156. Applied Honors Calculus II**
*Prerequisite: Score of 4 or 5 on the AB or BC Advanced Placement calculus exam. (4 credits)*

**175. Combinatorics and Calculus**
*Prerequisites: permission of a counselor. I (4 credits)*

**176. Dynamical Systems and Calculus**
*Prerequisite: Math 175 or permission of instructor. (4 credits)*

**185. Honors Calculus I**
*Prerequisite: permission of a counselor. I (4 credits)*

**186. Honors Calculus II**
*Prerequisite: Math 185 or permission of a counselor. II (4 credits)*

**215. Calculus III**
*Prerequisite: Math 116 (4 credits)*

**216. Introduction to Differential Equations**
*Prerequisite: Math 116 or Math 119, Math 156, or Math 186. I, II, IIIa, IIIb (4 credits) No credit after Math 316.*

**217. Linear Algebra**
*Prerequisite: Math 215 or Math 285. I, II (3 credits) No credit after Math 417 or Math 419.*

**255. Applied Honors Calculus III**
*Prerequisite: Math 156 or permission of instructor. (4 credits)*

**256. Applied Honors Calculus IV**
*Prerequisite: Math 255 or permission of instructor. (4 credits)*

**285. Honors Calculus III**
*Prerequisite: Math 186 or permission. I (4 credits)*

**286. Honors Differential Equations**
*Prerequisite: Math 285. II (3 credits)*

**288. Math Modelling Workshop**
*Prerequisites: Math 216, Math 316, or Math 286; and Math 217, Math 417, or Math 419. I (1 credit) Offered mandatory credit/no credit. May be elected for a total of 3 credits.*

**289. Problem Solving Seminar**
*Prerequisite: permission of instructor. I, II (1 credit) May be repeated for credit with permission of advisor.*

**295. Honors Mathematics I**
*Prerequisite: permission of the Honors Counselor. (4 credits)*

**296. Honors Mathematics II**
*Prerequisite: Math 295 or permission of the Honors Counselor. (4 credits)*

**312. Applied Modern Algebra**
*Prerequisite: Math 217. I, II, and occasionally IIIa (3 credits; 1 credit after Math 412)*

**316. Differential Equations**
*Prerequisites: Math 215 and Math 217 or equivalent. I, II (3 credits) Credit can be received for only one of Math 216 or Math 316, and credit can be received for only one of Math 316 or Math 404.*

**350 (Aero 350). Aerospace Engineering Analysis**
*Prerequisite: Math 216 or Math 316 or equivalent. I, II (3 credits)*

**354. Fourier Analysis and Its Applications**
*Prerequisites: Math 216, or Math 316, or Math 286. (3 credits)*

**371 (Eng 371). Numerical Methods for Engineers and Scientists**
*Prerequisites: Eng 103 or Eng 104, or equivalent; and Math 216. I, II (3 credits)*

**395. Honors Analysis I**
*Prerequisite: Math 296 or permission of the Honors Counselor. (4 credits)*

**396. Honors Analysis II**
*Prerequisite: Math 395. (4 credits)*

**404. Intermediate Differential Equations and Dynamics**
*Prerequisite: Math 216. Offered sporadically. (3 credits) No credit after Math 286 or Math 316.*

**412. Introduction to Modern Algebra**
*Prerequisites: Math 215 or Math 285 and Math 217. I, II (3 credits)*

*No credit granted to those who have completed or are enrolled in Math 512. Students with credit for Math 312 should take Math 512 rather than Math 412. One credit granted to those who have completed Math 312.*

**416. Theory of Algorithms**
*Prerequisites: Math 312 or Math 412 or EECS 303, and EECS 380 or permission. I, II (3 credits)*

**417. Matrix Algebra I**
*Prerequisites: three courses beyond Math 110. I, II, IIIa, IIIb (3 credits; none after Math 217)*

**419 (EECS 400). Linear Spaces and Matrix Theory**
*Prerequisite: four semesters of college math beyond Math 110. I, II, IIIb (3 credits; 1 credit after Math 417) No credit after Math 217 or Math 513.*

**420. Matrix Algebra II**
*Prerequisite: Math 217 or Math 417 or Math 419. II (3 credits)*

**422 (Bus 440). Risk Management and Insurance**
*Prerequisite: Math 115, junior standing and permission of instructor. I (3 credits)*

**423. Mathematics of Finance**
*Prerequisite: Math 217, Math 425 and EECS 183 or equivalents. I, II (3 credits)*

**425 (STAT 425). Introduction to Probability**
*Prerequisites: Math 215 or Math 255 or Math 285. I, II, IIIa, IIIb (3 credits)*

**431. Topics in Geo. for Teachers**
*Prerequisite: Math 215. II (3 credits)*

**433. Introduction to Differential Geometry**
*Prerequisite: Math 217 and Math 215 or Math 255 or Math 285. II (3 credits)*

**450. Advanced Mathematics for Engineers I**
*Prerequisites: Math 215, Math 216, Math 316 or Math 286. I, II, IIIb (4 credits)*

**451. Advanced Calculus I**
*Prerequisites: Math 285, or Math 215 and one subsequent course. I, II, IIIa (3 credits)*

**452. Advanced Calculus II**
*Prerequisites: Math 217, or Math 417, or Math 419 (may be concurrent) and Math 451. (3 credits)*

**454. Boundary Value Problems for Partial Differential Equations**
*Prerequisites: Math 216, or Math 316, or Math 286. I, II, IIIa (3 credits)*

**462. Mathematical Models**
*Prerequisites: Math 216, Math 256, Math 286, or Math 316; and Math 217, Math 417, or Math 419. II (3 credits; 1-3 credits after Math 362, depending on overlap)*

**463. Math Modeling in Biology**
*Prerequisite: Math 217, 417 or 419; and 286 or 316. II (3 credits)*

**464 (BiomedE 464). Inverse Problems**
*Prerequisites: Math 217, Math 417, or Math 419; and Math 216, Math 256, Math 286, or Math 316. II (3 credits)*

**471. Introduction to Numerical Methods**
*Prerequisites: Math 216, Math 316, or Math 286; and Math 217, Math 417, or Math 419; and a working knowledge of one high-level computer language. I, II, IIIb (3 credits)*

**475. Elementary Number Theory**
*Prerequisite: none. II (3 credits)*

**481. Introduction to Mathematical Logic**
*Prerequisite: Math 412 or Math 451 or equivalent experience with abstract mathematics. I (3 credits)*

**490. Introduction to Topology**
*Prerequisite: Math 412 or Math 451 or equivalent experience with abstract mathematics. I (3 credits)*

**498. Topics in Modern Mathematics**
*Prerequisite: Junior and Senior students from mathematics and other fields. I (3 credits)*

**512. Algebraic Structures**
*Prerequisite: Math 451 or Math 513 or permission of instructor. Math 512 requires more mathematical maturity than Math 412. Credit is not given for both Math 412 and Math 512. I (3 credits)*

**513. Introduction to Linear Algebra**
*Prerequisite: Math 412 or permission of instructor. I, II (3 credits)*

**520. Life Contingencies I**
*Prerequisite: Math 424 and Math 425 or permission of instructor. I (3 credits)*

**521. Life Contingencies II**
*Prerequisite: Math 520 or permission of instructor. II (3 credits)*

**522. Actuarial Theory of Pensions and Social Security**
*Prerequisite: Math 520 or permission of instructor. II (3 credits)*

**523. Risk Theory**
*Prerequisite: Math 425. I (3 credits)*

**525 (Stat 525). Probability Theory**
*Prerequisite: Math 450 or Math 451; or permission of the instructor. I, II (3 credits; 1 credit after Math 425)*

**531. Transformation Groups in Geometry**
*Prerequisite: Math 215, 255, or 285. (3 credits)*

**532. Discrete and Applied Geometry**
*Prerequisite: One of Math 217, Math 417, Math 419, or Math 513. (3 credits)*

**535. Introduction to Algebraic Curves**
*Prerequisite: Math 513. (3 credits)*

**537. Intro. to Diff. Manifolds**
*Prerequisite: Math 590 and Math 513. I (3 credits)*

**550 (PSCS 510). Introduction to Adaptive Systems**
*Prerequisite: permission of instructor or enrollment in Certificate Program.*

**552 (PSCS 520). Empirical Analysis of Nonlinear Systems**
*Prerequisite: enrollment in Certificate Program or permission of instructor.*

**555. Introduction to Functions of a Complex Variable with Applications**
*Prerequisite: Math 450 or Math 451. I, II, IIIa, IIIb (3 credits)*

**556. Methods of Applied Mathematics I**
*Prerequisites: Math 217 or Math 419 or Math 513; Math 451 and Math 555. I (3 credits)*

**557. Methods of Applied Mathematics II**
*Prerequisites: Math 217, Math 419, or Math 513; Math 451 and Math 555. II (3 credits)*

**558 (658). Ordinary Differential Equations**
*Prerequisite: Math 450 or Math 451.*

**559. Selected Topics in Applied Mathematics**
*Prerequisites: Math 217 or Math 417 or Math 419, and Math 451 or equivalent. I (3 credits)*

**561 (IOE 510) (SMS 518). Linear Programming I**
*Prerequisites: Math 217, Math 417 or Math 419. I, II, IIIa (3 credits)*

**562 (Aero 577) (IOE 511). Continuous Optimization Methods**
*Prerequisites: Math 217, Math 417, or Math 419. I (3 credits)*

**565. Combinatorics and Graph Theory**
*Prerequisite: Math 412 or Math 451 or equivalent experience with abstract mathematics. I (3 credits)*

**566. Combinatorial Theory**
*Prerequisites: Math 216,Math 256, Math 316, or Math 286 or permission of instructor. (3 credits)*

**567. Introduction to Coding Theory**
*Prerequisite: Math 217, 417, or 419. I (3 credits)*

**571. Numerical Methods for Scientific Computing I**
*Prerequisites: Math 217, Math 417, Math 419, or Math 513; and Math 450 or Math 451 or Math 454; or permission. I, II (3 credits)*

**572. Numerical Methods for Scientific Computing II**
*Prerequisites: Math 217, Math 419, or Math 513 and Math 454 or permission. II (3 credits)*

**575. Introduction to the Theory of Numbers I**
*Prerequisite: Math 451 and 513 or permission of instructor. II (3 credits)*

**582. Introduction to Set Theory**
*Prerequisite: Math 412 or 451 or equivalent experience with abstract. II (3 credits)*

**590. An Introduction to Topology**
*Prerequisite: Math 451. I (3 credits)*

**591. General and Diff. Topology**
*Prerequisite: Math 451. I (3 credits)*

**593. Algebra I**
*Prerequisite: Math 513. I (3 credits)*

**594. Algebra II**
*Prerequisite: Math 593. (3 credits)*

**596. Analysis I**
*Prerequisite: Math 451. (3 credits; 2 hours credit for those with credit for Math 555)*

**597. Analysis II**
*Prerequisites: Math 451, Math 513. I (3 credits)*

**602. Real Analysis II**
*Prerequisites: Math 590, Math 597. II (3 credits)*

**604. Complex Analysis II**
*Prerequisite: Math 596. I (3 credits)*

**623. Computational Finance**
*Prerequisite: Math 316 and 425 or 525. II (3 credits)*

**625 (Stat 625). Probability and Random Processes I**
*Prerequisite: Math 597. II (3 credits)*

**626 (Stat 626). Probability and Random Processes II**
*Prerequisite: Math 625. I (3 credits)*

**635. Differential Geometry**
*Prerequisite: Math 537 or permission of instructor. (3 credits)*

**650. Fourier Analysis**
*Prerequisite: Math 602 and Math 596. (3 credits)*

**651. Topics in Applied Mathematics I**
*Prerequisites: Math 451, Math 555, and one other 500 level course in analysis or differential equations. I (3 credits)*

**655. Topics in Fluid Dynamics**
*Prerequisite: Math 555, 556, 557 or 558 or permission of instructor. (3 credits)*

**656. Introduction to Partial Differential Equations**
*Prerequisites: Math 558, Math 596, and Math 597 or permission of instructor. (3 credits)*

**658. Ordinary Differential Equations**
*Prerequisite: One course in differential equations such as 404 or 558. (3 credits)*

**660 (IOE 610). Linear Programming II**
*Prerequisite: Math 561(IOE 510). II (3 credits)*

**663 (IOE 611). Non-linear Programming I**
*Prerequisite: Math 561(IOE 510). I (3 credits)*

**664. Combinatorial Theory I**
*Prerequisite: Math 512. I (3 credits)*

**665. Combinatorial Theory II**
*Prerequisite: Math 664 or equivalent. II (3 credits)*

**669. Topics in Combinatorial Theory**
*Prerequisite: Math 565 or Math 566 or permission of instructor. (3 credits)*

**671. Analysis of Numerical Methods I**
*Prerequisites: Math 571, Math 572, or permission of instructor. (3 credits)*

**672. Analysis of Numerical Methods II**
*Prerequisite: Linear algebra and advanced calculus; usually preceded by Math 671, but may be taken separately. (3 credits)*

## Physics

**(Subject = PHYSICS)**

**102. The Physical Universe – Motors, Magnets and Magnifiers**
*Prerequisite: Physics 126 or 240. (1 credit; mini-course)*

**103. The Physical Universe – Relativity and Quanta**
*Prerequisite: High school geometry, trigonometry, and algebra. (1 credit; mini-course)*

**104. The Physical Universe – What Einstein Never Knew**
*Prerequisite: High school geometry, trigonometry, and algebra. (1 credit; mini-course)*

**106. Everyday Physics**
*Prerequisite: none. (3 credits; $25 lab fee)*

**107. 20th Century Concepts of Space, Time, and Matter**
*Prerequisite: High school algebra and geometry. (3 credits)*

**112. Cosmology: The Science of the Universe**
*Prerequisite: Exposure to high school physics helpful. (3 credits)*

**115. Living with Physics**
*Prerequisite: Two and one-half years of high school mathematics, including trigonometry. No credit granted to those who have completed or are enrolled in Physics 125, 140, or 160. (3 credits)*

**119 (Chem 108) (GS 130). The Physical World**
*Prerequisite: high school algebra. I (Nat Sci) (4 credits)*

**125. General Physics: Mechanics, Sound, and Heat**
*Prerequisite: Two and one-half years of high school mathematics, including trigonometry. Physics 125 and 127 usually are elected concurrently. No credit if completed or enrolled in Physics 140, 145, or 160. (4 credits)*

**126. General Physics: Electricity and Light**
*Prerequisite: Physics 125. Physics 126 and 128 usually are elected concurrently. No credit if completed or enrolled in Physics 240 or 260. (4 credits)*

**140. General Physics I**
*Prerequisites: Calculus and Physics 141 to be taken concurrently. I, II, IIIa (4 credits)*

**141. Elementary Laboratory I**
*To be taken concurrently with Physics 140. I, II, IIIa (1 credit)*

**160. Honors Physics I**
*Prerequisite: Math 115 or equivalent, or permission of instructor. No credit granted to those who have completed or are enrolled in Physics 140. I, II (4 credits)*

**214 (RC Nat Sci 214). The Physicists and the Bomb**
*Prerequisite: High school mathematics. (4 credits)*

**240. General Physics II**
*Prerequisites: Physics 140 or equivalent; Physics 241 to be taken concurrently. I, II, IIIa (4 credits)*

**241. Elementary Laboratory II**
*To be taken concurrently with Physics 240. I, II, IIIa (1 credit)*

**260. Honors Physics II**
*Prerequisite: Physics 140 or Math 115, or equivalent, or permission of instructor. No credit granted to those who have completed or are enrolled in Physics 240. I, II (4 credits)*

**281. Physics and National Science Policy**
*Prerequisite: Junior standing; introductory physics courses preferred. (3 credits)*

**288. Physics of Music**
*II (3 credits)*

**333. Keller Tutor 140**
*Prerequisite: permission of instructor. I, II (1-3 credits)*

**334. Keller Tutor 240**
*Prerequisite: permission of instructor. I, II (1-3 credits)*

**340. Waves, Heat and Light**
*Prerequisites: Physics 240 or 260, Physics 241, Math 215 or equivalent. I, II (3 credits)*

**341. Waves, Heat and Light Lab**
*Prerequisites: Physics 240 or 260, Physics 241. (2 credits)*

**390. Introduction to Modern Physics**
*Prerequisites: Physics 340 or equivalent, Math 216 or permission of instructor. (3 credits)*

**401. Intermediate Mechanics**
*Prerequisites: Physics 126 or Physics 240, Physics 241 and Math 216 or equivalent. I, II (3 credits)*

**402. Light**
*Prerequisites: Physics 126 or Physics 240, Physics 241 and Math 216 or equivalent. A student can receive credit for only one: Physics 402 or EECS 334. I (3 credits)*

**405. Intermediate Electricity and Magnetism**
*Prerequisites: Physics 126 or Physics 240, Physics 241 and Math 216 or equivalent. I, II (3 credits)*

**406. Statistical and Thermal Physics**
*Prerequisites: Physics 126 or Physics 240, Physics 241 and Math 216. I, II (3 credits)*

**411. Introduction to Computational Physics**
*Prerequisites: Physics 340, Calculus, some knowledge of BASIC, FORTRAN or Pascal. I (3 credits)*

**413 (Complex Systems 541). Introduction to Nonlinear Dynamics and the Physics of Complexity**
*Prerequisites: Physics 401 or equivalent and familiarity with programming in BASIC. II (3 credits)*

**415. Special Problems for Undergraduates**
*Prerequisite: permission of instructor. I, II, III, IIIa, IIIb (arranged)*

**417 (Chem 417). Dynamical Processes in Biophysics**
*Prerequisites: Math 216 or equivalent, and Physics 242 or Chem 463 (or 468). II (3 credits)*

**435. Gravitational Physics**
*Prerequisites: Physics 340, Physics 401, Physics 405 or equivalent. I (3 credits)*

**441. Advanced Lab I**
*Prerequisites: Physics 390 and any Physics 400-level course. (2 credits)*

**442. Advanced Lab II**
*Prerequisites: Physics 390 and any Physics 400-level course. (2 credits)*

**451, 452. Methods of Theoretical Physics**
*Prerequisites: Physics 401, Math 450 or equivalent; Math 451. I; Math 452. II (3 credits each)*

**453. Quantum Mechanics**
*Prerequisites: Physics 340; Physics 401 or Physics 405 recommended. I, II (3 credits)*

**455. Electronic Devices and Circuits**
*Prerequisites: Physics 240, Physics 241. I (3 credits)*

**457. Subatomic Physics**
*Prerequisite: Physics 453. II (3 credits)*

**460. Quantum Mechanics II**
*Prerequisite: Physics 453. II (2 credits)*

**463. Introduction to Solid State Physics**
*Prerequisite: Physics 453 or permission of instructor. II (3 credits)*

**481. Physics and National Science Policy**
*Prerequisite: Junior standing; introductory physics courses preferred. (3 credits)*

**489. Physics of Music**
*(3 credits)*

**505, 506. Electricity and Magnetism I and II**
*Prerequisites: Physics 405, Math 450: Math 505. I (2 credits); Math 506. II (3 credits)*

**507. Theoretical Mechanics**
*Prerequisite: an adequate knowledge of differential equations; an introductory course in mechanics is desirable. I (3 credits)*

**510. Statistical Physics**
*I (3 credits)*

**511, 512. Quantum Mechanics I and II**
*Prerequisite: Physics 453. Physics 511 is a prerequisite for Physics 512; Physics 511. I; Physics 512. II (3 credits each)*

**513. Advanced Quantum Mechanics**
*I, II (3 credits)*

**515, 516. Supervised Research**
*Prerequisite: permission. I, II (4-6 credits each term)*

**517. Graduate Physics Laboratory**
*Prerequisite: graduate standing. I (3 credits)*

**518. Microcomputers in Experimental Research**
*Prerequisite: graduate standing. II (3 credits)*

**519. Group Theory**
*(to be arranged)*

**520. Condensed Matter Physics**
*Prerequisites: Physics 510, Physics 511 or equivalent. II (3 credits)*

**521. Elementary Particle Physics**
*Prerequisites: Physics 506, Physics 512, or equivalent. II (3 credits)*

**522. Atomic Physics**
*(to be arranged)*

**523. Advanced Quantum Mechanics II**
*Prerequisite: relativistic quantum mechanics at the level of Physics 513. II (3 credits)*

**525. Introductory Topics in Astrophysics**
*(3 credits)*

**526. Introductory Topics in Astrophysics II**
*II (3 credits)*

**527. Introductory Topics in Astrophysics III**
*I (3 credits)*

**529. Techniques of Experimental Physics**
*(3 credits)*

**530. Statistical Physics II**
*(to be arranged)*

**540. Advanced Condensed Matter**
*Prerequisite: Physics 520 or equivalent. (3 credits)*

**541. Particle Physics II**
*(to be arranged)*

**542 (EECS 638) (Appl Phys 609). Quantum Optics**
*Prerequisite: quantum mechanics electrodynamics and atom physics. I (even years) (3 credits)*

**601, 602. Particles and Fields**

**605, 606. Applied Group Theory**

**611 (Appl Phys 611)(EECS 634). Nonlinear Optics**
*Prerequisite: EECS 537 or EECS 538 or EECS 530. I (3 credits)*

**613, 614. Advanced Quantum Theory**

**615, 616. Advanced Classical Mechanics**

**617, 618. Physics of Continuous Media**

**619, 620. Solid State**

**621, 622. Theory of Fields**

**623, 624. Advanced Statistical Physics**

**625, 626. Elementary Particles**

**629 (ChemE 629). Complex Fluids**

**627, 628. Experimental High Energy Physics**

**631, 632. Advanced Mathematical Physics**

**633, 634. Fluid Dynamics**

**635, 636. General Relativity**

**637, 638. Advanced Nuclear Physics**

**639, 640. Low Temperature Physics**

**643, 644. Advanced Topics in Laser-Matter Physics**

**650 (Appl Phys 550) (EECS 538). Optical Waves in Crystals**
*Prerequisite: EECS 434. I (3 credits)*

**651 (Appl Phys 551) (EECS 539). Lasers**
*Prerequisites: EECS 537 and EECS 538. II (3 credits)*

**653, 654. Advanced Accelerator Physics**

**655, 656. Advanced Molecular Physics**

**665, 666. Contemporary Physics**

**667, 668. Advanced Astrophysics**

**671. Advanced Electroweak Theory and Constraints on Extensions of the Standard Model**

**673. Accelerators-Users**

**674, 675. Medical Physics**

**715. Special Problems**

**751 (Chem 751) (ChemE 751) (MacroSE 751) (MSE 751). Topics in Macromolecular Science**
*Prerequisite: permission of instructor. (2 credits)*

**990. Dissertation/Pre-Candidacy**

**995. Dissertation/Candidacy**

## Statistics

**(Subject = STATS)**

**100. Introduction to Statistical Reasoning**
*I, II, IIIa, IIIb (4 credits)*

**125. Games, Gambling, and Coincidences**
*I (3 credits)*

**170. The Art of Scientific Investigation**
*II (4 credits)*

**190. The History of Chance**
*II (3 credits)*

**250. Introduction to Statistics and Data Analysis**
*No credit granted to those who have completed or enrolled in Econ 404 or Stat 265, Stat 405 or Stat 412. I, II, IIIa, IIIb (4 credits) (NS)*

**265 (IOE 265). Probability and Statistics for Engineers**
*Prerequisites: Math 116 and Engr 101. I, II (4 credits)*

**403. Introduction to Statistics and Data Analysis II**
*Prerequisite: Stat 402. II (4 credits) (Excl)*

**405 (Econ 405). Introduction to Statistics**
*Prerequisite: Math 115 or permission of instructor. Juniors and seniors may elect concurrently with Econ 201 and Econ 202. No credit granted to those who have completed or are enrolled in Stat 265 or Stat 412. Students with credit for Econ 404 can only elect Stat 405 for 2 credits and must have permission of instructor. I, II (4 credits) (Excl)*

**406. Introduction to Statistical Computing**
*Prerequisites: Stat 402, or 405, 412, 425. II (4 credits) (Excl)*

**412. Introduction to Probability and Statistics**
*Prerequisites: taken concurrently with Math 215 and either EECS 283 or Eng 103. I, II, IIIa (3 credits)*

**413. The General Linear Model and Its Applications**
*Prerequisites: Stat 402, Math 217, co-registration in Stat 425 (Math 425) (or concurrent enrollment in Stat 425 (Math 425). Only two credits if student has taken Stat 403. I (4 credits) (MSA)*

**414. Topics in Applied Statistics**
*Prerequisites: Stat 413 or Stat 403 and permission and concurrent or previous enrollment in Stat 426. II (4 credits) (MSA)*

**425 (Math 425). Introduction to Probability**
*Prerequisite: Math 215. I, II, IIIb (3 credits) (MSA)*

**426. Introduction to Mathematical Statistics**
*Prerequisite: Stat 425. I, II (3 credits) (NS)*

**430. Applied Probability**
*Prerequisite: Stat 425 or equivalent. II (3 credits) (MSA)*

**466. (IOE 466) (Mfg 466). Statistical Quality Control**
*Prerequisite: IOE 265 (Stat 265) and IOE 366 or Stat 403. I, II (4 credits) (MSA)*

**470. Experimental Design**
*Prerequisite: Stat 402. I (4 credits) (MSA)*

**480. Survey Sampling Techniques**
*Prerequisite: Stat 402. II (4 credits) (MSA)*

**499. Honors Seminar**
*Prerequisite: permission of departmental honors advisor. I, II, IIIa, IIIb (2-3 credits) (MSA)*

**500. Applied Statistics I**
*Prerequisites: Math 417 and a course in statistics (Stat 426 or permission of instructor). I (3 credits)*

**501. Applied Statistics II**
*Prerequisite: Stat 500 or permission of the instructor. II (3 credits)*

**502. Analysis of Categorical Data**
*Prerequisite: Stat 426 or permission of instructor. I, II (3 credits)*

**503. Applied Multivariate Analysis**
*Prerequisite: Stat 500 or permission of instructor. I (3 credits)*

**504. Seminar on Statistical Consulting**
*Prerequisite: Stat 403 or Stat 500. I, II (3 credits)*

**505 (Econ 673). Econometric Analysis**
*Prerequisite: permission of instructor. (3 credits)*

**510. Mathematical Statistics I**
*Prerequisites: Math 450 or Math 451 and a course in probability or statistics, or permission. I (3 credits)*

**511. Mathematical Statistics II**
*Prerequisite: Stat 510 or permission of instructor. II (3 credits)*

**525 (Math 525). Probability Theory**
*Prerequisite: Math 450 or Math 451 or permission of instructor. I, II (3 credits)*

**526. Discrete State Stochastic Processes**
*Prerequisite: Stat 525 (Math 525) or EECS 501 or permission of instructor. (3 credits)*

**531. Statistical Analysis of Time Series**
*Prerequisite: Stat 511 or permission of instructor. I, II (3 credits)*

**535 (IOE 562). Reliability**
*Prerequisites: IOE 316 and IOE 366 or Stat 425 and Stat 426. I (3 credits)*

**550 (IOE 560) (SMS 603). Bayesian Decision Analysis**
*Prerequisite: Stat 511 or permission of instructor. (3 credits)*

**560 (BioStat 685). Introduction to Non-parametric Statistics**
*Prerequisites: Stat 511, permission of the instructor. I, II (3 credits)*

**575 (Econ 775). Econometric Theory I**
*Prerequisites: Stat 425, Math 417; or Econ 654 and Econ 674 or permission of instructor. (3 credits)*

**576 (Econ 776). Econometric Theory II**
*Prerequisite: Econ 775 or the equivalent. II (3 credits)*

**600, 601. Advanced Topics in Applied Statistics I and II**
*Prerequisite: Stat 501 or permission. 600, I; 601, II (3 credits each)*

**606. Statistical Computing**
*Prerequisites: Calculus, Linear algebra, some knowledge of probability and statistics. II (3 credits)*

**610, 611. Advanced Mathematical Statistics I and II**
*Prerequisites: Stat 620, 621 or Math 601 and Stat 510, 511, 610. I; 611. II (3 credits each)*

**620. Theory of Probability I**
*Prerequisite: Math 451 or the equivalent. I (3 credits)*

**621. Theory of Probability II**
*Prerequisite: Stat 620. II (3 credits)*

**625, 626 (Math 625, 626). Probability and Random Processes I and II**
*Prerequisite: Math 601 for I; Stat 625 for II (3 credits each)*

**628, 629. Probability**
*Prerequisites: Stat 625, Stat 628, I; Stat 629, II (3 credits each)*

**630. Topics in Applied Probability**
*Prerequisite: Stat 526 or Stat 626. I (3 credits)*

**631. Advanced Time Series Analysis**
*II (3 credits)*

**645 (IOE 645) (Mfg 645). Topics in Reliability and Maintainability**
*Prerequisites: Stat 526 (IOE 515) and Stat 535 (IOE 562). II (alternate years) (3 credits)*

*The University of Michigan, in cooperation with the armed services of the United States, provides an opportunity for all eligible male and female students to earn a commission in any of the three services (Army; Navy, including Marine Corps; and Air Force) upon completion of the degree requirement. This opportunity is available through enrollment in the Military Officer Education Program (MOEP), which is known nationally as the Reserve Officers Training Corps (ROTC).*

## Military Officer Education Programs

All three officer education programs (Army, Navy, and Air Force) offer four- and two-year program options, financial benefits, and scholarship opportunities. Minor variations, however, do exist among the programs, and students should consult the specific information under the respective program.

### Financial Benefits

All students enrolled in advanced (junior and senior year) officer education courses, whether or not on scholarship, receive a monthly stipend of $200 for the academic year. A uniform and the necessary books and equipment are furnished to all students. In addition, pay and travel allowances are provided for attendance at summer field training courses.

### Scholarships

In addition to the financial benefits provided for all students enrolled in the advanced courses, a limited number of two-, three-, and four-year merit-based scholarships are awarded on a competitive basis by each of the Officer Education Programs. These scholarships provide tuition, laboratory fees, full payment for required books, and a $200 monthly stipend.

### Course Election by Non-Program Students

Officer education courses are also open to University students not enrolled in the program by permission of the instructor.

## Air Force Officer Education Program

Program Office
Room 154, North Hall
764-2403
Chair: Colonel John Garghan II
Faculty: Major Young, Major Munford, and Captain McCall

Students who enroll as cadets in the Air Force Officer Education Program, which is known nationally as the Air Force Reserve Officers Training Corps (AFROTC), successfully complete the program and receive a University degree are commissioned as Second Lieutenants in the United States Air Force.

### Career Opportunities

Men and women can serve in a wide range of technical fields such as meteorology, research and development, communications and electronics, engineering, transportation, logistics, and intelligence as well as in numerous managerial and training fields such as administrative services, accounting and finance, personnel, statistics, manpower management, education and training, investigation, and information services. There are also opportunities in the pilot, navigator, space operations, and missile career fields. Advanced education or technical training for these career areas may be obtained on active duty at Air Force expense.

### Four-Year and Two-Year Programs

The four-year program consists of eight terms (16 credit hours) of course work. The first terms (freshman and sophomore years) comprise the General Military Course (GMC). No military obligation is incurred during the freshman year for AFROTC scholarship recipients and none during the freshman or sophomore years for non-scholarship AFROTC students. During the summer following the GMC, students are required to attend a four-week field training session. After completing field training, students enroll in the last four terms (junior and senior years) of AFROTC called the Professional Officer Course (POC). Once students attend the first POC class, they assume a contractual obligation to complete the program, accept a commission, and discharge the military service obligation.

The two-year program is for junior-level college students or graduate students with a two-year degree program who have not participated in the GMC but want to enter the POC. Application for the two-year program should be made by November 1 of the student's sophomore year. Students must attend a six-week field training session prior to entering the POC. Once they attend the first class, these students incur the same obligation as four-year program students.

### Financial Benefits and Scholarships

For a detailed description of the available financial benefits and scholarships, consult the appropriate sections in the general introduction to the Military Officer Education Programs.

### Course of Study

Students enroll in one course in Aerospace Studies (AS) during each term of participation in the program for a total of 16 credit hours.

- Basic course sequence (first and second year): Aerospace Studies 101, 102, 201, 202 (4 hours).
- Advanced course sequence (third and fourth years): Aerospace Studies 310, 311, 410, 411 (12 hours).

This sequence of courses attempts to develop an understanding of the global mission and organization of the United States Air Force, of the historical development of air power and its support of national objectives, of concepts of leadership, management responsibilities and skills, of national defense policy, and of the role of the military officer in our society.

### Flying Activities

Cadets who are chosen for pilot training, based on the physical and mental requirements, will receive up to 50 hours of dual and solo flight instruction under the supervision of an Air Force introductory flight course usually between their junior and senior years.

### Military Obligation

After being commissioned, graduates of the program will be called to active duty with the Air Force in a field usually related to their academic degree program. The period of service is four years for non-flying officers, eight years for navigators after completion of navigator training, and ten years for pilots after completion of flight training.

### Air Force Officer Education Course Listings

(Subject = AERO)
Course descriptions are found on the College of Engineering web site at http://courses.engin.umich.edu/

**101. The Air Force Today**
*Prerequisite: none. I (1 credit)*

**102. The Air Force Today**
*Prerequisite: AS 101. II (1 credit)*

**201. Evolution of U.S. Air Power**
*Prerequisite: AS 102. I (1 credit)*

**202. Evolution of U.S. Air Power**
*Prerequisite: AS 201. II (1 credit)*

**310. Air Force Leadership and Management**
*Prerequisite: AS 202. I (3 credits)*

**311. Air Force Leadership and Management**
*Prerequisite: AS 310. II (3 credits)*

**410. National Security Forces in Contemporary American Society**
*Prerequisite: AS 311. I (3 credits)*

**411. National Security Forces in Contemporary American Society**
*Prerequisite: AS 410. II (3 credits)*

**Note:** *A Leadership Laboratory (0 credit), meeting for one-and-one-half hours each week, accompanies each of the above-listed courses.*

## Army Officer Education Program

Program Office: Room 131, North Hall
764-2400, 764-2401; Scholarships: 647-3029
Chair: Lieutenant Colonel Lucier
Assistant Chair: Major Mohammed, email: halimoha@umich.edu

Upon graduation and completion of program requirements, students receive a commission as second lieutenant in the United States Army Reserve or in the Active Army.

### Career Opportunities

Graduates may request active duty in the Army as commissioned officers, or choose reserve duty service in the Army National Guard or Army Reserve in order to pursue a civilian career or graduate schooling.

Active duty officers are available for worldwide assignment. Service in the Army's 97 career specialties provides an opportunity to gain extensive management experience.

### Four-Year, Three-Year, and Two-Year Programs

Students may choose one of three program options as described in the general introduction to the Military Officer Education Programs. All programs include a five-week advanced summer camp at an Army post, which is taken as part of the advanced course sequence normally between the junior and senior years. The first two years of the four-year program can be taken without an obligation to the Army.

Students who intend to enroll in the two-year program should contact the chairman by February of their sophomore year to apply for attendance at a five-week summer basic camp before enrollment in the program the following fall term. Two-year candidates must have a total of two years of school remaining at the undergraduate and/or graduate level. Students with prior military service (or prior ROTC training) may enroll in the program with advanced standing.

### Financial Benefits and Scholarships

Army ROTC scholarships are merit-based and provide partial-to-full tuition and partial book fees. All advanced course students receive a $200/month stipend to help cover room and board. Engineering students may request an additional year of scholarship benefits if they are enrolled in a five-year program.

### Simultaneous Membership Program

Non-scholarship students can choose to join a Reserve or National Guard unit of their choice while enrolled at the University. The student trains as an officer trainee, gaining valuable leadership training as a member of the Reserve Forces and can collect over $1,100 per year in addition to the $200/month stipend previously mentioned.

### Branch Assignments

In their last year, cadets are classified for branch assignments to one of the following 16 branches of the Army in accordance with their personal preference, aptitude, academic background, and the needs of the Army: Corps of Engineers, Signal Corps, Aviation, Armor, Field Artillery, Air Defense Artillery, Adjutant General's Corps, Military Intelligence, Finance Corps, Infantry, Medical Service Corps, Military Police Corps, Ordnance Corps, Quartermaster Corps, Transportation Corps, and Chemical Corps.

### Course of Study

Students enroll in one course in Military Science (MS) during each term of participation in the program for a total of 12 credit hours distributed as follows:

- Basic Course sequence (first and second years): Military Science 101, 102, 201, 202 (4 hours total).
- Advanced Course sequence (third and fourth years): Military Science 301, 302, 401, 402 (8 hours total).

The complete course of instruction includes professional ethics, professional writing and briefing, principles of military leadership, staff management principles, military justice, and tactics. In addition to the classroom courses, students participate in Leadership Laboratories (one 90 minute period per week). Training includes orienteering, rappelling, marksmanship, land navigation, and physical training. In addition, courses in human behavior, effective writing, mathematics, computer science, and military history are required for completion of the program.

### Military Obligation

Students may request non-active duty assignments in the Army Reserve or National Guard in order to pursue graduate schooling or civilian careers; or they may request a limited period of active duty. All Advanced Course students are obligated to eight years of service which may be served in an active or reserve status depending on individual preference and Army needs. No obligation is incurred during the freshman and sophomore years.

**Note:** A Leadership Laboratory (0 credit), meeting for one and one-half hour each week, accompanies each of the above listed MS courses.

### Army Officer Education Course Listings

(Subject = MILSCI)

Course descriptions are found on the College of Engineering web site at http://courses.engin.umich.edu/

**101. Introduction to Officership**
*Prerequisite: none. (1 credit)*

**102. Introduction to Leadership**
*Prerequisite: none. (1 credit)*

**103. Leadership Laboratory**
*Prerequisite: none. (1 credit)*

**201. Military Leadership**
*Prerequisite: none. (1 credit)*

**202. History of the Military Art**
*Prerequisite: none. (1 credit)*

**301. Leading Small Organizations I**
*Prerequisite: permission of Chairman. (2 credits)*

**302. Leading Small Organizations II**
*Prerequisite: permission of Chairman. (2 credits)*

**401. Leadership Challenges and Goal-Setting**
*Prerequisite: permission of Chairman. (2 credits)*

**402. Military Professionalism and Professional Ethics**
*Prerequisite: permission of Chairman. (2 credits)*

## Navy Officer Education Program

Program Office: Room 103, North Hall, 764-1498
Commander Roper; Lieutenants Godsil, Fullan, Murphy, and Zook; Captain Bartolotto, USMC

Students enrolled as midshipmen in the Navy Officer Education Program who successfully complete the program and receive a university degree are commissioned as officers in the United States Navy or Marine Corps.

### Career Opportunities

Graduates of the program have a wide range of job and career opportunities as commissioned officers in the Navy or Marine Corps. Navy officers may choose duty in surface ships, aviation, submarines, or nursing. Marine Corps officers may choose aviation, infantry, armor, or artillery specialties. After graduation, all commissioned officers receive additional training in their chosen field.

### Program Length

The program normally includes eight terms of course work. A military obligation is incurred at the beginning of the sophomore year for scholarship students. Non-scholarship students may enroll in the College Program and take normal ROTC courses, but without incurring a military obligation. College Program students are considered for scholarship each year; selections are made based on university academic performance.

### Financial Benefits and Scholarships

Scholarships cover tuition, lab fees, books, uniforms, and a monthly stipend, for a length of two to five years of study. For a more detailed description of the available financial benefits and scholarships, consult the appropriate sections in the general introduction to the Military Officer Education Programs. Additionally, the Navy awards scholarships for study at the University of Michigan to students chosen on the basis of selections made by a national committee. Criteria for eligibility vary among the several programs offered. Details are available from the program chair.

### Course of Study

Students enroll in Naval Science (NS) courses during each term of participation in the program. In addition, all students are required to elect college course work in calculus, physics, and other Navy required courses. Students also participate in a four- to six-week summer training exercise during the periods between academic years.

### Military Obligation

Depending on the program in which they are enrolled, graduates have a four or five year active duty service obligation. Those who are selected for additional education may incur an additional service obligation upon completion of that training.

### Navy Officer Education Course Listings

(Subject = NAVSCI)
Course descriptions are found on the College of Engineering web site at http://courses.engin.umich.edu/

**101. Introduction to Naval Science**
*Prerequisite: none. I (2 credits)*

**102. Seapower and Maritime Affairs**
*Prerequisite: none. II (2 credits)*

**201 (NA 102). Introduction to Ship Systems**
*Prerequisite: none. I (3 credits)*

**202 (EECS 250). Electronic Sensing Systems**
*Prerequisite: Physics 240 or EECS 230. II (3 credits)*

**301 (Astron 261). Navigation**
*Prerequisite: none. I (3 credits)*

**302. Naval Operations**
*Prerequisite: none. II (3 credits)*

**402. Leadership and Ethics**
*II (2 credits)*

**410. Amphibious Warfare**
*Prerequisite: none. (3 credits)*

**Note:** *The courses listed herein are offered primarily for the students participating in the program; however, they are open to, and may be taken by, any University enrolled student.*

*Students who are candidates for the M.S. and M.S.E. degrees, the post-Master's Professional Engineering degree, or the Ph.D. degree are enrolled in the Horace H. Rackham School of Graduate Studies; it's Bulletin should be consulted for complete information.*

*The Master of Engineering degree and the Doctor of Engineering in Manufacturing degree are offered through the College of Engineering.*

*Anyone contemplating graduate work should consult with the program advisor for the desired program. Information on graduate programs by department is in this Bulletin.*

### Admissions Information

Depending on which degree you seek, your application will be made either to the Horace H. Rackham School of Graduate Studies, or to the College of Engineering.

## Graduate Degree Options

The University of Michigan College of Engineering offers the following graduate degree programs throughout 11 departments and three programs:
Master of Science (M.S.)
Master of Science in Engineering (M.S.E.)
Master of Engineering (M.Eng.)
Doctor of Philosophy (Ph.D.)
Doctor of Engineering (D.Eng.)

### Departments

Aerospace Engineering
Atmospheric, Oceanic and Space Sciences
Biomedical Engineering
Chemical Engineering
Civil and Environmental Engineering
Electrical Engineering and Computer Science
Industrial and Operations Engineering
Materials Science and Engineering
Mechanical Engineering
Naval Architecture and Marine Engineering
Nuclear Engineering and Radiological Sciences

### Programs

InterPro: Interdisciplinary Professional Programs:
- Automotive Engineering
- Financial Engineering
- Pharmaceutical Engineering
- Plastics Engineering

Program in Manufacturing
Applied Physics
Macromolecular Science and Engineering

## Horace H. Rackham School of Graduate Studies

### The Horace H. Rackham School of Graduate Studies administers the following graduate programs:

Master of Science (MS)
Master of Science in Engineering (MSE)
Professional Engineer
Doctorate of Philosophy (Ph.D.)

Application materials should be sent to the individual department to which you are applying and to:
*Office of Graduate Admissions*
*Rackham Graduate School*
*915 East Washington, Room 106*
*Ann Arbor, Michigan 48109-1070*

For questions regarding the application process or to obtain an application packet please contact Rackham at 734-764-8129.

To obtain detailed information on the Rackham admissions process for both domestic and international students go on line to www.rackham.umich.edu/Admis/appadm.html.

To obtain an on line application go to www.rackham.umich.edu/Admis/rackhamalt.html or you may complete the e-mail request form for application materials at www.rackham.umich.edu/Request.html

### Master of Science/Master of Science in Engineering

The master of science and master of science in engineering degrees represent mastery of some discipline in the College of Engineering. They require 30 credits of course work, taken predominantly from the area of study. Some programs involve theses or internships. Others require only coursework.

### Professional Engineering Degrees

The professional engineering degree programs require a minimum of 30 credit hours of work beyond the Master of Science in Engineering level or its equivalent, taken at this University with a grade of "B" or better. Successful completion of a qualifying examination for admission to candidacy is required.

### Doctor of Philosophy – Ph.D.

The doctoral degree is conferred in recognition of marked ability and scholarship in a chosen field of knowledge. A part of the work consists of regularly scheduled graduate courses of instruction in the chosen field and in such cognate subjects as may be required by the committee. In addition, the student must pursue independent investigation in a subdivision of the selected field and must present the results of the investigation in the form of a dissertation.

A student becomes an applicant for the doctorate when admitted to the Horace H. Rackham School of Graduate Studies and accepted in a field of specialization. Candidacy is achieved when the student demonstrates competence in his her broad field of knowledge through completion of a prescribed set of courses and passing a comprehensive exam.

There is no general course or credit requirement for the doctorate. In most areas, a student must pass a comprehensive examination in a major field of specialization and be recommended for candidacy for the doctorate. A special doctoral committee is appointed for each applicant to supervise the work of the student both as to election of courses and in preparation of the dissertation.

Requirements regarding foreign language and non-technical courses are left to individual departments or programs, and to the Graduate School. A prospective doctoral student should consult the program advisor for specific details.

## College of Engineering

The College of Engineering administers the following graduate programs:
Master of Engineering (MEng)
Doctorate of Engineering in Manufacturing (DEng)

### Master of Engineering – M.Eng.

The College of Engineering offers the master of engineering degree as a professional, practice-oriented degree, designed to further the education of engineers who have practical experience in industry, and plan to return to industry after completion of their selected program. This degree can be completed in one calendar year (12 months). Programs are organized around a team-project experience with industry.

Information on these programs can be requested by sending an e-mail to: engin.pro.prgms@umich.edu. Applications may also be obtained by contacting the individual departments or by calling 734-647-7024.

Application materials should be sent to:

*Admissions Officer*
*Center for Professional Development*
*2121 Bonisteel Boulevard, Room 273*
*Ann Arbor, Michigan 48109-2092*

### Doctorate of Engineering in Manufacturing (DEng)

The Doctor of Engineering in Manufacturing is a graduate professional degree in engineering for students who have already earned a B.S.E. degree and an M.S.E. degree in any engineering discipline; or a Master of Business Administration.

To obtain detailed information on the DEng admissions process for both domestic and international students go on line to http://pim.engin.umich.edu/.
Applicants may also call 734-6476-7024.

Application materials should be sent to:

*Admissions Officer*
*Center for Professional Development*
*2121 Bonisteel Boulevard, Room 273*
*Ann Arbor, Michigan 48109-2092*

### Application Status

Some departments or programs review applications on a rolling basis as applications are received; others review applications on a scheduled basis. Before contacting the department or program please allow at least three weeks for processing.

### Admissions Criteria

Contact individual departments or programs for specific admissions criteria. Admission is usually determined by an evaluation of the following:
• Transcript of your academic record
• Recommendations from three faculty members who have supervised your course work or research

• Graduate Record Examination (GRE); test scores must be taken within five years of application (NOTE: required for Ph.D. candidates, check with individual departments for specific requirements for Master's students).
• Written description of your graduate study objectives
• Test of English as a Foreign Language (TOEFL), or the Michigan English Language Assessment Battery (MELAB), for applicants who studied at an institution that did not teach English as a second language, or for whom English is not their native language

### Five-Year Combined BSE/Masters Programs

In many fields, the Master's degree is rapidly becoming the entry level requirement for engineering graduates seeking employment. The College of Engineering, therefore, offers two different options for those students who wish to obtain a Bachelor's and Master's degree simultaneously. Both of these options are academically demanding and require recommendation from the student's undergraduate program advisor.

The Engineering Global Leadership (EGL) Honors program is currently available in the Mechanical and Industrial and Operations Engineering Departments with diverse master's options upon conclusion of the BSE (ME) or BSE (IOE). For those students interested in building a global perspective into their academic plan, the EGL program is a rigorous program with at least a 3.6 core GPA admission requirement. Students maximize their humanities/social sciences and free and non-technical electives, in order to complete business and cultural cores, in addition to their departmental and core degree requirements. See the EGL program description below for details.

The five-year Simultaneous Graduate/Undergraduate Study (SGUS) program permits students who enter the program in the second term of their junior year, to receive the BSE and MSE degrees (or the BSE and MEng degrees), upon completion of a minimum of 149 credit hours. SGUS program options are available in almost every department. In addition to pursuing BSE and Masters' degrees within the same department, there are also options to pursue BSE and Master's degrees in differing departments. See the SGUS description below for more details.

### The Engineering Global Leadership Honors Program

The Engineering Global Leadership Honors Program (EGL) combines the traditional engineering undergraduate curriculum with a core of courses in the School of Business Administration, and a cultural core leading to both a Bachelor of Science in Engineering and a Masters degree in five years (typically).

Employers tell us that the two gaps most affecting their competitiveness are the inabilities of most professionals to communicate across the engineering and business boundary, to operate comfortably in another culture. This Honors program is designed to educate students capable of bridging both of these gaps. The business core teaches engineers the rudiments of marketing, accounting, and finance, and the cultural core teaches the language, history and customs of a student-selected region of the world of competitive importance to the US. Career placement, and salaries tell us that students with this training are in high demand.

The program is currently available in the departments of Industrial and Operations Engineering and Mechanical Engineering. The following EGL tracks are possible:
-BSE ME/MEng Mfg
-BSE IOE/MSE IOE
-BSE ME/MSE IOE
-BSE IOE/MS Financial Engineering
-BSE IOE/MEng Mfg

*Requirements*
The program requirements include:
24 (IOE EGL) or 20 (ME EGL) credits of coursework in humanities/social sciences
12 of these credits must be associated with the cultural core
8 credit hours of a 2nd year language
12 credit hours of business-related courses
a synthesis project that places student learning in an industry context

The EGL honors program is extremely rigorous —

admissions requirements range from a 3.6 for IOE students to a 3.75 for some ME EGL students. Those admitted to the program will be expected to earn a minimum of 16 credits per semester.

For more information and an application contact:
*Melissa Eljamal*
*245A Chrysler Center*
*2121 Bonisteel Boulevard*
*Ann Arbor, MI 48109*
*(734) 647-7028*
*eljamalm@engin.umich.edu*

### Simultaneous Graduate/Undergraduate Study (SGUS)*

The five-year Simultaneous Graduate/Undergraduate Study (SGUS) program permits students who enter the program in the second term of their junior year, to receive the BSE and MSE degrees (or the BSE and MEng degrees) upon completion of a minimum of 149 credit hours. The baccalaureate may be awarded upon completion of the undergraduate requirements or concurrently with the Master's degree. Students apply to the SGUS program early in the second semester of their junior year. Recommendation from the appropriate Undergraduate Program Advisor is required, and the standard department graduate admission process is used. SGUS admissions requirements will vary; interested students should contact the department in which they would like to pursue graduate study.

*This section includes some information on Concurrent Undergraduate Graduate Studies Program (CUGS).

## SGUS

### BSE in Aerospace Engineering/MSE in Aerospace Engineering

Students enrolled in the College of Engineering who complete 90 credit hours toward the BSE degree in Aerospace Engineering, and who meet all other conditions required for admission as determined by the Department Graduate Committee, may apply for, and be granted admission to, the combined bachelor's/master's program. Please contact the Aerospace Engineering department for more complete information.

*Web site: www.engin.umich/dept/aero*
*Contact: Margaret Fillion*
*Office: Aerospace Engineering Dept., 3054 FXB*
*Phone: (734) 764-3311*
*Advisor: Professor Anthony Waas*

### BSE in Chemical Engineering/MS Biomedical Engineering
### BSE in Electrical Engineering/MS Biomedical Engineering
### BSE in Industrial and Operations Engineering/ MS Biomedical Engineering
### BSE in Materials Science and Engineering/ MS Biomedical Engineering
### BSE in Mechanical Engineering/MS Biomedical Engineering
### BSE in Nuclear Engineering and Radiological Sciences/MS Biomedical Engineering

This SGUS program is open to all undergraduate students from the above areas who have achieved senior standing (85 credit hours or more), and have an overall cumulative GPA of 3.2 or higher. Please contact the Department of Biomedical Engineering for more complete program information.
*Web site: www.bme.umich.edu*
*Contact: Susan Bitzer*
*Office: 3304 G.G. Brown*
*Phone: (734) 764-9588*
*Advisor: Professor James Grotberg*

### BSE in Chemical Engineering/MSE in Chemical Engineering

A University of Michigan undergraduate with a GPA of 3.5 or greater may apply, during the second term of the junior year, for admission to the departmental SGUS combined degree program leading to both the baccalaureate and master's degrees. Up to 9 hours of prior approved elective coursework may be applied toward both degrees (typically leading to a total of 128 for the BSE plus 30 for the MSE) for 149 total credit hours. The 9 double counted elective credits must be acceptable for Rackham credit, and must include at least two courses appropriate for Rackham Graduate School cognate credit. The 21 chemical engineering graduate credits may include up to 6

hours of ChemE 698 (directed study or practical training under faculty supervision), or ChemE 695 (research). Please contact the Chemical Engineering department for more complete program information.
*Web site: www.engin.umich.edu/dept/cheme*
*Contact: Susan Hamlin*
*Office: Program Office,*
*3074C H.H. Dow*
*Phone: (734) 763-1148*
*Advisor: Professor Robert Ziff*

### BSE in Civil and Environmental Engineering/ MSE in Civil Engineering

The program is open to all Civil and Environmental Engineering undergraduate students, who have completed 80 or more credit hours with a cumulative GPA of at least 3.5, and who have selected an area of concentration. Students who do not meet the GPA requirements may petition the Civil and Environmental Engineering Graduate Committee for admission. Please contact the Civil and Environmental Engineering department for more complete program information.
*Web site: www.engin.umich.edu/dept/cee*
*Contact: Chauna Meyer*
*Office: Program Office,*
*2340 G.G. Brown*
*Phone: (734) 764-8495*
*Advisor: Professor Steven J. Wright*

### BSE in Civil and Environmental Engineering / MSE in Construction Engineering and Management

The program is open to all Civil and Environmental Engineering undergraduate students who have completed 80 or more credit hours, with a cumulative GPA of at least 3.5. Students who do not meet the GPA requirement may petition the Civil and Environmental Engineering Graduate Committee for admission. Please contact the Civil and Environmental Engineering department for complete program information.
*Web site: www.engin.umich.edu/dept/cee*
*Contact: Chauna Meyer*
*Office: Program Office,*
*2340 G.G. Brown*
*Phone: (734) 764-8495*
*Advisor: Professor Robert I. Carr*

### BSE or BS in one of the EECS programs or Computer Science/MSE or MS in one of the Electrical Engineering and Computer Science (EECS) programs

The program is a Concurrent Undergraduate/Graduate Studies Program (CUGS) through Rackham, that is open to all EECS and Computer Science undergraduates, who have completed 85 or more credit hours with a cumulative GPA of at least 3.6. Please contact the EECS Department for more complete program information.
*Web site: www.eecs.umich.edu*
*Contact: EECS Graduate Office,*
*3314 EECS*
*Phone: (734) 764-2390*

### BSE in Chemical Engineering/ MSE in Environmental Engineering

The program is open to all Chemical Engineering undergraduate students, who have completed 75 or more credit hours, with a cumulative GPA of at least 3.5. Students who do not meet the GPA requirement may petition the Civil and Environmental Engineering Graduate Committee for admission. Please contact the Environmental and Water Resources Engineering Program Office in the Civil and Environmental Engineering department for more complete program information.
*Web site: www.engin.umich.edu/dept/cee*
*Contact: Chauna Meyer*
*Office: Program Office, 116 EWRE*
*Phone: (734) 764-8495*
*Advisor: Professor Steven J. Wright*

### BSE in Materials Science and Engineering/ MSE in Materials Science and Engineering

Students should apply to the program in the second term of their junior year for provisional admission into the program, in order to be advised appropriately regarding planning for undergraduate and graduate course selections. No dual enrollment will be required. Other requirements include a minimum

undergraduate grade point average of 3.2 for provisional admission and subsequent enrollment into the SGUS program in Materials Science and Engineering. A maximum of 9 credits of prior approved course work may be double counted. A maximum of 15 credit hours that are double counted or transferred for graduate credit may be allowed. Double counting of required undergraduate courses are not allowed, but courses elected to meet technical or free elective BSE requirements may be allowed. Contact the Materials Science and Engineering department for more complete program information.
*Web site: mseweww.engin.umich.edu*
*Contact: Renee Hilgendorf*
*Office: 2168 H.H. Dow Building*
*Phone: (734) 763-9790*

### BSE in Nuclear Engineering and Radiological Sciences/MSE in Nuclear Engineering and Radiological Sciences

This program is open to all Nuclear Engineering and Radiological Sciences (NERS) undergraduate students who have completed 85 or more credit hours. All NERS undergraduates are eligible to apply for admission to this program during the second semester of their junior year. Recommendation of the Undergraduate Program Advisor is required, and the standard Rackham graduate application process is followed. All undergraduate students with a minimum cumulative GPA of 3.3 would be automatically accepted into the simultaneous degree program. Applications of students who do not meet the required GPA will be reviewed by the NERS Graduate Admission Committee.
*Web site: www.engin.umich.edu/dept/nuclear*
*Contact: Pam Derry*
*Office: 1919 Cooley*
*Phone: (734) 936-3130*
*Advisor: Professor Ronald M. Gilgenbach*

### BSE in Civil and Environmental Engineering/ MEng in Construction Engineering and Management

The program is open to all Civil and Environmental Engineering undergraduate students who have completed 80 or more credit hours with a cumulative GPA of at least 3.5. Students who do not meet the GPA requirement may petition the Civil and Environmental Graduate Committee for admission. Please contact the Civil and Environmental Engineering department for more complete program information.
*Web site: www.engin.umich.edu/dept/cee*
*Contact: Chauna Meyer*
*Office: Program Office,*
*2340 G.G. Brown*
*Phone: (734) 764-8495*
*Advisor: Professor Robert I. Carr*

### MEng Manufacturing

M.Eng in Manufacturing in combination with one of the following undergraduate degrees:
BSE in Aerospace Engineering
BSE in Chemical Engineering
BSE in Civil and Environmental Engineering
BSE in Electrical Engineering and Computer Science
BSE in Industrial and Operations Engineering
BSE in Materials Science and Engineering
BSE in Mechanical Engineering
BSE in Naval Architecture and Marine Engineering

The Program in Manufacturing (PIM) offers SGUS programs leading to the above degrees. These are the eight engineering departments that participate in the interdisciplinary PIM. These programs are open to all undergraduates in these departments who have completed 80 or more credits of course work with a GPA of 3.2 or better, and at least two part- or full-time industrially relevant work experiences (e.g., summer internships or coop experience). Students who meet these criteria must apply to PIM during the second semester of their junior year for admission to the program. A listing of the program requirements is available in the PIM office, 2219 G.G. Brown Building. Students establish their course selections in consultation with their advisor.
*Web site: www.engin.umich.edu/dept/pim*
*Contact: Henia Kamil*
*Office: 1539 H.H. Dow (mezzanine)*
*Phone: (734) 764-3312*
*Advisor: Professor Debasish Dutta*

### BSE/MSE in Naval Architecture and Marine Engineering
### BSE/MEng in Concurrent Marine Design

This program permits outstanding Naval Architecture and Marine Engineering students to receive the BSE and MSE (or the BSE and MEng) degrees after completing a minimum of 149 credit hours. The student benefits from the continuity of study, and the inefficiencies of transferring from an undergraduate to a graduate program are eliminated. The program allows junior year students with a 3.2 or better GPA, to apply early in the second semester of their junior year (once 55 credit hours have been completed), for a simultaneous graduate/undergraduate program, which allows them to double count up to 9 credits of technical or free electives. In consultation with their advisor, students select technical electives that will be relevant to the master's program of study. Students are admitted using the normal department graduate admission process, with the admission standards required for expected successful completion of the program. Recommendation from the Undergraduate Program Advisor is required. Please contact the Naval Architecture and Marine Engineering department for more complete program information.

*Web site: www.engin.umich.edu/dept/name*
*Contact: Celia Eidex*
*Office: 221 NAME*
*Phone: (734) 936-0566*
*Advisor: Professor Michael G. Parsons*

# AEROSPACE ENGINEERING

*Margaret Fillion (mafn@umich.edu)*
*Graduate Advisor: Professor Anthony Waas*
*3057 François-Xavier Bagnoud Building*
*(dcw@umich.edu)*
*1320 Beal Avenue*
*Ann Arbor, Michigan 48109-2140*
*(734) 615-4406*
*(734) 763-0578 fax*
*www.engin.umich.edu/dept/aero*

## Graduate degrees

Master of Science in Engineering (M.S.E.) in Aerospace Engineering

Master of Engineering (M.Eng.) in Space Systems

Doctor of Philosophy (Ph.D.) in Aerospace Engineering

### M.S.E. in Aerospace Engineering

This degree is designed for students who desire a curriculum that is focused on the scientific aspects of Aerospace Engineering. A total of 30 credit hours is required (typically 10 classes). Of these, 15 credit hours must be 500-level classes in Aerospace Engineering, and 6 credits must be from approved courses in Math. A thesis is optional. Consult the official university publications for specific degree requirements. An MSE degree is required to continue for the Ph.D. degree.

Admission requirements include a strong performance in an undergraduate program in engineering or science and submission of acceptable GRE scores. Students have substantial flexibility in selecting courses, but courses must be approved by a Graduate Advisor.

Students are strongly encouraged to consult with faculty in their intended areas of specialization to discuss the composition of their program.

### M.Eng. in Space Systems (MEngSS)

The MEngSS provides a comprehensive set of courses and training in space-related science and the systems approach to designing and managing complex space systems. The M.Eng. in Space Systems requires 30 credits of course work, of which 18 must be at the 500-level or higher and 24 must be graded (not P/F). Course elections must include:

- Depth in a main discipline (9 hrs) For example, an electrical engineering undergraduate could select control and communications; an aerospace undergraduate could select structures or propulsion.
- Breadth by crossing engineering/science boundaries (9 hrs)
- Systems engineering (6 hrs)
- Team design experience (6 hrs)

### Ph.D. in Aerospace Engineering

Study towards the Ph.D. degree requires a strong background in an area of specialization and an ability to carry out independent research. Students must complete, in order:

*Precandidacy Status*
A student must apply for and be admitted to precandidacy status before taking the Preliminary Exam. A student must have completed (or be completing the final term of) an MSE degree and should have a G.P.A. above 6.5 out of 9.0 (equivalent to 3.5/4.0) in relevant courses. Admission is determined by the Graduate Committee. Students who have a master's degree when admitted may be granted precandidacy status upon admission. Application for precandidacy status should be made during the second semester of the MSE degree.

*Preliminary Exam*
To become a PhD candidate, a student must demonstrate a high level of competency by passing a Preliminary Exam. To take the exam the student must be accepted as a Precandidate and have had research experience as a Research Assistant or have completed successfully three credits of directed study (AE 590) supervised by a faculty member in the department. Precandidates must be registered in the department during the term in which the exam is taken.

*Candidacy*
Candidacy status is achieved upon successful completion of the Preliminary Exam, Rackham cognate requirements, and 36 fee hours which may include AE 900 (Dissertation/Precandidate). Students are admitted to Candidacy who, in the view of the faculty, have a good chance of completing the PhD program.

*Ph.D. Degree*
The Ph.D. degree is awarded upon successful completion of a Ph.D. dissertation, a Ph.D. defense, and an overall accumulation of 68 fee hours. See the *Rackham Student Handbook* for details. There is no foreign language requirement, and there are no specific course

requirements. Students should have taken a minimum of 16 graduate courses beyond the bachelor's degree.

*The Dissertation*
The student must carry out original research, present a written dissertation, and defend the dissertation at a final defense. The research is done under the supervision of a faculty adviser in the Aerospace Engineering department and a dissertation committee. Students are encouraged to begin research in the first year of graduate study.

## Fields of Study

### Propulsion, Aerodynamics and Combustion

*Air-Breathing Propulsion and Combustion Science*
Fundamental classes are offered in fluid mechanics, combustion, and turbulent mixing. A graduate laboratory class is offered in high temperature gas dynamics. Applied propulsion classes include Rocket Propulsion and Turbojet Propulsion. Research covers the areas of laser-based flow visualization, velocity field imaging, holography, spray combustion, supersonic mixing, hydrogen combustion in a scramjet-like device, and soot formation.

*Space Propulsion*
Classes are offered in the areas of electric propulsion, space plasma physics, kinetic theory of rarefied gases, and the space environment. Ion thruster experiments employ spectroscopic methods in one of the most advanced university facilities. A specialized Masters of Engineering Degree in Space Systems is available.

*Aerodynamics and Turbulence*
Courses cover basic and advanced wing theory, boundary layers and aerodynamic drag, compressible high speed flows, effects of turbulence on drag and mixing, and a graduate-level laboratory. Research projects utilize flow visualization to study the fundamental nature of turbulent mixing and employ MEMS devices to control turbulence and aerodynamics.

*Computational Fluid Dynamics of Transonic and Hypersonic Vehicles*
Classes provide in-depth development of numerical algorithms. Research projects use these algorithms to model hypersonic re-entry, delta wings, solar wind on space vehicles, shock buffeting of transonic vehicles, and aeroacoustics.

### Structural Mechanics

*Advanced Materials for Airframe Applications*
Fundamental courses are offered in structural and solid mechanics that emphasize the basic knowledge required to address several contemporary topics in the design and analysis of aircraft and spacecraft structures. Areas of research include composite materials, composite structures, fracture mechanics, design of composite microstructures and novel instrumentation for probing materials.

*Adaptive Materials and Constitutive Modeling for Wings and Control Surfaces*
Advanced courses are offered that address structural and material instabilities found in aerospace structures and in advanced materials. Research includes theoretical and experimental studies of adaptive materials, such as shape memory alloys, and their application to smart structures.

*Aeroelasticity, Structural Dynamics, Optimal Design of Structures*
Courses focus on structural dynamics and aeroelasticity of fixed wing and rotary wing vehicles including finite element computations for optimal structural design. Research includes aeroelasticity and aeroservoelasticity of rotary- and fixed-wing vehicles. Optimal structural design of aerospace vehicles with multi-disciplinary constraints is pursued.

### Flight Dynamics and Controls

*Control of Aircraft*
Courses emphasize vehicle dynamics and performance, automatic control systems, sensors, and stochastic processes. One research project is the Uninhabited Aerial Vehicle. An unmanned aircraft with an on-board computer is being developed for search and rescue, meteorological data collection, and traffic monitoring.

*Intelligent Control of Spacecraft*
Control methods using neural networks and artificial intelligence are used to improve spacecraft pointing accuracy. Adaptive control methods are used for vibration suppression.

*Astrodynamics*
Courses in astrodynamics, guidance, and control prepare students for projects that include reorientation of spacecraft systems using reaction wheels and design of

autopilots, and exploring cometary atmospheres.

### Aerospace Vehicles

This area focuses on courses that deal with the behavior of the entire vehicle, such as aircraft, helicopters and spacecraft. Several courses emphasize large-scale system integration and multidisciplinary design aspects that play a key role in the development of modern rotary- and fixed-wing aircraft as well as spacecraft.

This area of activity has been reinforced recently with the establishment of the new FXB Center for Design of Rotary- and Fixed-Wing Air Vehicles, with Professor Friedmann as its director. Research activities in the Center are aimed at improving vehicle performance and reducing cost through innovative design. The Center also plays an important role in supporting the teaching of aerospace design in the Department. Current activities in the Center focus on rotary- and fixed-wing aeroelasticity, active control of vibration and flutter and noise reduction in helicopters. Eventually the Center will encompass a much broader range of activities.

## Facilities

The department's laboratories include subsonic and supersonic wind tunnels; shock and detonation tubes; laser diagnostic equipment; structural test and diagnostic equipment; and a wide range of optical, electronic, and computer diagnostic equipment. Students also gain experience in the use of computers for system design, and simulation.

**Note:** Please refer to pages 64-70 of this *Bulletin* for Aerospace Engineering course descriptions and a listing of Aerospace Engineering faculty.

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*2071 Randall Laboratory*
*Ann Arbor, Michigan 48109-1120*
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## Program Description

The quickening pace of development at the frontier between physics and engineering creates a need for interdisciplinary training and research which is not readily accommodated by traditional single-focus graduate programs. The University of Michigan Applied Physics Program is designed to fill this gap, providing students with the opportunity to gain a solid base in the fundamentals of modern physics while exploring applications in the context of various branches of engineering.

The program, which spans the Physical Science Division of the College of Literature Science and the Arts and the College of Engineering, offers graduate studies leading to the Doctor of Philosophy (Ph.D.) degree in Applied Physics. Coursework and research are structured to meet individual goals so that the program is appropriate for students intending to pursue careers in industry, academia, or government service.

From nonlinear optics to the latest developments in ultramicroscopy, Michigan has a distinguished record of innovation in applied physics. With a broad range of multidisciplinary research, and access to the most advanced facilities, the program offers a dynamic environment for graduate training. The opportunities and challenges for bridging science and technology have never been more exciting, nor the potential impact on our society's needs greater. The University of Michigan Applied Physics Program is committed to a leading role in this endeavor.

## Admission Criteria for the Ph.D. Degree

The Applied Physics Program is designed for students intending to pursue coursework and research leading to the Ph.D. degree. Accordingly, students are not admitted as candidates for the Master of Science degree. However, our students are usually eligible to receive a Masters degree in Applied Physics or Electrical Engineering at the time they become candidates for the Ph.D. degree.

A completed application and transcripts of all previous academic records must be on file.

The admission committee will take into account the applicant's background in the physical sciences, engineering physics and related disciplines. A good grounding in basic physics is expected with at least 15 hours of introductory and intermediate coursework in classical mechanics, statistical physics, electricity and magnetism, and quantum physics. Graduate Record Examination general scores are required and the GRE Subject Test in Physics is recommended. Three letters of recommendation must be submitted. At least two of the letters must be from an academic institution. Students from non-English-speaking countries are required to demonstrate proficiency in English via the TOEFL examination. The minimum score for admission is 560.

Applications will be processed for Fall term admission. The deadline for applications for financial aid consideration is February 1st.

## Requirements for the Ph.D. Degree

The curriculum leading to the Ph.D. degree in Applied Physics combines coursework in the fundamentals of physical theory, its applications to modern technology, and practical "hands-on" training in the research laboratories.

Applied Physics is administered as an intercollegiate degree program with participating faculty in the College of Literature Science and the Arts, and the College of Engineering. General admission and degree requirements are administered by the Horace Rackham Graduate School.

The program is normally four to five years with an emphasis on coursework during the first two years. Students are encouraged to become involved in research at the earliest opportunity and are required to complete a supervised research project in their first year. When students complete the basic academic core, have satisfied the qualification procedure (see below), have formed a Dissertation Committee, and have obtained approval for their Dissertation Prospectus, they are eligible for admission to Candidacy for the Ph.D. Candidacy is normally achieved after four or five semesters of graduate work.

## Candidacy

In order to achieve candidacy and form a dissertation committee, seven prescribed 500 level courses must be passed with a grade B or better. In addition, four elective courses (chosen in consultation with the program advisor according to the student's research needs) must be completed satisfactorily. Satisfactory completion of one four-credit hour course on non-thesis research is also required, under the supervision of a faculty member. Prior approval by the program committee must be obtained before beginning this supervised research course. All first, second, and third year students are required to enroll in the weekly seminar course (AP 514).

## Qualifying Procedure

The decision to qualify a student for Ph.D. study is based on the student's academic record, performance in a four-credit hour supervised research project, and the results of a two-part qualifying examination. The first part of the qualifying examination consists of a written examination on basic undergraduate-level physics. The second part of the qualifying examination is an oral examination, beginning with a brief presentation of the student's supervised research followed by questions on standard undergraduate-level physics. The student is expected to qualify within two years of entering the graduate program.

## Preliminary Examination

A preliminary examination of the plans for dissertation research will be made by the student's Dissertation Committee. The preliminary examination will take the form of a presentation to the committee of a Dissertation Prospectus stating the objectives and proposed methods of investigation. Over the signatures of the Dissertation Committee, the program committee will authorize the student to proceed with the thesis research.

Students normally will have formed their Dissertation Committee by the end of their fifth term in graduate school. Approval of the Dissertation Prospectus is a program requirement prior to Candidacy.

# Applied Physics Courses

**(Subject = APPPHYS)**

**AP 514. Applied Physics Seminar**
*Prerequisite: graduate studies. I, II (1 or 2 credits)*

Graduate seminars are required each term to familiarize students with current research and problems. Given by a mix of faculty, external lecturers, and the students themselves to acquaint students with the scope of research activity and opportunities, the goal of the seminar structure is to promote a strong interaction among the interdisciplinary work being done in applied physics.

**AP 518. (Elective) Microcomputers in Experimental Research**
*I (3 credits)*

A graduate-level laboratory course in the application of computers to experimental research, this course is designed to give students hands-on experience of modern techniques of data acquisition, data handling and analysis, and graphical presentation of results, using microcomputers. A number of experiments will be carried out which illustrate how to interface modern research instrumentation in a variety of commonlyencountered experimental situations.

**AP 530 (EECS 530). Electromagnetic Theory I**
*Prerequisite: EECS 330 or Physics 438. I (3 credits)*

Maxwell's equations, constitutive relations and boundary conditions. Potentials and the representation of electromagnetic fields. Uniqueness, duality, equivalence, reciprocity and Babinet's theorems. Plane, cylindrical, and spherical waves. Waveguides and elementary antennas. The limiting case of electro- and magneto-statics.

**AP 537 (EECS 537). Classical Optics**
*Prerequisite: EECS 330 and EECS 334. I (3 credits)*

Theory of electromagnetic, physical, and geometrical optics. Classical theory of dispersion. Linear response, Kramers-Kronig relations, and pulse propagation. Light scattering. Geometrical optics and propagation in inhomogeneous media. Dielectric waveguides. Interferometry and theory of coherence. Diffraction, Fresnel and Fraunhofer. Gaussian beams and ABCD law.

**AP 540 (EECS 540). Applied Quantum Mechanics I**
*Prerequisite: permission of instructor. I (3 credits)*

Introduction to nonrelativistic quantum mechanics. Summary of classical mechanics, postulates of quantum mechanics and operator formalism, stationary state problems (including quantum wells, harmonic oscillator, angular momentum theory and spin, atoms and molecules, band theory in solids), time evolution, approximation methods for time independent and time dependent interactions including electromagnetic interactions, scattering.

**AP 541 (EECS 541). Applied Quantum Mechanics II**
*Prerequisite: AP 540 or EECS 540. I (3 credits)*

Continuation of nonrelativistic quantum mechanics. Advanced angular momentum theory, second quantization, non-relativistic quantum electrodynamics, advanced scattering theory, density matrix formalism, reservoir theory.

**AP 546 (EECS 546). Ultrafast Optics**
*Prerequisite: EECS 537. II (3 credits)*

Propagation of ultrashort optical pulses in linear and nonlinear media, and through dispersive optical elements. Laser mode-locking and ultrashort pulse generation. Chirped-pulse amplification. Experimental techniques for high time resolution. Ultrafast Optoelectronics. Survey of ultrafast high field interactions.

**AP 550 (EECS 538) (Physics 650). Optical Waves in Crystals**
*Prerequisite: EECS 434. I (3 credits)*

Propagation of laser beam: Gaussian wave optics and the ABCD law. Crystal properties and the dielectric tensor; electro-optic effects and devices; acousto-optic diffraction and devices. Introduction to nonlinear optics: coupled mode theory and second harmonic generation; phase matching.

**AP 551 (EECS 539) (Physics 651). Lasers**
*Prerequisite: EECS 537 and EECS 538. II (3 credits)*

Complete study of laser operation: the atom-field interaction; homogeneous and inhomogeneous broadening mechanisms; atomic rate equations; gain, amplification and saturation; laser oscillation; laser resonators, modes, and cavity equations; cavity modes; laser dynamics, Q-switching and modelocking. Special topics such as femto-second lasers and ultrahigh power lasers.

### AP 552 (EECS 552). Fiber Optical Communications

*Prerequisite: EECS 434 or EECS 538 or permission of instructor. II odd years (3 credits)*

Principles of fiber optical communications and networks. Point-to-point systems and shared medium networks. Fiber propagation including attenuation, dispersion and nonlinearities. Topics covered include erbium-doped amplifiers, Bragg and long period gratings, fiber transmission based on solitons and non-return-to-zero, and time- and wavelength-division-multiplexed networks.

### AP 601 (Physics 540). Advanced Condensed Matter

*(3 credits)*

A unified description of equilibrium condensed matter theory (using Green's functions); critical phenomena, Anderson localization and correlated electron theory.

### AP 609 (EECS 638) (Physics 542). Quantum Theory of Light

*Prerequisite: quantum mechanics electrodynamics and atom physics. I even years. (3 credits)*

The atom-field interaction; density matrix; quantum theory of radiation including spontaneous emission; optical Bloch equations and theory of resonance fluorescence; coherent pulse propagation; dressed atoms and squeezed states; special topics in nonlinear optics.

### AP 611 (EECS 634) (Physics 611). Nonlinear Optics

*Prerequisite: EECS 537 or EECS 538 or EECS 530. I (3 credits)*

Formalism of wave propagation in nonlinear media; susceptibility tensor; second harmonic generation and three-wave mixing; phase matching; third order nonlinearities and four-wave mixing processes; stimulated Raman and Brillouin scattering. Special topics: nonlinear optics in fibers, including solitons and self-phase modulation.

### AP 619 (Physics 619). Advanced Solid State Physics

*Prerequisite: 520 (or 463), Physics 511, Physics 510 or permission of instructor. (3 credits)*

Photon, neutron, and electron scattering in condensed matter: elastic and inelastic scattering in condensed matter. The theory of neutron, electron, and photon (Rayleigh, Brillouin, Raman, and x-ray) scattering will be presented with an overview of the corresponding experimental techniques; linear response theory, fluctuation-dissipation theorem, elementary excitations in condensed matter, hydrodynamics and symmetry analysis using group theory.

### AP 633 (Physics 633). Fluid Dynamics

*(3 credits)*

The course begins with a derivation of the hydrodynamical equations as prototypical phenomenological equations, based on general conservation laws and the second law of thermodynamics; two dimensional ideal fluid flow, the Joukowsky theory of the airfoil, gravity waves and the theory of tides, solitary waves, incompressible viscous flow and the Stokes formula, Sommerfeld's theory of lubrication, the turbulent wake, Prandtl's theory of the boundary layer, shock waves, relativistic hydrodynamics, fluctuations in hydrodynamics, etc.

### AP 644 (Physics 644). Advanced Atomic Physics

*(3 credits)*

Laser atom interactions: Absorption, emission, and saturation, theory of line width, multiphoton absorption, stimulated and spontaneous Raman scattering; single photon, multiphoton and above-threshold ionization; Rydberg physics; AC stark shifts and ponderomotive effects; multichannel quantum defect theory; Floquet theory; Mechanical effects of light on atoms (atom traps, molasses), atom interferometry.

### AP 669 (Chem 669). Physics of Extended Surfaces

*Prerequisite: quantum mechanics or solid state physics, or permission of instructor. (3 credits)*

Chemical physics of extended surfaces: basic surface phenomena which control the physical and chemical properties of extended surfaces. A wide range of surface methods and issues regarding metal, semiconductor and insulator surfaces will be discussed. Fundamental principles regarding the geometric and electronic structure of surfaces, adsorption-desorption processes, surface reactions, and ion-surface interactions will be discussed.

### AP 672 (NERS 572). Intermediate Plasma Physics II

*Prerequisite: NERS 571. II (3 credits)*

Waves in non-uniform plasmas, magnetic shear; absorption, reflection, and tunneling gradient-driven microinstabilities; BGK mode and nonlinear Landau damping; macroscopic instabilities and their stabilization; non-ideal MHD effects.

### AP 674 (NERS 674). High-Intensity Laser Plasma Interactions

*Prerequisite: NERS 471, NERS 571 or permission of instructor. (3 credits)*

Coupling of intense electromagnetic radiation to electrons and collective modes in time-dependent and equilibrium plasmas, ranging from underdense to solid-density. Theory, numerical modes and experiments in laser fusion, x-ray lasers, novel electron accelerators and nonlinear optics.

# ATMOSPHERIC, OCEANIC AND SPACE SCIENCES

*Margaret Reid (margreid@umich.edu) or*
*Janet Lineer (janetl@umich.edu)*
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*2455 Hayward*
*Ann Arbor, Michigan 48109-2143*
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*(734) 764-4585 fax*
*http://aoss.engin.umich.edu*

## Graduate Degrees

Master of Engineering (M.Eng.) in Applied Remote Sensing and Geoinformation Systems

Master of Engineering (M.Eng.) in Space Systems

Master of Science (M.S.) in Atmospheric and Space Sciences

Master of Science (M.S.) in Physcial Oceanography

Master of Science (M.S.) in Geoscience and Remote Sensing

Doctor of Philosophy (Ph.D.) in Atmospheric and Space Sciences

Doctor of Philosophy (Ph.D.) in Physical Oceanography

Doctor of Philosophy (PhD.) in Geoscience and Remote Sensing

Doctor of Philosophy (Ph.D.) in Space and Planetary Physics

### M.Eng. in Applied Remote Sensing and Geoinformation Systems

The mission of the M.Eng. degree in Applied Remote Sensing and Geoinformation Systems is to provide graduates with a sound basis in sensors, interpretation of data system fundamentals, a 'kit of tools' to apply remote sensing to the student's areas of interest and relevant team project and design experience in specific application tailored to local, national and global needs. Contact Margaret Reid (margreid@umich.edu) for more information.

### M.Eng. in Space Systems

The mission of the M.Eng. degree in Space Systems is to provide highly capable professionals with the successful integration of the scientific, engineering, and management considerations in space systems. In particular, managers at all levels must have a broad interdisciplinary background: they must be able to see branches, trees, and the entire forest at the same time. We educate a new type of interdisciplinary engineer for future managerial and systems engineering roles in space-related industries and government agencies. Contact Margaret Reid (margreid@umich.edu) for more information.

### M.S. in Atmospheric and Space Sciences
### M.S. in Physical Oceanography
### M.S. in Geoscience and Remote Sensing

Applicants to the master's program may have a bachelor's degree in any field of study, but they are expected to have completed minimum requirements in mathematics, physics, and chemistry. Normally this would include five semesters of mathematics, eight credit hours of physics including two laboratories, and five credit hours of chemistry. Thirty semester hours are required for the master's degree, 15 of which must be from the Department's offerings. A minimum of four additional hours must be in mathematics and/or natural science. A student will select a research topic if required in conjunction with an appropriate faculty member, who will guide the student in the preparation of both the research and the thesis or research essay. Satisfactory completion of the thesis or research essay will normally count for six credit hours of the total 30 hours required for the master of science degree.

Contact Janet Lineer (janetl@umich.edu) for more information.

### Ph.D. in Atmospheric and Space Sciences
### Ph.D. in Physical Oceanography
### Ph.D. in Geoscience and Remote Sensing
### Ph.D. in Space and Planetary Physics

The applicant for the doctorate is expected to have ability and scholarship of a high order one of the following areas: atmospheric science, oceanography, space and planetary physics, or geoscience and remote sensing. The student is expected to carry a course load of nine to 12 semester hours (three to four courses) each semester until the dissertation work is begun. There are no foreign language requirements. During the first year students must select courses from among the core courses for their particular program. After the second year, each student must pass a qualifying examination before he/she can be advanced to candidacy. After the student reaches the candidate status, he/she will concentrate on a dissertation topic under the guidance of an advisor. Contact Janet Lineer (janetl@umich.edu) for more information.

## Research in AOSS

### Atmospheric Research

AOSS provides an educational and research environment in which a student can examine a wide range of issues in the atmospheric sciences. Our faculty has research interests in: global climate change (emphasizing modeling of atmospheric and aerosol chemistry), regional and urban air pollution, chemical kinetics, radiative transfer, remote sensing, aerosol-cloud-climate interactions, and atmospheric dynamics. In addition, we are now developing a high-resolution computational framework for advanced climate simulation. Students enjoy extensive computational facilities as well as laboratories for measurement of the chemical and physical properties of the atmosphere. We have an active seminar series that includes a series of Distinguished Lectures by experts from outside of the University of Michigan as well as a series of lectures by staff and students within the Atmospheric Sciences.

In addition, our faculty members are extensively involved in observations of the Earth from space. They are involved in optical measurements from the Upper Atmosphere Research Satellite and the soon-to-be-launched TIMED satellite, in microwave measurements from the TRMM satellite, and in ozone studies from the Total Ozone Mapping Spectrometer. AOSS also participates in field campaigns, designing and integrating instruments on balloons, aircraft and sounding rockets to study the dynamics and composition of the atmosphere and the near-space environment of the Earth.

### Planetary and Space Research

AOSS is known as a leading center for the study of the Earth, the planets, other objects, and plasma regions within and beyond the solar system. Our faculty members are active in space instrumentation, data analysis, computer simulation, laboratory simulation, and theory. The associated Space Physics Research Laboratory (SPRL) has developed a strong reputation as one of the handful of university centers able to design, construct, test and operate space flight instruments. Our faculty members who emphasize planetary science seek to understand the origin and evolution of the atmospheres of the planets, of their satellites, and of comets. Our faculty who emphasize plasma phenomena in space seek to understand the space environment, including the environment near the Earth where most satellites exist, the heliospheric environment produced by the sun, and some more distant space plasma systems.

SPRL has played a significant role in the U.S. Space Program since its founding in 1946, making it one of the first university-owned facilities in the world to participate in space research, beginning with work involving captured World War II V-2 rockets. In the past two decades, SPRL faculty and engineers have designed and built over 30 spaceborne instruments as well as numerous sounding rocket, balloon, aircraft, and ground-based instruments.

Recent research by AOSS faculty members has involved making instruments and/or interpreting data from the Galileo Jupiter mission, the Hubble Space Telescope, the CASSINI mission to Saturn and Titan, the Infrared Space Observatory, and the Voyager missions. New projects will involve the use of advanced technologies. These include the Mercury Messenger mission, the development of advanced particle detectors and mass spectrometers, microwave detector systems, the TIMED Doppler Interferometer (TIDI), Space Tethers, and Remote Sensing Research. With 10 instructional faculty members, 25 research faculty members (who can supervise students), and 20 engineers and technicians, we provide a rich intellectual environment and a tremendous opportunity for students to learn through frequent interaction with a wide range of expert colleagues.

**Note:** Please refer to pages 73-78 of this *Bulletin* for Atmospheric, Oceanic and Space Sciences course descriptions and a listing of Atmospheric, Oceanic and Space Sciences faculty.

# BIOMEDICAL ENGINEERING

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*(734) 936-1905 fax*
*www.bme.umich.edu*

## Graduate degrees

Master of Science (M.S.) in Biomedical Engineering

Doctor of Philosophy (Ph.D.) in Biomedical Engineering

### M.S. in Biomedical Engineering

The Department of Biomedical Engineering at the University of Michigan is a graduate program in the Rackham School of Graduate Studies granting the M.S. and Ph.D. degrees in Biomedical Engineering.

The Department and the Center for Biomedical Engineering Research are jointly supported by the College of Engineering and the Medical School.

The Department is interdisciplinary. A student may plan a widely diversified educational program to advance the student's personal goals. Research opportunities are as diversified as the range of activities conducted by the University units supporting the Department and the Center for Biomedical Engineering Research.

*Entrance requirements for the Department of Biomedical Engineering*

Those students with a Bachelor of Science in Engineering or Physics degree should present a minimum background of:

- One course in organic chemistry or biochemistry
- One course in either basic biology or introductory physiology that has laboratory experience
- One course in a generally related area of the biological sciences such as anatomy, experimental psychology, microbiology, physiology, pharmacology, etc.

Those students with a Bachelor of Science or Bachelor of Arts degree and majors in related bioengineering areas such as experimental psychology, physiology, zoology, microbiology, and biochemistry, must complete the above requirements plus the following:

- Two terms of college physics
- Mathematics through differential equations
- One course in basic electronic circuits
- Two courses of either mechanics, fluid mechanics, or thermodynamics

Students may enter prior to meeting all the prerequisites if approved by the admissions committee. These students must plan to complete the prerequisites during their enrollment in the program in addition to the stipulated requirements for the Master of Science or Doctor of Philosophy degree in Biomedical Engineering.

*Degree Requirements*

In order to obtain the master's degree in biomedical engineering, students must complete at least 30 credit hours of graduate study beyond the bachelor's degree. Within this requirement, a group of core courses or their equivalents in the biological sciences, and several graduate level engineering and physical science courses must be completed. Directed research work is required to familiarize the student with the unique problems associated with biological systems research.

The core course requirements or their equivalent total 12-23 credit hours for each sub-group of the curriculum. There are six (6) curriculum options available:

- Bioelectrical option
- Biomaterials option
- Biomechanics option
- Biotechnology option
- Biomedical Imaging option
- Rehabilitation option

Please see department booklet for further details. A grade of "B" or better must be attained in each course used toward the master's degree.

### Ph.D. in Biomedical Engineering

The doctoral degree is conferred in recognition of marked ability and scholarship in some relatively broad field of knowledge. A part of the work consists of regularly scheduled graduate courses of instruction in the chosen field and in such cognate subjects as may be required by the committee. In addition, the student must pursue independent investigation in a subdivision of the selected field and must present the result of the investigation in the form of a dissertation.

A student becomes an applicant for the doctorate when admitted to the Horace H. Rackham School of Graduate Studies and accepted in a field of specialization. Candidacy is achieved when the student demonstrates competence in her/his broad field of knowledge through completion of a prescribed set of courses and passing a comprehensive examination.

There is no general course or credit requirement for the doctorate. In most areas, a student must pass a comprehensive examination in a major field of specialization and be recommended for candidacy for the doctorate. A special doctoral committee is appointed for each applicant to supervise the work of the student both as to election of courses and in preparation of the dissertation.

Requirements regarding foreign language and nontechnical courses are left to individual departments or programs, and to the Graduate School. A prospective doctoral student should consult the program advisor regarding specific details.

A pamphlet that describes the general procedure leading to the doctorate is available in the Graduate School office, 110 Rackham Building, upon request.

## Facilities

The facilities available for student research include state-of-the-art, well-equipped laboratories in the Medical School and the College of Engineering, the clinical facilities of the University of Michigan Hospitals, and the Ann Arbor Veteran's Administration Hospital. Students have access to patients and real medical problems with The University of Michigan Hospital on the campus. The University of Michigan's College of Engineering and Medical School have long been regarded as the finest in the country. Bridging these two worlds is the Biomedical Engineering Department, consistently ranked in the top ten nationally in recent years.

**Note:** Please refer to pages 84-88 of this *Bulletin* for Biomedical Engineering course descriptions and a listing of Biomedical Engineering faculty.

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## Graduate Degrees

Master of Science in Engineering (M.S.E.) in Chemical Engineering

Doctor of Philosophy (Ph.D.) in Chemical Engineering

### M.S.E. in Chemical Engineering

The minimum requirement for the M.S.E. degree for a student entering with a baccalaureate degree in chemical engineering is 30 graduate credit hours with an average grade of "B." A thesis is not required. The course work must include at least 21 hours in chemical engineering (courses with a ChemE prefix), of which up to 6 credit hours of research are accepted (ChemE 695); and at least two courses outside the chemical engineering program. The required courses are Fluid Flow (ChemE 527), Chemical Reactor Engineering (ChemE 528), Transport Processes (ChemE 542), Chemical Engineering Research Survey (ChemE 595), and two chemical engineering elective courses in mathematics, modeling, and/or thermodynamics. Each student is encouraged to develop a program to fit his or her professional objective and should consult with the graduate advisor concerning a plan of study.

### Ph.D. in Chemical Engineering

The doctoral degree is conferred in recognition of marked ability and scholarship in some relatively broad field of knowledge. A part of the work consists of regularly scheduled graduate courses of instruction in the chosen field and in such cognate subjects as may be required by the committee. In addition, the student must pursue independent investigation in a subdivision of the selected field and must present the result of the investigation in the form of a dissertation.

A student becomes an applicant for the doctorate when admitted to the Horace H. Rackham School of Graduate Studies and accepted in a field of specialization. Candidacy is achieved when the student demonstrates competence in her/his broad field of knowledge through completion of a prescribed set of courses and passing a comprehensive examination.

The course requirements are the same as the M.S.E. degree, plus seven (7) additional credits. In most areas, a student must pass a comprehensive examination in a major field of specialization and be recommended for candidacy for the doctorate. A special doctoral committee is appointed for each applicant to supervise the work of the student both as to election of courses and in preparation of the dissertation.

Requirements regarding foreign language and nontechnical courses are left to individual departments or programs, and to the Graduate School. A prospective doctoral student should consult the program advisor regarding specific details.

A pamphlet that describes the general procedure leading to the doctorate is available in the Graduate School office, 110 Rackham Building, upon request.

## Facilities

The facilities located in the H.H. Dow Building and G.G. Brown Building include absorption, biochemical engineering, catalysis, chemical sensors, light scattering and spectroscopy, polymer rheology, DNA sequencing/analysis on a microchip, colloids, nanomaterials, novel separations, process dynamics, real-time computing, and surface science laboratories.

**Note:** Please refer to pages 91-94 of this *Bulletin* for Chemical Engineering course descriptions and a listing of Chemical Engineering faculty.

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*2350 Hayward*
*Ann Arbor, Michigan 48109-2125*
*(734) 764-8495*
*(734) 764-4292 fax*
*www.engin.umich.edu/dept/cee/*

## Graduate Degrees

Master of Science in Engineering (M.S.E.) in Civil Engineering

Master of Science in Engineering (M.S.E.) in Construction Engineering and Management

Dual M.S.E. in Construction Engineering and Management/Master of Architecture

Dual M.S.E. in Construction Engineering and Management/Master of Business Administration

Master of Engineering (M.Eng.) in Construction Engineering and Management

Dual M.Eng. in Construction Engineering and Management/Master of Architecture

Dual M.Eng. in Construction Engineering and Management/Master of Business Administration

Master of Science in Engineering (M.S.E.) in Environmental Engineering

Doctor of Philosophy (Ph.D.) in Civil Engineering

Doctor of Philosophy (Ph.D.) in Environmental Engineering

## Programs of Study

Programs of advanced study, research, and design are available in the five major areas listed below. The strength of the curriculum is enhanced by a variety of complementary programs of study and research available throughout the University of Michigan.

### Construction Engineering and Management

Construction Decision and Support Systems
Construction Management and Cost Engineering
Construction Methods and Equipment
E-Commerce and Information Technologies
Human Resources in Construction
Occupational Health and Safety
Planning, Scheduling, and Layout
Productivity Analysis and Improvement

### Environmental and Water Resources Engineering

Graduate degrees offered in either Civil or Environmental Engineering:
Coastal Hydraulics
Computational Hydraulics
Free Surface Flow
Containment Fate and Transport
Water Quality Modeling
Environmental Chemistry and Microbiology
Global Environmental Change
Hazardous Substance Treatment and Control Technology
Process Engineering
Water and Waste Treatment
Surface and Groundwater Hydrology
Turbulent Mixing in Surface Waters
Water Resources Policy and Risk-Benefit Analysis

### Geotechnical Engineering

Earthquake Engineering
Geoenvironmental Technology
Physicochemical Properties
Rock Mechanics
Soil Properties and Dynamics
Soil and Site Improvement
Geosynthesis Slope Stablity

### Materials and Highway Engineering

High-Performance Cement-Based Fibrous Composites
Materials for Infrastructure Rehabilitation
Materials Structure Interactions
Micromechanics and Fracture Mechanics of Materials
Microstructural Analysis and Material Durability
Pavement Materials and Geotextiles

### Structural Engineering

Advanced Composites in Construction
Bridge Structures
Earthquake Engineering and Structural Dynamics
Elastic and Inelastic Analysis/Design
Material and Member Behavior
Reliability and Risk Analysis
Repair and Strengthening of Structures

## Master of Science Programs/Master of Engineering Programs

The Department of Civil and Environmental Engineering (CEE) offers three Master of Science in Engineering

(M.S.E.) degree programs and one Master of Engineering (M.Eng.) degree program.

The M.S.E. and M.Eng. programs require 30 credit hours of graduate work (typically 10 courses) and do not require a thesis or other major research project. At least two courses, of which one is mathematically oriented, must be taken in departments other than CEE.

The Graduate Record Examination (GRE) is required for application to the M.S.E. and M.Eng. programs. Letters of recommendation are also required. Degree programs differ in the undergraduate degrees they require for regular admission.

Students who do not meet undergraduate degree requirements for regular admission may be granted conditional admission. Students may be required to take courses without graduate credit to remedy the deficiencies in their undergraduate programs.

### M.S.E. in Civil Engineering

This program requires at least 15 hours of CEE courses. A student should expect to take at least eight hours in the area of specialization but will not be permitted to apply more than 21 hours in one area of specialization toward the M.S.E. degree. Study programs are available in the following areas of specialization:

Construction Engineering and Management
Geotechnical Engineering
Hydraulic and Hydrologic Engineering
Materials and Highway Engineering
Structural Engineering

Regular admission is open to students holding an undergraduate degree in Civil Engineering or an equivalent.

### M.S.E. in Construction Engineering and Management

This program requires at least 18 hours of graduate courses in the Construction Engineering and Management Program. Also available are dual degree programs by which a student can receive an M.S.E. in Construction Engineering and Management and a Master of Architecture degree or a Master of Business Administration degree. Regular admission is open to students holding a degree in any engineering discipline.

### M.Eng. in Construction Engineering and Management

This program requires at least 18 hours of graduate courses in the Construction Engineering and Management Program. Also available are dual degrees by which a student can receive an M.Eng. in Construction Engineering and Management and a Master of Architecture degree or a Master of Business Administration degree. Regular admission is open to students holding a degree in any engineering discipline. Applicants with bachelor's degrees in architecture or other non-engineering programs may be granted admission if they have taken a year of calculus and a year of physics.

### M.S.E. in Environmental Engineering

This program requires at least 15 hours of graduate courses in the Environmental and Water Resources Engineering Program. Specific course requirements are given in the departmental Guidelines for this MSE degree. Students holding an engineering or science degree will be considered for regular admission.

## Ph.D. Programs

CEE offers the Doctor of Philosophy (Ph.D.) with two designations. Ph.D. programs usually include 50 to 60 hours of graduate coursework beyond the bachelor's degree level. Foreign languages are not required. The focus of doctoral studies is the student's dissertation research, which must make a significant contribution to professional knowledge in the field. Major steps toward the Ph.D. degree include:

- qualifying examination (usually taken after completion of one or two terms of coursework beyond the master's degree)
- appointment of dissertation committee
- completion of coursework and English proficiency requirement
- preliminary examination
- advancement to candidacy
- completion of dissertation
- final oral examination

Admission to the Ph.D. program is granted only to students who show promise and provide sufficient evidence that they can meet scholastic requirements of study, including independent research, at an advanced level. The qualifying examination is only open to students with a GPA of better than B+.

### Ph.D. in Civil Engineering
Areas of specialization include:
Construction Engineering and Management
Geotechnical Engineering
Hydraulic and Hydrologic Engineering
Materials and Highway Engineering
Structural Engineering

### Ph.D. in Environmental Engineering
Areas of specialization include:
Environmental Chemistry and Microbiology
Fate and Transport of Surface and Groundwater Contaminants
Hazardous Waste Treatment and Management
Water Quality Engineering
Environmental Policy and Economics

## Facilities
The department maintains outstanding experimental and digital computational facilities. Many of the laboratories are recently constructed, and contain state-of-the-art equipment. These include the Advanced Civil Engineering Materials, Construction Engineering, Environmental and Water Resources Engineering, W.S. Housel Materials, Hydraulics, F.E. Richart Soil Dynamics, Soil Mechanics, and Structural Engineering and Dynamics laboratories. Environmental contamination remediation technology research facilities are also available to faculty and students. Externally funded research in the department exceeds $6 million annually.

**Note:** Please refer to pages 97-104 of this *Bulletin* for Civil and Environmental Engineering course descriptions and a listing of Civil and Environmental Engineering faculty.

*http://www.eecs.umich.edu/*
*To request an application: admit@eecs.umich.edu*

*Detailed contact information for each area in the Electrical Engineering and Computer Science Department is located at the end of this chapter on page 221.*

## Graduate Degrees

### Computer Science and Engineering Graduate Degrees

Master of Science in Engineering (M.S.E.) in Computer Science and Engineering

Master of Science (M.S.) in Computer Science and Engineering

Doctor of Philosophy (Ph.D.) in Computer Science and Engineering

### Electrical Engineering Graduate Degrees

Master of Science (M.S.) in Electrical Engineering

Master of Science in Engineering (M.S.E.) in Electrical Engineering

Doctor of Philosophy (Ph.D.) in Electrical Engineering

### Electrical Engineering: Systems Graduate Degrees

Master of Science (M.S.) in Electrical Engineering: Systems

Master of Science in Engineering (M.S.E.) in Electrical Engineering: Systems

Doctor of Philosophy (Ph.D.) in Electrical Engineering: Systems

### Other Graduate Degrees

Doctor of Philosophy (Ph.D.) in Geoscience and Remote Sensing, an EECS/AOSS/Civil Interdisciplinary Graduate Program

## Electrical Engineering and Computer Science Department

Electrical Engineering and Computer Science (EECS) is one of the highest-ranking EECS departments in the country, and many of its faculty are recognized as leaders in their field. The department is composed of three divisions: Computer Science and Engineering (CSE); Electrical Science and Engineering (ESE); and Systems Science and Engineering (SSE). The department's size and scope mean that students may choose from a variety of research areas and participate in integrated research projects. This system provides for multidisciplinary studies, allows students to tailor a program to their needs, and is responsive to changes in rapidly emerging fields. Also, students may have an opportunity to take advantage of other excellent programs at the University of Michigan. Faculty members in EECS have joint projects in other engineering departments and in a wide range of non-engineering programs including medicine, music, physics, information and library science, education, and others.

Master's and Ph.D. degrees are available in the following degree programs:

**Computer Science and Engineering**
Hardware
Intelligent Systems
Software
Theory
VLSI

**Electrical Engineering**
Circuits and Microsystems
Electromagnetics
Optics
Solid State
VLSI

**Electrical Engineering: Systems**
Control
Communications
Signal Processing

## Master of Science
## Master of Science in Engineering

Generally, the M.S.E. and M.S. degree programs in a given area are identical except for admission requirements. Students desiring admission to the M.S.E. program must have an earned bachelor's degree in computer engineering. Application procedures are described in a departmental brochure containing information for prospective students. The principal requirements for the specific M.S.E. and M.S. degrees are listed below. (A more complete statement on master's degree requirements is available on the web http://www.eecs.umich.edu).

### M.S. and M.S.E. in Computer Science and Engineering

The graduate program in CSE is organized into five broad areas: (1) hardware systems, (2) intelligent systems, (3) software and programming languages, (4) theory of computation, and (5) VLSI (Very Large Scale Integration; this area spans courses from hardware systems and classes from the EE Division).

A student must satisfy the regulations of the Rackham School of Graduate Studies, the College of Engineering, and the regulations as specified by the program brochure(s) and the program office.

A student must earn at least 30 credit hours of graduate level coursework, of which at least 24 hours must be technical courses, at least 15 hours must be CSE coursework at the 500 level or higher (excluding credit hours earned in individual study, research or seminar courses). The student must also satisfy course requirements in "kernel" areas of software, hardware, artificial intelligence and theory. A maximum of six credit hours of individual study, research and seminar courses will be accepted toward the master's degree. The VLSI concentration has slightly different course requirements; please refer to the CSE Brochure available on the web for details.

The program requires that the grade point average received in CSE coursework must be at least 5.0 (based on Rackham's 9.0 scale). An individual course grade of B- or better (4.0 or better on Rackham's 9.0 scale) is required for the credit hours received in any course to be counted towards any master's degree requirement. A master's thesis is optional. Credit hours transferred may be applied to meet any master's degree requirement except the 15 credit hours of 500 level CSE coursework required. (Rackham specifies limitations to the circumstances under which credits may be transferred. See the Rackham Student Handbook.) Courses of an insufficiently advanced level, or which substantially duplicate in level and/or content courses already completed by the student, may not be counted as meeting any master's degree requirements.

### M.S. and M.S.E. in Electrical Engineering

The Graduate Program in Electrical Engineering covers topics such as circuits and microsystems, electronics, VLSI, electromagnetics, optics, solid state materials, devices, and integrated circuits. The M.S.E. and M.S. degree programs are identical except for admission requirements.

A student must earn at least 30 credit hours of graduate-level coursework, of which at least 24 credit hours must be in technical courses, at least 12 credit hours must be EECS coursework at the 500-level or higher (excluding credit hours earned in individual study, research, or seminar courses), and at least 3 credit hours must be in mathematics. The student must also choose a major and minor area and satisfy a requirement in circuits and microsystems, electromagnetics, optics, or solid state.

The minor area must be different from the major (except in VLSI) and must be chosen from either the previous list or biosystems, communications, computers, control systems, or signal processing. For each designated major and minor area there is a set of courses called the "kernel." The major and minor requirements are to be satisfied by taking courses from the respective kernels. Specifically, at least nine credit hours must be earned from the kernel of the major area, with at least six of these at the 500-level or higher. At least six credit hours must be earned from the kernel of the minor area, with at least 3 of these at the 500-level or higher. A grade point average of "B" or higher is required overall and also in EECS coursework. Course grades must be "B-" or higher to earn credit toward the master's degree.

A maximum of four credit hours of individual study, research, and seminar courses (EECS 599 and similar courses) will be accepted toward the master's degree. A master's thesis is optional.

Up to six credit hours may be transferred from other universities if the department grants approval. The student must also satisfy the regulations of the Rackham School of Graduate Studies and the College of Engineering.

Courses of an insufficiently advanced level, or which substantially duplicate in level and content courses already completed by the student, may not be counted as meeting any master's degree requirements.

### M.S. and M.S.E. in Electrical Engineering: Systems

The Graduate Program in Electrical Engineering: Systems is identified with the disciplines of communications, control, signal and image processing. Systems theory, stochastic systems, information theory modulation and coding, estimation and detection, robotics, networks, manufacturing, bioelectrical science, and other disciplines in which the emphasis is on the design and analysis of systems of interacting components or devices—rather than on the physical components or devices themselves—comprise the essential nature of the program.

A student must earn at least 30 credit hours of graduate-level coursework of which at least 24 credit hours must be in technical courses, at least 12 credit hours must be in EECS coursework at the 500-level or higher (excluding credit hours earned in individual study, research or seminar courses). The student must also choose major and minor area, and complete a "kernel" of courses in each. The major area must be in communication, control systems, or signal processing. The minor area must be different from the major and must be chosen from either the previous list or biomagnetics, optics or solid state. At least nine credit hours must be earned from the kernel of the major area, with at least six of these at the 500-level or higher. At least six credit hours must be earned from the kernel of the minor area, with at least three of these at the 500-level or higher. Course grades must be "B-" or better in order to be counted towards any requirements. A master's thesis is optional. Up to six credit hours may be transferred if the department grants approval. The student must also satisfy the regulations of the Rackham School of Graduate Studies and the College of Engineering.

## Doctor of Philosophy

### Ph.D. in Computer Science and Engineering

### Ph.D. in Electrical Engineering

### Ph.D. in Electrical Engineering: Systems

### Ph.D. in Geoscience and Remote Sensing

The doctoral degree is conferred in recognition of marked ability and scholarship in some relatively broad field of knowledge. A part of the work consists of regularly scheduled graduate courses of instruction in the chosen field and in such cognate subjects as may be required by the committee. In addition, the student must pursue independent investigation in a subdivision of the selected field and must present the result of the investigation in the form of a dissertation.

A student becomes an applicant for the doctorate when admitted to the Horace H. Rackham School of Graduate Studies and accepted in a field of specialization. Candidacy is achieved when the student demonstrates competence in her/his broad field of knowledge through completion of a prescribed set of courses and passing a comprehensive examination.

There is no general course or credit requirement for the doctorate. In most areas, a student must pass a comprehensive examination in a major field of specialization and be recommended for candidacy for the doctorate. A special doctoral committee is appointed for each applicant to supervise the work of the student both as to election of courses and in preparation of the dissertation.

Requirements regarding foreign language and non-technical courses are left to individual departments or programs, and to the Graduate School. A prospective doctoral student should consult the program advisor regarding specific details.

A pamphlet that describes the general procedure leading to the doctorate is available in the Graduate School office, 1004 Rackham Building, upon request.

## Facilities

EECS departmental academic units, faculty members, and most of the research laboratories are housed in the modern EECS Building and in several nearby research buildings. EECS is home to more than a dozen state-of-the-art research laboratories, and it supports other inter-departmental research laboratories. The EECS research environment is strengthened by a University-wide computer network infrastructure. The College of Engineering's CAEN network, one of the largest campus networks, supports both instructional and research computing and has links to research facilities throughout Michigan, the nation, and the world.

## Contact Information

### Computer Science and Engineering

Dawn Freysinger
(csegrad@eecs.umich.edu)
3405 EECS Building
1301 Beal Avenue
Ann Arbor, Michigan 48109-2122
(734) 647-1807
(734) 763-1503 fax

### Electrical Engineering

Beth Stalnaker
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1301 Beal Avenue
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(734) 647-1758
(734) 763-1503 fax

**Electrical Engineering: Systems**

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(734) 763-1503 fax

**Note:** Please refer to pages 110-124 of this *Bulletin* for Electrical Engineering and Computer Science (EECS) course descriptions and a listing of EECS faculty.

# INDUSTRIAL AND OPERATIONS ENGINEERING

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*(734) 764-3451 fax*
*www.ioe.engin.umich.edu/*

## Graduate Degrees

Master of Science (M.S.) in Industrial and Operations Engineering

Joint M.S. in Industrial and Operations Engineering/ Master of Business Administration (M.B.A.)

Master of Science in Engineering (M.S.E.) in Industrial and Operations Engineering

Master of Science in Industrial and Operations Engineering and Health Services Administration

Doctor of Philosopy (Ph.D.) in Industrial and Operations Engineering

### M.S. and M.S.E. in Industrial and Operations Engineering

The Master of Science degree in Engineering in Industrial and Operations Engineering is available to students who complete the M.S.E. course requirements and have a bachelor's degree from a recognized program in engineering. The Master of Science degree in Industrial and Operations Engineering is available to students with a bachelor's degree from a recognized program in physics, mathematics, or other field related to engineering. Students who hold bachelor's degrees from other fields and who wish to receive an M.S. in Industrial and Operations Engineering should consult with the program advisor as specialized programs (usually involving additional credit hours over basic requirements) can be provided.

The basic requirements include 30 credit hours of approved graduate level courses, of which: at least 18 hours must be in IOE courses; at least five courses must be at a 500 or higher level, of which at least three must be from IOE (IOE 590, independent study, does not count towards this requirement); no more than 6 credit hours of independent study. At least two courses (4.5 credit hours) must be from outside the IOE department. Students are required to make up deficiencies in their preparation in probability, statistics, computer programming, and English. An overall grade point average of "B" or higher in graduate courses taken in the program is required.

Special options, for which sequences of courses have been defined, include:

1. Operations Research
2. Ergonomics
3. Production/Distribution Systems
4. Quality Engineering and Applied Decision Making
5. Management Engineering
6. Occupational Health and Safety Engineering
7. Public Systems Analysis

Material describing these options and other details of the graduate programs are available from the graduate student advisor, 1603 IOE Building.

### Industrial and Operations Engineer

This professional degree program requires a minimum of 30 credit hours of work beyond the Master of Science in Engineering or its equivalent. A grade point average of B+ or better is required. Successful completion of the qualifying exam (as described under "The Ph.D. Degree") is required.

The total graduate program (which includes the Master's and the Industrial and Operations Engineer degree program) shall include:

1. At least 24 credit hours of graduate course work in the IOE Department, or jointly in the departments or areas concerned, if the degree is interdisciplinary. The Departmental Program Advisors may specify the actual courses to be taken in the program.

2. At least three courses in cognate fields other than mathematics.

3. At least nine hours in mathematics beyond the mathematics course requirements for the Bachelor of Science in Engineering.

4. A preliminary examination to be conducted by a committee to be set up by the IOE Graduate Program Advisor in consultation with the student, on a proposal for a research, design, development, or an application project. The Committee reviews the potential and the feasibility of the proposal and whether it is suitable for a professional degree project.

5. At least six credit hours devoted to the research, design, development or application project approved by the preliminary examination committee. The student must prepare a written report covering this work. A committee of faculty members supervises the work.

conducts an oral examination, and approves the final report.

### Joint M.B.A./M.S. in Industrial and Operations Engineering

The School of Business Administration and the College of Engineering Department of Industrial and Operations Engineering offer a joint degree program enabling a student to pursue concurrent work in Business Administration and Industrial and Operations Engineering leading to the M.B.A/M.S. (I.O.E) degree. The program is arranged so that all requirements for the degrees are completed in two and one-half years of enrollment with the required 65 credit hours completed.

Students interested in the M.B.A./M.S. (I.O.E) joint program must apply to, and be admitted by, both schools, using their respective application forms and indicating that application is being made to the joint program. Only one application fee is necessary. Students are expected to meet the prerequisites for each program. In particular, the statistics requirement for the IOE program should be discussed with an advisor prior to beginning either program. This joint program is not open to students who have earned either the M.B.A. or M.S. (I.O.E) degrees. However, students registered in the first year of either program may apply.

Students admitted to this joint program must satisfy the following degree requirements:

1. The MBA 60-credit-hour degree program including:
   a. the 31.5-credit-hour MBA core (no credit is awarded for Business Administration core courses successfully waived; credit must be earned with Business electives);
   b. 13.5 elective hours in Business Administration (12 of the 13.5 must be approved by IOE);
   c. 15 credit hours of transferable electives from the Department of Industrial and Operations Engineering.
2. The 18 hours of graduate-level IOE courses, including at least nine credit hours in courses numbered 500 or above. Directed study courses and seminar classes may not be counted toward the IOE 500-level or above requirement.
3. A 2-credit independent study in IOE or the Business School which would lead to a paper integrating business and IOE perspectives on a particular area of interest.

The total credit hours for the joint degree program will be at least 65.

The dual program can begin with studies in either school; however, because of the sequential nature of the core course in the M.B.A program, most students will find it advantageous to start the first year in the Business School. Students who wish to begin with Industrial Operations Engineering should consult a counselor in the Business School to work out an appropriate plan of study.

### Master's in Industrial and Operations Engineering and Health Services Administration

This 60-credit-hour interdepartmental master's degree program is administered jointly by the Industrial and Operations Engineering department in the College of Engineering and the Health Services Management and Policy department in the School of Public Health. This program prepares graduates for engineering and administrative positions in hospitals and other health organizations. The degree provides a comprehensive program in health administration and engineering. Areas of study include hospital administration, hospital systems engineering, management information systems, computer aided systems and operations analysis.

### Ph.D. in Industrial and Operations Engineering

The doctoral degree is conferred in recognition of marked ability and scholarship in some relatively broad field of knowledge. A part of the work consists of regularly scheduled graduate courses of instruction in the chosen field and in such cognate subjects as may be required by the committee. In addition, the student must pursue independent investigation in a subdivision of the selected field and must present the result of the investigation in the form of a dissertation.

A student becomes an applicant for the doctorate when admitted to the Horace H. Rackham School of Graduate Studies and accepted in a field of specialization. There is no general course or credit requirement for the doctorate.

At the end of the first year in the program, a student must pass a qualifying examination to continue in the program. This exam is given in six courses, chosen with the consent of the student's advisor. Most students, at the end of their second year, take a preliminary examination in their chosen area of concentration. At present there are five such areas. The student must also satisfy a breadth requirement before taking the exam. After successfully passing this exam, the student is admitted to candidacy and selects a doctoral committee to supervise preparation of the dissertation. A defense of the dissertation in the presence of this committee is required.

A pamphlet that describes the general procedure leading to the doctorate is available in the Graduate School Office, 1004 Rackham Building, upon request.

## Facilities

The department has well-equipped laboratories in human performance, industrial systems, plant flow analysis, quality control, and computation. In addition to the facilities on campus, the department has excellent relationships with various firms within the Ann Arbor-Detroit area so that students are exposed to actual operating industrial, service, and other business systems.

**Note:** Please refer to pages 129-135 of this *Bulletin* for Industrial and Operations Engineering course descriptions and a listing of Industrial and Operations Engineering faculty.

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*2300 Hayward Street*
*Ann Arbor, Michigan 48109-2136*
*(734) 763-0480*
*(734) 647-0079 fax*
*http://interpro.engin.umich.edu*

The University of Michigan College of Engineering established InterPro—the Office of Interdisciplinary Professional Programs—to foster cooperation among disciplines within the College of Engineering and throughout the University of Michigan. InterPro serves as the conduit for incorporating the best practices of existing interdisciplinary programs into new ones and develops programs that are responsive to the needs of industry and professional engineers. Graduate programs currently offered through InterPro include:

- Automotive Engineering
- Financial Engineering
- Pharmaceutical Engineering
- Plastics Engineering
- Program in Manufacturing (PIM)

## Automotive Engineering

### M.Eng. in Automotive Engineering

The Master of Engineering in Automotive Engineering is an advanced professional degree program designed specifically for today's modern engineering world. It is intended for engineers who desire to pursue and enhance careers in the automotive industry or in government laboratories with automotive research, development, or regulatory programs. The M.Eng. degree program emphasizes engineering practice and is ideally suited to working engineers who desire broader graduate experience but may not be able to take full time leave from work.

The M.Eng. degree in Automotive Engineering requires a total of 30 credit hours of course work, of which at least 24 credit hours must be graded, and at least 18 credit hours must be in courses at the 500-level and above. A minimum grade point average of 5.0/9.0 ("B" average) is also required. The credits will be distributed in categories arranged to meet the degree's objectives:

1. *Systems Engineering Core (9 credits, graded)*

   One course should be selected per area from three core areas: Engineering Systems, Powertrain, Vehicle.

2. *Engineering Electives (9 credits; graded)*

   The student must take at least two courses in other engineering disciplines of their choice. (e.g. Design and Manufacturing; Electronics; Energy; Materials; Noise; Vibration and Harshness; and Ride and Handling)

3. *Management and Human Factors (6 credits; graded)*

   Two courses must be taken in the Management and Human Factors core. Those courses should emphasize business and management, ergonomics and human factors, law and professional ethics, operations research, etc.

4. *Automotive Engineering Seminar and Project (6 credits, S/U)*

   To provide a significant and industrially relevant team-project experience, a series of seminars will expose students to the wide spectrum of automotive engineering. A capstone project will synthesize the student's knowledge and apply it to an industrially relevant problem.

Applicants are expected to have a bachelor's degree in engineering or a related science. The prerequisites for admission include at least two years of college engineering mathematics; undergraduate course work in at least three of the engineering core areas of Automotive Engineering; and the equivalent of two years of full-time industrial experience in Automotive Engineering. Students with outstanding qualifications who do not have two years of industrial experience will be considered for admission if they have relevant summer internship or co-op experience. The Graduate Record Examination (General Test) is recommended but not required. A full-time student can complete the degree program in one calendar year.

Web site: *http://auto.engin.umich.edu*
Contact: *Henia Kamil*
Office: *1539 H.H. Dow Building, 2300 Hayward Street*
Phone: *(734) 763-0480*
Advisor: *Professor Dennis Assanis*

## Financial Engineering

### M.S. Financial Engineering

The M.S. (FE) program consists of at least 30 credit hours that can be completed in two or three terms. Entering students should have a strong mathematical background that includes the following topics which may also be completed (without program credit) after admission. These prerequisites are typically satisfied by all IOE majors, Mathematics and Statistics majors with applied concentrations, EECS majors with economic interests, and Economics or Business majors with technical interests. To complete the program in 30 credit hours, students must have completed some combination of the core courses such as IOE 452 and IOE 510/Math 561/SMS 518. This preparation is common for both IOE and Mathematics undergraduates. Students without some of the core material will require at least 36 credit hours to complete the program.

*Prerequisites:*

- Two years of college mathematics including multivariable calculus, differential equations and linear algebra (Math 115, 116, 215, 216 or 316, 217 or 417)
- Two terms of calculus-based probability and statistics (Math/Stat 425 and Stat 426 or IOE 316 and 365)
- Basic microeconomic theory/time value of money/time interest: (Econ 401 and Math 424, IOE 201, or 451)
- An introductory finance course (such as Econ 435 or Math 423)
- Accounting principles (Acc 471 or Acc 501)
- Computer programming experience in C or C++ (EECS 280 or EECS 284) and spreadsheets.

All students must complete the required core (or demonstrate equivalent knowledge through prior coursework or a placement examination). The core consists of financial concepts in capital budgeting, investments, financial markets, and derivative instruments and securities plus analytical tools in optimization, stochastic processes, and statistics.

*Required core*

Finance:

- Capital budgeting, models for optimal decision making and discrete time models in finance (IOE 452, Capital Budgeting and IOE 453, Financial Engineering–offered Winter Term only)
- Mathematics of finance, interest rate term structure and continuous-time models in finance (Math 623, Computational Finance offered Winter Term only)
- Investments (Fin 608, Portfolio Analysis and investments–offered both Fall and Winter Terms; Fin 609, Fixed Income Securities and Markets–offered both Fall and Winter Terms)
- International finance (Fin 613, International Finance and International Financial Markets– offered Fall Term only):
- Financial engineering Part I and Part II ( IOE 552 FE–Part I offered Fall Term only; IOE 553 FE–Part II offered Winter Term only)

Analysis/Design Tools:

- Optimization (IOE 510/Math 561/SMS 518, Linear Programming I–offered both Fall and Winter Terms)
- Applied Statistics (Stat 500–offered Fall Term only)
- Stochastic processes (IOE 515, Stochastic Processes–offered Fall Term only or Math/Stat 526, Discrete State Stochastic Processes–offered Winter Term only)

In addition to the core classes above, the program will require at least 3 elective courses chosen in consultation with an advisor to form a concentration area. The following areas and courses have been identified.

*Electives/Concentration Areas*

**Capital markets:** (for students expected to seek employment in financial institutions in the areas of quantitative research, trading and arbitrage, derivatives and product structuring, risk management, investment banking and brokerages, asset/liability management, and in financial departments of non-financial firms and public institutions):

- Finance (Fin 585, Futures; Fin 619, Risk Management and Financial Engineering)
- Nonlinear dynamic stochastic optimization (IOE 511/Math 562, Continuous Optimization Methods; IOE 611/Math 663, Nonlinear Programming; IOE 512, Dynamic Programming; EECS 558, Stochastic Control)
- Numerical partial differential equations (Math 572, Numerical Methods for Scientific Computing II)
- Empirical analysis of complex systems (CSCS 520, PHY 580)

- Applied probability, stochastic processes and stochastic analysis in finance (Stat 630, Topics in Applied Probability; Econ 675, Applied Economics: Time Series)

**Insurance/risk management systems, forecasting:** (typical work in risk management group, pension management, insurance companies, industrial economic forecasting groups)

- Actuarial science (Math 522, Actuarial Theory of Pensions and Social Security; Math 523, Risk Theory)
- Time series analysis and forecasting (Empirical analysis of complex systems (CSCS 520, PHY 580); IOE 565, Forecasting and Time Series Analysis; IOE 560/Stat 550/SMS 603 Bayesian Decision Analysis; Econ 677/Stat 531, Analysis of Time Series; Econ 574/PPS 574 Advanced Quantitative Methods: Forecasting and Modeling)

**Operations and information systems:** (typical work in middle office, operational area of financial institutions as well as corporate users and information systems specialty firms)

- Information systems/software engineering (EECS 481, Software Engineering; EECS 484/IOE 484, Database Management Systems; EECS 486, Object-Based Software Development; EECS 581, Software Engineering Tools; EECS 584, Advanced Database Systems; IOE 573, Analysis, Design and Management of Large Scale Information Systems, IOE 575, Information Systems Engineering)
- Artificial intelligence/pattern recognition (EECS 492, Introduction to Artificial Intelligence; EECS 543, Knowledge-Based Systems; EECS 545, Machine Learning)
- Simulation (Computer Modeling of Complex Systems (PSCS, new), IOE 474, Simulation; NucEng 590, Monte Carlo Methods)
- Electronic commerce (EECS, new)

Students with sufficient background and experience (for example, those who are already studying towards a graduate technical degree at U of M) could complete the program in two to three terms. Students with limited experience and less developed backgrounds would benefit from an internship and a three to four term experience.

Web site: *www.umich.edu/~fep*
Contact: *Henia Kamil*
Office: *1539 H.H. Dow Building, 2300 Hayward Street*
Phone: *(734) 763-0480*
Advisor: *Professor Romesh Saigal*

## Pharmaceutical Engineering

### M.Eng. in Pharmaceutical Engineering

The Master of Engineering in Pharmaceutical Engineering is an interdisciplinary program of the College of Engineering and the College of Pharmacy at the University of Michigan. This new program is in response to changes in the laboratory and marketplace and reflects the most up-to-date advances in the pharmaceutical industry. Selected topics include process engineering in drug discovery; computational biology, chemistry, and engineering; receptor biology and chemical signaling; automated, high-throughput characterization and analyses; solid-state science and engineering; scale translation in pharmaceutical development; biomanufacturing and cGMP issues; and novel gene and drug delivery systems.

Practical training is a key component of the enrolled students' experience. Summer internships at various pharmaceutical and life science-related companies are available for qualified students.

Professionals with a BS in chemical engineering or a related field who are employed in a pharmaceutical or life science-related company may be admitted into the program, if they meet all the prerequisites. U-M Chemical Engineering undergraduates and Pharmacy undergraduates with a GPA of 3.5 and above are also encouraged to apply. Chemical Engineering students should apply beginning the second semester of their junior year and Pharmacy students during the first semester of their first year at the College of Pharmacy.

Web site: *www.interpro.engin.umich.edu/pharmaceutical*
Contact: *Henia Kamil*
Office: *1539 H.H. Dow Building, 2300 Hayward Street*
Phone: *(734) 763-0480*
Advisor: *Professor Henry Wang*

## Plastics Engineering

### M.Eng. Plastics Engineering

The plastics industry has an annual growth rate on the order of 20%, and this is expected to at least continue if not increase in the future. The primary limitation for future growth is the lack of professionals with the necessary skills to work in this industry. These skills include an interdisciplinary knowledge of plastics engineering, from materials characterization and design to product and process development, as well as a background in business and management and experience in working in interdisciplinary teams. Our program in plastics engineering gives students such skills to be successful in this fast-growing field.

Three departments in the College of Engineering are principally involved in the Plastics Engineering degree: Chemical Engineering, Materials Science and Engineering, and Mechanical Engineering and Applied Mechanics. Many of these faculty members are involved in interdisciplinary research activities at the boundaries of the traditional disciplines, through the Center for Advanced Polymer Engineering Research (CAPER). The Masters of Engineering degree in Plastics Engineering takes advantage of these activities and brings the knowledge gained through this research into the classroom.

*Background*

The Masters of Engineering in Plastics Engineering is an interdisciplinary program in the College of Engineering at the University of Michigan, Ann Arbor. This unique program provides the opportunity for students to gain a deep understanding in a particular plastics engineering discipline while also gaining breadth in complementary engineering disciplines. The program also incorporates courses in business and management and provides students with the opportunity to work on a team project with a plastics industry. Students who graduate from this program will have both enhanced interdisciplinary skills in plastics engineering and the business and teamwork skills necessary to guide product and process development in this fast-growing field.

*Program Overview*

The Masters of Engineering in Plastics Engineering is a 30 credit-hour interdisciplinary program. The credit hours are distributed among the following areas:

- *Materials*, including polymer materials science, polymer physics, and polymer mechanical properties and failure
- *Mechanics*, including viscoelasticity, fluid mechanics, and heat transfer
- *Processing & Manufacturing*, including polymer processing, rheology, and manufacturing and design
- *Business*, including accounting, organizational behavior, and economics
- *Team Project*

This program is designed to strengthen a student's core engineering skills in a given discipline while being flexible enough to provide the opportunity to explore complementary areas. Moreover, our students will gain valuable business skills for product and process development. The interdisciplinary team project focuses on a current problem in the plastics industry.

*Admission Requirements*

Professionals who are employed in a plastics-related industry may be admitted into the program, if they meet all of the prerequisites. Some specific admission requirements include the following:

- The equivalent of at least two years of full-time work experience in the industrial plastics environment; this work experience can include both full-time and part-time employment (summer, co-op).
- An undergraduate degree in an area related to the field of Plastics Engineering such as Chemical Engineering, Materials Science and Engineering, Mechanical Engineering, Biomedical Engineering, or Nuclear Engineering. Applicants with undergraduate Chemistry or Physics degrees who have appropriate industrial experience may also be considered.

Interested students can obtain an application form from the Interdisciplinary Professional Programs (InterPro)

Web site: *interpro.engin.umich.edu/plastics*
Contact: *Henia Kamil*
Office: *1539 H.H. Dow Building,*
*2300 Hayward Street*
Phone: *(734) 763-0480*
Advisor: *Professor Stacy Bike*

## Program in Manufacturing

### Degree Programs

M.Eng. in Manufacturing

Joint M.Eng./MBA in Manufacturing Degree

D.Eng. in Manufacturing

Five-Year Simultaneous Graduate/Undergraduate Degree (See page 202 of this Bulletin)

### For all PIM program information, contact:

Web site: *pim.engin.umich.edu*
Contact: *Henia Kamil*
Office: *1539 H.H. Dow Building, 2300 Hayward Street*
Phone: *(734) 764-3312*
Advisor: *Professor Debasish Dutta*

### M.Eng. in Manufacturing

The Master of Engineering (M.Eng.) in Manufacturing is a graduate professional degree in engineering for students who have already earned a B.S.E. degree in any field of enginering (e.g., aerospace, mechanical, electrical, civil, industrial, naval, chemical, materials science), and who have relevant industrial experience.

A total of 30 credit hours is required, of which at least 24 credit hours must be graded (not pass/fail), and at least 18 graded credit hours must be in courses at the 500-level and above, in addition to Mfg 501. Entrance requirements are similar to other master's degree programs in the College of Engineering, except that entering students are expected to have the equivalent of two years full-time relevant industrial experience. Students with outstanding qualifications who do not have two years of industrial experience may be considered for admission if they have relevant summer internship or co-op experience.

Prerequisites for admission include: a) at least two years of college engineering mathematics (including probability and statistics); and b) a course in manufacturing processes.

Admitted students in the M.Eng. in Manufacturing program must take the course sequence Topics in Manufacturing (Mfg 501); and Manufacturing Project (Mfg 503). Lists of acceptable courses in each distribution area are available; substitutions require the approval of the program advisor.

### Joint M.Eng./M.B.A. in Manufacturing

The School of Business Administration and the Program in Manufacturing within the College of Engineering Graduate Studies offer a joint degree program that enables qualified people to pursue concurrent work in business administration and manufacturing studies leading to the M.B.A. and M.Eng. in Manufacturing degrees. The program is arranged so that all requirements are satisfied simultaneously.

This joint degree program is not open to students who have earned either the M.B.A. or M.Eng. in Manufacturing degrees. Students registered in the first year of either program may apply.

### Doctor of Engineering (D.Eng.) in Manufacturing

The Doctor of Engineering in Manufacturing (D. Eng. in Mfg.) is a graduate professional degree in engineering for students who have already earned a B.S.E. degree and an M.S.E. degree in any field of engineering (e.g., aerospace, chemical, civil and environmental, electrical engineering and computer science, industrial and operations, materials science, mechanical, naval architecture and marine) or a Master of Business Administration.

The degree can also be pursued in part at the University of Michigan Dearborn Campus. A total of 50 credit hours is required, of which 24 letter-graded credit hours (i.e., not pass/fail) and at least 18 credit hours must be taken at the Ann Arbor Campus. Students must maintain a cumulative GPA of 6.0/9.0 (B+). The entrance requirements are a B.S.E. and M.S.E. or M.B.A., and at least two years of full-time relevant industrial experience. The general portion of the Graduate Record Examination (GRE) is required. Applications are accepted for both fall and winter terms.

Qualifying examinations must be taken in four areas of manufacturing from a variety of examination areas offered by various departments. Following the completion of required course work and qualifying examinations, a student is required to take a preliminary examination to test his/her knowledge of the primary and supporting field. Each student must complete an industrially relevant, engineering-practice-oriented dissertation, supervised by a dissertation committee, as a requirement of the degree.

## Manufacturing Courses

**(Subject = MFG)**

### MFG 401 (ENG 401). Total Quality Management

*Prerequisite: none. I, II (3 credits)*

The technical and management aspects of total quality management. Topics include voice of the customer, metrics, cross-functional teams, and systems aspects. Examples from engineering and business operations such as dimensional tolerancing, quality function deployment, process control, simultaneous engineering, lean production, purchasing, inventory control, and scheduling systems.

### MFG 402 (ME 401). Engineering Statistics for Manufacturing Systems

*Prerequisite: senior or graduate standing. I (3 credits)*

Fundamentals of statistics. Independent t-test and paired t-test. Two-level factorial design. Fractional factorial designs. Matrix algebra and canonical analysis. Regression analysis (Least Squares Method). Response surface methodology. Probability. Binomial and Poisson distributions. Single sampling plan. Statistical process control (SPC). Taguchi methods. Introductory time series analysis and Defect Preventive Quality Control.

### MFG 410 (NA410) Marine Structures II

*Prerequisite: NA 310. I (4 credits)*

Structural modeling and analysis techniques applied to ship and marine structure components. Equilibrium and energy methods applied to elastic beam theory; static bending, torsion and buckling. Shear flow and warping of multi-cell cross sections. Stiffened and composite plates. Plastic analysis of beams. Thick walled pressure vessels. Course project using finite element analysis.

### MFG 423 (EECS 423). Solid-State Device Laboratory

*Prerequisite: EECS 320. I (3 credits)*

Semiconductor material and device fabrication and evaluation: diodes, bipolar and field-effect transistors, passive components. Semiconductor processing techniques: oxidation, diffusion, deposition, etching, photolithography. Lecture and laboratory.

### MFG 425 (EECS 425). Integrated Circuit Laboratory

*Prerequisite: EECS 320, EECS 427. II (2 credits)*

Integrated circuit fabrication; mask design, photographic reduction; photoresist applica-tion, exposure, development, and etching, oxidation; diffusion; metal film deposition by evaporation and sputtering; die bonding, wire bonding, and encapsulation; testing of completed integrated circuits.

### MFG 426 (IOE 425). Manufacturing Strategies

*Prerequisite: senior standing. I, II (2 credits)*

Review of philosophies, systems, and practices utilized by world-class manufacturers to meet current manufacturing challenges, focusing on ìlean productionî in the automotive industry, including material flow, plant-floor quality assurance, job design, work and management practices. Students tour plants to analyze the extent and potential of the philosophies.

### MFG 427 (EECS 427). VLSI Design I

*Prerequisite: EECS 311 or EECS 313. I, II (4 credits)*

Design techniques for rapid implementations of very large-scale integrated (VLSI) circuits, MOS technology and logic. Structured design. Design rules, layout procedures. Design aids: layout, design rule checking, logic and circuit simulation. Timing. Testability. Architectures for VLSI Projects to develop and lay out circuits.

### MFG 433 (EIH 556) (IOE 433). Occupational Ergonomics

*Prerequisite: Not open to students who have credits for IOE 333. I (3 credits)*

Principles, concepts, and procedures concerned with worker performance, health, and safety. Topics include biomechanics, work physiology, psychophysics, work stations, tools, work procedures, word standards, musculoskeletal disorders, noise, vibration, heat stress, and the analysis and design of work.

### MFG 441 (IOE 441). Production and Inventory Control

*Prerequisite: IOE 310, IOE 316. I, II (4 credits)*

Basic models and techniques for managing inventory systems and for planning production. Topics include deterministic and probabilistic inventory models; production planning and scheduling; and introduction to factory physics.

### MFG 447 (IOE 447). Facility Planning

*Prerequisite: IOE 310, IOE 316. I (4 credits)*

Fundamentals in developing efficient layouts for single-story and multi-story production and service facilities. Manual procedures and microcomputer-based layout algorithms. Algorithms to determine the optimum location of facilities. Special considerations for multi-period, dynamic layout problems.

### MFG 448 (ChemE 447). Waste Management in Chemical Engineering

*Prerequisite: ChemE 342, ChemE 343. I (3 credits)*

Control of gaseous, liquid, and solid wastes. Regulations and management procedures. Waste minimization and resource recovery. Separations and reaction engineering approaches.

### MFG 449 (IOE 449). Material Handling Systems

*Prerequisite: IOE 310, IOE 316. II alternate years (2 credits)*

Review of material handling equipment used in warehousing and manufacturing. Algorithms to design and analyze discrete parts material storage and flow systems such as Automated Storage/Retrieval Systems, order picking, conveyors, automated guided vehicle systems and carousels.

### MFG 452 (ME 452). Design for Manufacturability

*Prerequisite: ME 350. I (3 credits)*

Conceptual design. Design for economical production, Taguchi methods, design for assembly; case studies. Product design using advanced polymeric materials and com-posites; part consolidation, snap-fit assemblies; novel applications. Design projects.

### MFG 453 (ME 451). Properties of Advanced Materials for Design Engineers

*Prerequisite: ME 382. II (3 credits)*

Mechanical behavior and environmental degradation of polymeric-, metal-, and ceramic-matrix composites; manufacturability of advanced engineering materials; use of composite materials in novel engineering designs.

### MFG 454 (ME 454). Computer Aided Mechanical Design

*Prerequisite: Eng 101, ME 360. II (3 credits)*

Introduction to the use of the digital computer as a tool in engineering design and analysis of mechanical components and systems. Simulation of static, kinematic and dynamic behavior. Optimal synthesis and selection of elements. Discussion and use of associated numerical methods and application software. Individual projects.

### MFG 455 (IOE 452). Capital Budgeting

*Prerequisite: IOE 201, IOE 310, IOE 366. II (2 credits)*

The financial background for capital budgeting decisions is developed. Decisions with capital rationing, portfolio optimization, and rate selection are considered. Examples and cases are used to illustrate the capital asset pricing model and efficient market theory.

### MFG 456 (IOE 453). Financial Engineering

*Prerequisite: IOE 201, IOE 310, IOE 366. II (2 credits)*

The tools, methodology, and basic theory of financial engineering is developed. Decisions involving option pricing, hedging with futures, asset-liability, matching, and structuring synthetic securities are considered and illustrated with examples and cases.

**MFG 458 (MSE 485). Design Problems in Materials Science and Engineering**
*Prerequisite: MSE 480. I, II (1-4 credits) (to be arranged)*
Design problem supervised by a faculty member. Individual or group work in particular field of materials of particular interest to the student. The design problem is arranged at the beginning of each term by mutual agreement between the student and a faculty member. Written and oral reports are required.

**MFG 459 (EECS 459). Advanced Electronic Instrumentation**
*Prerequisite: EECS 360 or EECS 359 or EECS 453 or EECS 458. I (3 credits)*
Systematic design of optimum measuring instruments which give maximum confidence in results. Analog and digital signal processing, transducer modeling. A/D and D/A conversion, survey of modern instrumentation components.

**MFG 460 (NA 460). Ship Production Engineering, Planning and Control**
*Prerequisite: NA 270, NA 276, NA 277. I (4 credits)*
Application of production engineering and operations management to the production of complex marine systems, such as ships, offshore structures, and yachts. Applicability of various manufacturing and operations management philosophies, production engineering, planning and scheduling, performance measurement, and control to the operation of ship and boat yards.

**MFG 463 (IOE 463). Work Measurement and Prediction**
*Prerequisite: IOE 333, IOE 334, IOE 366. I (2 credits)*
Contemporary work measurement techniques are used to evaluate, predict, and enhance human performance through improved design of manufacturing and service work environments. Lectures and laboratory exercises cover the following topics: human variability in work performance, time study, learning curves, performance rating, allowances, work sampling, and pre-determined time systems.

**MFG 466 (IOE 466) (Stat 466). Statistical Quality Control**
*Prerequisite: IOE 265 (Stat 265) or permission of instructor. I, II (4 credits)*
Quality Improvement Philosophies; Modeling Process Quality, Statistical Process Control, Control Charts for Variables and Attributes, CUSUM and EWMA, Short Production Runs, Multivariate Quality Control, Auto Correlation, Engineering Process Control, Economic Design of Charts, Fill Control, Precontrol, Adaptive Schemes, Process Capability, Specifications and Tolerances, Gage Capability Studies, Acceptance Sampling by Attributes and Variables, International Quality Standards.

**MFG 467 (EECS 467) (ME 467). Robotics: Theory, Design and Application**
*Prerequisite: ME 360 and senior standing. I, II (3 credits)*
Basic concepts underlying the design and application of computer-controlled manipu-lators: Manipulator geometry, work volume, sensors, feedback control of manipulator linkages, kinematics, trajectory planning, programming, robot system architecture, design and application. Lab experiments cover kinematics, dynamics, trajectory planning, control of manipulators and motion by fixed robots and mobile robots.

**MFG 470 (NA 470). Foundations of Ship Design**
*Prerequisite: NA 310, NA 321, NA 330, NA 340. I (4 credits)*
Organization of ship design. Preliminary design methods for sizing and form; powering, maneuvering, and seakeeping estimation; arranging; propulsion; structural systhesis; and safety and environmental risk of ships. Extensive use of design computer environment. Given owner's requirements, students individually create and report the conceptual/preliminary design for a displacement ship.

**MFG 480 (MSE 480). Materials Science in Engineering Design**
*Prerequisite: senior standing. I (3 credits)*
Design concepts. Engineering economics. Problems of scaling. Materials substitution. Competitive processes. Case histories. Professional and ethical considerations. Written and oral presentations of solutions to design problems.

**MFG 481 (Aero 481). Airplane Design**
*Prerequisite: senior standing. (4 credits)*
Power-required and power-available characteristics of aircraft on a comparative basis, calculation of preliminary performance, stability, and control characteristics. Design procedure, including lay-outs and preliminary structural design. Subsonic and super-sonic designs. Emphasis on design techniques and systems approach. Lectures and laboratory.

**MFG 482 (EECS 481). Software Engineering**
*Prerequisite: EECS 380. I, II (3 credits)*
Pragmatic aspects of the production of software systems, dealing with structuring principles, design methodologies and informal analysis. Emphasis is given to development of large, complex software systems. A term project is usually required.

**MFG 483 (Aero 483). Aerospace System Design**
*Prerequisite: senior standing. II (4 credits)*
Aerospace system design, analysis and integration. Consideration of launch facilities, booster systems, spacecraft systems, communications, data processing, and project management. Lectures and laboratory.

**MFG 484 (Aero 484). Computer Aided Design**
*Prerequisite: Aero 414, senior standing. I (4 credits)*
Computer generation of geometric models. Calculation of design parameters. Finite element modeling and analysis. Each student will complete a structural component design project using industry standard applications software.

**MFG 488 (ME 487). Welding**
*Prerequisite: ME 281. I (3 credits)*
Study of the mechanism of surface bonding, welding metallurgy, effect of rate of heat input on resulting microstructures, residual stresses and distortion, economics and capabilities of the various processes.

**MFG 490 (Eng 490). Special Topics in Engineering**
*(to be arranged)*
Individual or group study of topics of current interest selected by the faculty.

**MFG 492 (ME 482). Machining Processes**
*Prerequisite: senior standing. II (4 credits)*
Mechanics of 2-D and Basic 3-D cutting. Industrially-applicable, mechanistic force models for practical processes including turning, facing, boring, face milling, end milling, and drilling. Surface generation and wear-based economic models. Motivation for and methods of applying developed models in simultaneous engineering. Three hours of lecture and one two-hour laboratory.

**MFG 493 (EECS 493) (IOE 437). User Interface Design and Analysis**
*Prerequisite: EECS 481. I (3 credits)*
Current theory and design techniques concerning how user interfaces for computer systems should be designed to be easy to learn and use. Focus on cognitive factors, such as the amount of learning required, and the information-processing load imposed on the user, rather than ergonomic factors.

**MFG 499. Special Topics to be specified by department**
*(to be arranged)*

**MFG 501 (OM 701). Topics in Manufacturing**
*Prerequisite: graduate standing in PIM. I (3 credits)*
This course is intended to provide students with an understanding of the changing role manufacturing plays in developed economies and the major dynamics creating these changes.

**MFG 503 (OM 703). Manufacturing Project**
*Prerequisite: Mfg 501; mandatory satisfactory/unsatisfactory. I, II, III, IIIa, IIIb (3 credits)*

This project course in intended to provide students with an industrially-relevant team project experience in manufacturing.

**MFG 504 (CEE 502). Artificial Intelligence Applications in Civil Engineering**

*Prerequisite: senior or graduate standing. I (3 credits)*

Introduction to artificial intelligence for engineers; theoretical concepts of AI explored and illustrated with applications in civil engineering and construction management, such as facilities design, site layout, planning and scheduling, selection of construction equipment and operation methods, construction automation. Students acquire hands-on experience with expert systems in final project.

**MFG 514 (MacroSE 514) (MSE 514). Composite Materials**

*Prerequisite: MSE 350 I alternate years. (3 credits)*

Behavior, processing and design of composite materials, especially fiber composites. Emphasis is on the basic chemical and physical processes currently employed and expected to guide the future development of the technology.

**MFG 516 (Aero 516). Mechanics of Fibrous Composites**

*Prerequisite: Aero 414 or AM 412 (ME 412). I (3 credits)*

Effective stiffness properties of composites. Constitutive description of laminated plates. Laminated plate theory. Edge effects in laminates. Nonlinear theory of generally laminated plates. Governing equations in the Von Karman sense. Laminated plates with moderately large deflections. Postbuckling and nonlinear vibration of laminated plates. Failure theories and experimental results for laminates.

**MFG 517 (ChemE 517). Biochemical Science and Technology**

*Prerequisite: ChE 344, Biol 311 or equivalent; permission of instructor. II (3 credits)*

Concepts necessary in the adaptation of biological and biochemical principles to industrial processing in biotechnology and pharmaceutical industries. Topics include rational screening, functional genomics, cell cultivation, oxygen transfer, etc. Lectures, problems, and library study will be used.

**MFG 518 (ME 518). Composite Materials: Mechanics, Manufacturing, and Design**

*Prerequisite: senior or graduate standing. I alternate years (3 credits)*

Composite materials, including naturally occurring substances such as wood and bone, and engineered materials from concrete to carbon-fiber reinforced epoxies. Development of micromechanical models for a variety of constitutive laws. Link between processing and as-manufactured properties through coupled fluid and structural analyses.

**MFG 523 (EECS 523). Digital Integrated Circuits**

*Prerequisite: EECS 317, EECS 320; and either EECS 412 or EECS 423 or EECS 427 or EECS 512. I (3 credits)*

Device technologies for LSI circuits. Approaches to logic implementation, including gate arrays, master-slices, PLAs. Non-volatile semiconductor memory structures, including ROM, PROM, EPROM and EAROM. Static and dynamic random access memory and microcomputers. Relationship of terminal performance to the design, layout and fabrication techniques used. Circuit layout and computer simulation.

**MFG 524 (EECS 524). Field-Effect-Transistors and Microwave Monolithic Integrated Circuits Technology**

*Prerequisite: EECS 420; and EECS 525 or EECS 528; and graduate standing. II (3 credits)*

Physical and electrical properties of III-V Physical and electrical properties materials, epitaxy and ion-implantation, GaAs and InP based devices (MESFETs and HEMTs varactors) and Microwave Monolithic Integrated Circuits (MMICs) Cleaning, Photolithography, metal and dielectric deposition, wet and dry etching. Device isolation, ohmic and Schottky contacts, dielectrics, passive component technology, interconnects, via holes, dicing and mounting. Study of the above processes by DC characterization.

**MFG 527 (EECS 527). Computer-Aided Design for VLSI System**

*Prerequisite: EECS 478. II (3 credits)*

Theory of circuit layout partitioning and placement algorithms. Routing algorithms, parallel design automation on shared memory and distributed memory multiprocessors, simulated annealing and other optimization techniques and their applications in CAD, layout transformation and compaction, fault-repair algorithms for RAMs & PLAs hard-ware synthesis from behavioral modeling, artificial intelligence based CAD.

**MFG 528 (EECS 528). Principles of Microelectronics Process Technology**

*Prerequisite: EECS 422, EECS 424. I (3 credits)*

Theoretical analysis of the chemistry and physics of process technologies used in micro-electronics fabrication. Topics include semiconductor growth, material characterization, lithography tools, photoresist models, thin film deposition, chemical etching, plasma etching, electrical contact formation, microstructure processing and process modeling.

**MFG 533 (CEE 533). Construction Performance Management**

*Prerequisite: senior or graduate standing. I, II, IIIa (3 credits)*

Ergonomics, job analysis, and job design. Work physiology, environmental factors. Repetitive motion disorders, overexertion, and traumatic injuries. Occupational health and safety with focus on underlying causes and prevention of illnesses and injuries rather than or regulation. Risk, safety, and loss management.

**MFG 534 (BiomedE 534) (IOE 534). Occupational Biomechanics**

*Prerequisite: IOE 333, IOE 334 or IOE 433 (EIH 556). II (3 credits)*

Anatomical and physiological concepts are introduced to understand and predict human motor capabilities, with particular emphasis on the evaluation and design of manual activities in various occupations. Quantitative models are developed to explain (1) muscle strength performance, (2) cumulative and acute musculoskeletal injury, (3) physical fatigue, and (4) human motion control.

**MFG 535 (IOE 533). Human Factors in Engineering Systems I**

*Prerequisite: IOE 333, IOE 365 or IOE 433, (EIH 556). II (3 credits)*

Principles of engineering psychology applied to engineering and industrial production systems visual task measurement and design, psycho-physical measurements, signal detection theory and applications to industrial process control. Human information processing, mental workload evaluation, human memory and motor control processes.

**MFG 536 (CEE 536). Critical Path Methods**

*Prerequisite: senior or graduate standing. I, IIIa (3 credits)*

Basic critical path planning and scheduling with arrow and precedence networks; project control; basic overlapping networks; introduction to resource leveling and least cost scheduling; fundamental PERT systems.

**MFG 539 (IOE 539). Occupational Safety Engineering**

*Prerequisite: IOE 265 or BioStat 500. I (3 credits)*

Design/modification of machinery/products to eliminate or control hazards arising out of mechanical, electrical, thermal, chemical, and motion energy sources. Application of retrospective and prospective hazard analysis, systems safety, expert systems and acci-dent reconstruction methodologies. Case examples: industrial machinery and trucks, construction and agriculture equipment, automated manufacturing systems/ processes.

**MFG 541 (IOE 541). Inventory Analysis and Control**

*Prerequisite: IOE 310, IOE 316. II alternate years (3 credits)*

Models and techniques for managing inventory systems and for planning production. Topics include single item and multi-item inventory models, production planning and control, and performance evaluation of manufacturing systems.

**MFG 542 (MSE 542). Reactions in Ceramic Processes**

*Prerequisite: MSE 440 or graduate standing. I, II (3 credits)*

Dissociation, sintering, vitrification, devitrification, and thermochemical reactions in ceramic processing.

**MFG 543 (IOE 543). Theories of Scheduling**
*Prerequisite: IOE 316 and IOE 310. II alternate years (3 credits)*
The problem of scheduling several tasks over time, including the topics of measures of performance, single-machine sequencing, flow shop scheduling, the job shop problem, and priority dispatching. Integer programming, dynamic programming, and heuristic approaches to various problems are presented.

**MFG 545 (IOE 545). Queue Networks**
*Prerequisite: IOE 515 or EECS 501. I alternate years (3 credits)*
Introduction to queueing networks. Topics include product and non-product form networks, exact results and approximations, queuing networks with blocking, and polling systems. Applications from manufacturing and service industries are given as examples.

**MFG 548 (IOE 547). Plant Flow Systems**
*Prerequisite: IOE 310, IOE 416. II (3 credits)*
Analytical models for the design and throughput performance evaluation of material handling systems used in discrete parts flow production facilities. Analysis of design and control issues for manual and automated handling systems including lift trucks, micro-load automatic storage/retrieval systems and automated guided vehicle systems.

**MFG 550 (CEE 550). Quality Control of Construction Materials**
*Prerequisite: CEE 351. II (3 credits)*
Construction material specification and test procedures. Sampling methods, data collection and statistical data distributions. Quality control charts, development of quality assurance specifications and acceptance plans. Examples using data from actual field construction and laboratory experiments collected by destructive and non-destructive methods.

**MFG 551 (CEE 554). Materials in Engineering Design**
*Prerequisite: CEE 351 or per instructor. II (3 credits)*
Integrated study of materials properties, processing, performance, structure, cost, and mechanics, as related to engineering design and materials selection. Topics include design process, materials properties and selection; scaling; materials database, process-ing and design, and optimization. Examples will be drawn from cement and ceramics, metals, polymers and composites.

**MFG 552 (ME 552). Electromechanical System Design**
*Prerequisite: EECS 210 or equivalent. I (3 credits)*
Design of electromechanical systems with emphasis placed on the integration of mechanical and electrical principles. Topics include: electromechanical device design: generators/alternators, electrical motors, measurement/sensing devices; digital control: microprocessors, AD/DA converters, data transmission and acquisition; electromechanical system design: mixed domain modeling, real time control and mechatronic systems.

**MFG 553 (ME 553). Microelectromechanical Systems**
*Prerequisite: senior or graduate standing. II alternate years (3 credits)*
Basic integrated circuit (IC) manufacturing processes; electronics devices fundamentals; microelectromechanical systems fabrications including surface micromachining, bulk micromachining, LIGA and others. Introduction to micro-actuators and microsensors such as micromotors, grippers, accelerometers and pressure sensors. Mechanical and electrical issues in micromachining. IC CAD tools to design microelectromechanical structures using MCNC MUMPs service. Design projects.

**MFG 554 (IOE 564) (ME 554). Computer Aided Design Methods**
*Prerequisite: ME 454 or ME 501. I (3 credits)*
Generalized mathematical modeling of engineering systems, methods of solution and simulation languages. Analysis methods in design; load, deformation, stress and finite element considerations; nonlinear programming. Computational geometry; definition and generation of curves and surfaces. Computer graphics; transformations; clipping and windowing; graphics systems; data structures; command languages; display processors.

**MFG 555 (ME 555). Design Optimization**
*Prerequisite: Math 451 and Math 217 or equivalent. II (3 credits)*
Mathematical modeling of engineering design problems for optimization. Boundedness and monotonicity analysis of models. Differential optimization theory and selected numerical algorithms for continuous nonlinear models. Emphasis on the interaction between proper modeling and computation. Students propose design term projects from various disciplines and apply course methodology to optimize designs.

**MFG 556 (ME 556). Fatigue in Mechanical Design**
*Prerequisite: stress-based finite element course recommended. I, II (3 credits)*
A broad treatment of stress, strain, and strength with reference to engineering design and analysis. Major emphasis is placed on the analytical and experimental determination of stresses in relationship to the fatigue strength properties of machine and structural components. Also considered are deflection, post-yield behavior, residual stresses, temperature and corrosion effects.

**MFG 557 (ME 557). Materials in Manufacturing and Design**
*Prerequisite: senior or graduate standing. I, II (3 credits)*
Material selection on the basic cost, strength, formability and machinability. Advanced strength analysis of heat treated and cold formed parts including axial, bending, shear and cyclic deformation. Correlations of functional specifications and process capabilities. Problems in redesign for productibility and reliability.

**MFG 558 (ME 558). Discrete Design Optimization**
*Prerequisite: senior or graduate standing. I alternate years (3 credits)*
Fundamentals of discrete optimization for engineering design problems. Mathematical modeling of engineering design problems as discrete optimization problems, integer programming, dynamic programming, graph search algorithms, and introduction to NP completeness. A term project emphasizes applications to realistic engineering design problems.

**MFG 559 (ME 559). Smart Materials and Structures**
*Prerequisite: EECS 210 or equivalent. I alternate years (3 credits)*
This course will cover theoretical aspects of smart materials, sensors and actuator technologies. It will also cover design, modeling and manufacturing issues involved in integrating smart materials and components with control capabilities to engineering smart structures.

**MFG 560 (ME 551). Mechanisms Design**
*Prerequisite: ME 350. II (3 credits)*
Basic concepts. Type synthesis – creative design of mechanisms; graph theory. Precision-point Burmester theory for dimensional synthesis of linkages. Applications. Cam and follower system synthesis. Joint force analysis and dynamic analysis formulations. Analytical synthesis of programmable and compliant mechanisms. Use of software for synthesis and analysis. Design projects.

**MFG 561 (IOE 565) (ME 563). Time Series Modeling, Analysis, Forecasting**
*Prerequisite: IOE 366 or ME 401. I (3 credits)*
Time series modeling, analysis, forecasting, and control, identifying parametric time series, autovariance, spectra, Green's function, trend and seasonality. Examples from manufacturing, quality control, ergonomics, inventory, and management.

**MFG 562 (ME 560). Modeling Dynamic Systems**
*Prerequisite: ME 360. I (3 credits)*
A unified approach to the modeling, analysis and simulation of energetic dynamic sys-tems. Emphasis on analytical and graphical descriptions of state-determined systems using Bond Graph language. Analysis using interactive computer simulation programs. Applications to the control and design of

dynamic systems such as robots, machine tools and artificial limbs.

**MFG 563 (NA 562). Concurrent Marine Design Management**
*Prerequisite: B.S. in Engineering. I (3 credits)*
Combination capstone and management development course to provide students the opportunity to apply basic naval architectural and related engineering knowledge to a real life business situation and to apply newly gained management skills. Management and organization concepts, theories and processes will be presented in the context of the marine industry.

**MFG 564 (Aero 564). Computer Aided Design and Manufacturing**
*Prerequisite: Aero 484 or ME 454 or permission of instructor based on familiarity with industrial standard CAE software. II (3 credits)*
Computer generation of geometric models, optimal design for manufacturing, manufacturing methods based on geometric models such as numerical control tool path generation, plastic mold design and rapid prototyping using stereolithography. Testing and redesign.

**MFG 565 (Aero 565). Optimal Structural Design**
*Prerequisite: Aero 350, Aero 414. I (3 credits)*
Optimal design of structural elements (bar, trusses, frames, plates, sheets) and systems; variational formulation for discrete and distributed parameter structures; sensitivity anal-ysis; optimal material distribution and layout; design for criteria of stiffness, strength, buckling, and dynamic response.

**MFG 566 (ChemE 566). Process Control in Chemical Industries**
*Prerequisite: ChemE 343, ChemE 460. II (3 credits)*
Techniques of regulation applied to equipment and processes in the chemical and petro-chemical industries. Linear and nonlinear control theory, largely in the spectral domain. Controller types, transducers, final control elements, interacting systems, and applications.

**MFG 567 (EECS 567) (ME 567). Introduction to Robotics: Theory and Practice**
*Prerequisite: EECS 380. II (3 credits)*
Introduction to robots considered as electro-mechanical computational systems performing work on the physical world. Data structures representing kinematics and dynamics of rigid body motions and forces and controllers for achieving them. Emphasis on building and programming real robotic systems and on representing the work they are to perform.

**MFG 568 (IOE 567). Advanced Work Measurement and Design**
*Prerequisite: IOE 433 or IOE 463. II (3 credits)*
Non-traditional approaches to job evaluation are applied to a variety of manufacturing and service jobs. Topics include: computer-aided job analyses and design, ergonomic work measurement, evaluation of white collarproductivity, and high level predetermined time systems. Case studies are used extensively to develop observational, analytical, and design skills.

**MFG 569 (IOE 566). Advanced Quality Control**
*Prerequisite: IOE 466. II (3 credits)*
An applied course on Quality Control including Statistical Process Control Modifications, Linear, Stepwise and Ridge Regression Applications, Quality Function Deployment, Taguchi Methods, Quality Policy Deployment, Tolerancing Systems, Process Control Methodologies and Measurement Systems and Voice of the Customer Methodologies Time Series, Experimental Design, Total Quality Management and case studies.

**MFG 570 (EECS 568). Process Control for Microelectronics Manufacturing**
*Prerequisite: graduate standing or permission of instructor. I (3 credits)*
Selected processing steps in microelectronics manufacturing, design of experiments, process and substrate sensors, statistical process control, run-to-run control, real-time control, failure diagnostics, computer implementation of control systems.

**MFG 571 (NA 571). Ship Design Project**
*Prerequisite: prior arrangement with instructor. I, II, IIIa (to be arranged)*
Individual (or team) project, experimental work, research or directed study of selected advanced topics in ship design. Primarily for graduate students.

**MFG 572 (NA 570). Advanced Marine Design**
*Prerequisite: graduate standing required. II (4 credits)*
Organization of marine product development; concurrent marine design. Shipbuilding policy and build strategy development. Group behaviors; leadership and facilitation of design teams. General theories and approaches to design. Conceptual design of ships and offshore projects. Nonlinear programming, multicriteria optimization, and genetic algorithms applied to marine design.

**MFG 573 (NA 561). Marine Product Modeling**
*Prerequisite: NA 570. II (3 credits)*
Fundamental aspects of marine product modeling, data exchange, and visualization. Simulation Based Design. Introduction to activity modeling and information modeling. Overview of Object Oriented Programming. Geometric modeling of solids and surfaces. Simulation and visualization. Virtual prototyping.

**MFG 575 (NA 575). Computer-Aided Marine Design Project**
*Prerequisite: none. I, II, IIIa, IIIb, III (2-6 credits), (to be arranged)*
Development of computer-aided design tools. Projects consisting of formulation, design, programming, testing, and documentation of programs for marine design and constructional use.

**MFG 577 (MSE 577). Failure Analysis of Materials**
*Prerequisite: MSE 350. II (3 credits)*
Analysis of failed structures due to tensile overload, creep, fatigue, stress corrosion, wear and abrasion, with extensive use of scanning electron microscope. Identification and role of processing defects in failure.

**MFG 578 (NA 580). Optimization, Market Forecast and Management of Marine Systems**
*Prerequisite: NA 500. I (4 credits)*
Optimization methods (linear, integer, nonlinear, sequential) concepts and applications in the operations of marine systems. Forecasting methods (ARMA, Fuzzy sets, Neural nets) concepts and applications to shipping and shipbuilding decisions. Economics of merchant shipbuilding and ship scrapping. Elements of maritime management: risk and utility theory. Deployment optimization.

**Mfg 579 (NA 582). Reliability and Safety of Marine Systems**
*Prerequisite: EECS 401 or Math 425 or Stat 412. II (3 credits)*
Brief review of probability, statistics, trade-off analysis, and elements of financial management. Thorough presentation of the methods and techniques of reliability analysis. Marine reliability, availability, maintenance, replacement, and repair decisions. Safety and risk analysis. FMEA, fault-tree and event-tree analysis. Marine applications.

**MFG 580 (ME 580). Rheology and Fracture**
*Prerequisite: ME 382. I (3 credits)*
Mechanisms of deformation, cohesion, and fracture of matter. Unified approach to the atomic-scale origins of plastic, viscous, viscoelastic, elastic, and anelastic behavior. The influences of time and temperature on behavior. Stress field of edge and screw disloca-tions, dislocation interactions, and cross slip.

**MFG 581 (ME 581). Friction and Wear**
*Prerequisite: background in materials and mechanics desirable. II (3 credits)*
The nature of solid surfaces, contact between solid surfaces, rolling friction, sliding friction, and surface heating due to sliding; wear and other types of surface attrition are considered with reference to practical combinations of sliding materials, effect of absorbed gases, surface contaminants or other lubricants on friction, adhesion, and wear; tire and brake performance.

**MFG 582 (MSE 523) (ME 582). Metal-Forming Plasticity**
*Prerequisite: ME 211. II (3 credits)*
Elastic and plastic stress-strain relations; yield criteria and flow rules; analyses of various plastic forming operations. Effects of work hardening and friction, temperature, strain rate, and anisotropy.

**MFG 583 (ME 583). Scientific Basis for Reconfigurable Manufacturing**
*Prerequisite: graduate standing or permission of the instructor. II (alternate years) (3 credits)*
Fundamental concepts in manufacturing with emphasis on welding, machining, and forming. Input and output variables for process control. Characteristics of sensors for feedback in manufacturing. Fiber optics, interferometry, infrared thermal imagery, tactile sensing, force/torque sensing for robots, force dynamometers, acoustic emission. Signal processing. Process modeling for control.

**MFG 584 (ME 584). Control of Machining Systems**
*Prerequisite: ME 461 or equivalent. II (3 credits)*
Advanced control and sensing methodologies for machining processes: milling, turning, drilling, grinding and laser cutting. Machine tool structure. CNC programming. Drive components. Trajectory interpolators. Selection of control parameters. Software compensation and adaptive control. The design process of a comprehensive machining system. Two-hour lecture and two-hour lab per week.

**MFG 585 (ME 585). Machining Dynamics and Mechanics**
*Prerequisite: graduate standing. I even years (3 credits)*
Dynamic cutting process models and process stability issues. Advanced cutting process mechanics and modeling including cutting process damping, thermal energy and cutting temperature, and wear evolution. Single and multi-DOF stability analysis techniques, stability margins and stability charts. Modeling approximations for industrial applications.

**MFG 586 (MSE 580). Materials Science and Engineering Design**
*I (2 credits)*
Design of materials processing systems. Selection and utilization of materials in engineering applications, economic aspects of design, estimating procedures.

**MFG 587 (ME 587) (OM 587). Reconfigurable Agile Manufacturing**
*Prerequisite: one 500-level manufacturing or design or business class. II (3 credits)*
Product-process-market modeling. Principles of mass production. Agility in product design. Agility in manufacturing processes. Flexible line boring. Optimal batch size. System reliability. Product quality. CAD/CAM and CNC. Agility in marketing and delivery. Virtual organizations. Agile scheduling. Using agile strategies in product development.

**MFG 589 (ME 589). Failure Analysis Case Studies**
*Prerequisite: preceded or accompanied by ME 350. II (3 credits)*
Detailed case study of a variety of service failures in engineering structures such as vehicles, medical implants, hoisting equipment, machinery, and consumer products such as ladders, mowers, and tools. Procedures for analysis include applications of optical and electron microscopy; load history, dynamics, and stress analysis; indentation hardness analysis; accident investigation and reconstruction techniques; specification and standards; fracture mechanics. The expert's role in product liability litigation.

**MFG 590. Study or Research in Selected Manufacturing Topics**
*Prerequisite: permission of instructor. I, II, IIIa, IIIb, III (1-3 credits)*
Individual study of specialized aspects of Manufacturing engineering.

**MFG 591 (IOE 591). Queuing Networks in Manufacturing (Special Topics)**
*Prerequisite: permission of instructor. (to be arranged)*
This is a special topics course in the area of queuing networks.

**MFG 594 (EECS 594). Introduction to Adaptive Systems**
*Prerequisite: EECS 303, Math 425 (Stat 425). I (3 credits)*
Programs and automata that learnby adapting to their environment; programs that utilize genetic algorithms for learning. Samuel's strategies, realistic neural networks, connectionist systems, classifier systems, and related models of cognition. Artificial intelligence systems, such as NETL and SOAR, are examined for their impact upon machine learning and cognitive service.

**MFG 598 (EECS 598). Control of Semiconductor Manufacturing Equipment (Special topics)**
*Prerequisite: none. I, II, III, IIIa, IIIb (1-4 credits)*
This is a special topics course in the area of applications of control technology to semiconductor manufacturing.

**MFG 599. Special Topics**
*Prerequisite: see individual department requirements. I, II, IIIa, IIIb, III (3 credits)*

**MFG 605. Factory Physics**
*Prerequisite: none. II (3 credits)*
This is a course on the basic concepts and techniques of operations and inventory management. The foundation of the course is a system of manufacturing laws collectively known as "Factory Physics". These laws relate to measures of plan performance, such as throughput, cycle time, work-in-process, customer service, variability, and quality, in a consistent manner and provide a framework for evaluating and improving operations. Concepts and methods are examined via exercises and case studies.

**MFG 617 (ChemE 617). Advanced Biochemical Technology**
*Prerequisite: ChemE 517 or permission of instructor. II alternate years (3 credits)*
Practical and theoretical aspects of various unit operations required to separate and purify cells, proteins, and other biological compounds. Topics covered include various types of chromatography, liquid/liquid extractions, solid/liquid separations, membrane processing and field enhanced separations. This course will focus on new and non-traditional separation methods.

**MFG 622 (MSE 622) (NERS 622). Ion Beam Modification and Analysis of Materials**
*Prerequisite: NERS 421, NERS 521 or MSE 350 or permission of instructor. II alternate years (3 credits)*
Ion-solid interactions, ion beam mixing, compositional changes, phase changes, micro-structural changes; alteration of physical and mechanical properties such as corrosion, wear, fatigue, hardness; ion beam analysis techniques such as RBS, NRA, PIXE, ion channeling, ion micro-probe; accelerator system design and operation as it relates to implantation and analysis.

**MFG 623 (EECS 623). Integrated Sensors and Sensing Systems**
*Prerequisite: EECS 413 and either EECS 423 or EECS 424 or EECS 425 or EECS 523. I (4 credits)*
Fundamental principles and design of integrated solid-state sensors and sensing systems. Micro machining and wafer bonding. Micro structures for the measurement of visible and infrared radiation, pressure, acceleration, temperature, gas purity, ion concentrations. Merged process technologies for sensors and circuits. Data acquisition circuits, micro actuators and integrated micro systems.

**MFG 634 (IOE 633). Man-Machine Systems**
*Prerequisite: IOE 533 or IOE 536 or equivalent. II (3 credits)*
Introduction to advanced concepts in the identification, design, analysis, development, and implementation of human operated systems; existing and emerging systems identified from industrial and service organizations. Students handle case examples. Relevant theories of communication, decision, and control augmented by reading and laboratory demonstrations where appropriate.

**MFG 645 (IOE 645) (Stat 645). Topics in Reliability and Maintainability**

*Prerequisite: IOE 515 (Stat 526) and IOE 562 (Stat 535). II alternate years (3 credits)*

Advanced topics in reliability and maintainability. Examples include models for component and system reliability, probabilistic design, physics of failure models, degradation modeling and analysis, models form maintainability and availability, and maintenance and monitoring policies

**MFG 990. Dissertation/Pre-Candidate**

*Prerequisite: permission of thesis committee; mandatory satisfactory/unsatisfactory. I, II, III (2-8 credits); IIIa, IIIb (1-4 credits)*

Dissertation work by doctoral student not yet admitted to status as candidate.The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**MFG 995. Dissertation/Candidate**

*Prerequisite: College of Engineering authorization for admission as a doctoral candidate; mandatory satisfactory/unsatisfactory. I, II, III (8 credits); IIIa, IIIb (4 credits)*

Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

# MACROMOLECULAR SCIENCE AND ENGINEERING

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## Program Description

Macromolecular Science and Engineering is an interdisciplinary program that provides the academic and research basis for studies in the science and technology of synthetic and natural macromolecules. Such large molecules exhibit unusual and specific properties as compared to small molecules and a large field has developed in unraveling the scientific foundations of this behavior, both in the synthetic and the biological areas.

The Program at UM is one of the very few where students can achieve competence in both the traditional discipline of their choice and the interdisciplinary field of Macromolecular Science and Engineering. It is a unique graduate program structure that allows a tailor fitting by the students to their individual interests while permitting the faculty to train the students in the Program to a high level of competence. A Ph.D. is offered in Macromolecular Science and Engineering with concentrations in the areas of Biomaterials Engineering, Biomedical Engineering, Chemistry, Chemical Engineering, Materials Science & Engineering, or Physics. The focus is mainly on the Ph.D., but Master's degrees are also granted.

The faculty members are drawn from the departments listed above in addition to Biologic and Materials Science, and Mechanical Engineering; thus making the Program a truly cooperative and interdisciplinary endeavor. The faculty believe the approach taken permits the students to eventually make a more significant contribution to macromolecular science. It also allows the students to develop the self-confidence needed to adapt to the changes inherent in modern research and development. The specific Program requirements include completing most of the course requirements prescribed in each option by the end of the second year, passing a two part comprehensive written examination, selection of a research area and a Research Supervisor and Dissertation Committee. There are also some general Ph.D. Degree requirements set by the Rackham Graduate School.

Counseling on both the general and specific requirements is provided by an advisor representing the Executive Committee of the Macromolecular Science and Engineering Program. The advisor is designated through a selection process during the student's first month. The student then chooses among several major options: Biomaterials Engineering, Biomedical Engineering, Chemistry (organic or physical), Chemical Engineering, Materials Science and Engineering, or Physics. An individualized option is also available.

The progress to a Ph.D. is normally four to five years with coursework being emphasized during the first two years. Students are approved for candidacy after they have completed the basic prescribed courses satisfactorily, passed the comprehensive exam, formed a Dissertation Committee and passed a preliminary oral examination by that Committee. Candidacy is usually achieved within four terms.

## Research

An early start in research is encouraged as soon as the students have demonstrated satisfactory progress in courses and have selected a Research Supervisor. The interdisciplinary nature of the Program allows for a wide range of research possibilities.

## Representative Course Programs

It is recommended that in all the options an introductory course such as MacroSE 412 be taken as part of these credits by all students who do not have a strong polymer background. The majority of the option courses taken should be 500 level or above. See Course Descriptions for individual course information.

### Biomaterials Engineering Option

A minimum of 30 hours of course work from Biomaterials Engineering and Macromolecular Science Courses. This must include a a minimum of 12 hours from Biomaterials and 12 hours from MacroSE. These courses must include a graduate course in biomaterials, biochemistry and biophysics.

### Biomedical Engineering Option

A minimum of 30 hours of course work from Biomedical Engineering and Macromolecular Science Courses. This must include a minimum of 12 hours from Biomedical Engineering and 12 hours from MacroSE. These courses must include a graduate course in biomaterials, biochemistry, and/or biophysics and biomedical engineering.

### Chemistry Option (Organic or Physical)

A minimum of 30 hours of course work from Chemistry and Macromolecular Science Courses. This must include a minimum of 12 hours from Chemistry and 12 hours from MacroSE.

For an Organic option, these courses must include: MacroSE 790, MacroSE 800, MacroSE 535, MacroSE 536, MacroSE 538, Chem 540, Chem 541, Chem 542.

For a Physical option, these courses must include: MacroSE 790, MacroSE 800, MacroSE 535, MacroSE 536, Chem 571, Chem 576, Chem 580 and another approved Chemistry course.

### Chemical Engineering Option

A minimum of 30 hours of course work from Chemical Engineering and Macromolecular Science courses. This must include a minimum of 12 hours from ChE and 12 hours from Macromolecular Science. These courses must include: MacroSE 790, MacroSE 800, MacroSE 535, MacroSE 536, ChE 528, graduate courses in transport phenomena, numerical methods or mathematical modeling and polymer processing.

### Materials Science and Engineering Option

A minimum of 30 hours of course work from Materials Science and Engineering and Macromolecular Science courses. This must include a minimum of 12 hours from MSE and 12 hours from MacroSE.

These courses must include: MacroSE 790, MacroSE 800, MacroSE 535, MacroSE 536, a graduate course in metals and a graduate course in ceramics.

### Physics Option

A minimum of 30 hours of course work from Physics and Macromolecular Science courses. This must include a minimum of 12 hours from Physics and 12 hours from MacroSE.

These courses must include: MacroSE 790, MacroSE 800, Phys 418, MacroSE 536, Phys 505, Phys 506, Phys 507, Phys 510 and an advanced course in physical properties of polymers.

### Individualized Options

An individualized option may be proposed by students. Such students must submit a detailed program in writing to the executive committee for approval.

## Macromolecular Courses

**(Subject = MACROMOL)**

**MacroSE 413 (ChemE 413) (MSE 413). Polymeric Materials**
*Prerequisites: MSE 220 or 250. I (4 credits)*
The synthesis, characterization, microstructure, rheology, and properties of polymer materials. Polymers in solution and in the liquid, liquid-crystalline, crystalline, and glassy states. Engineering and design properties, including viscoelasticity, yielding, and fracture. Forming and processing methods. Recycling and environmental issues.

**MacroSE 415 (ChemE 415) (Mfg 415) (MSE 415). Applied Polymer Processing**
*Prerequisites: MSE 413 or equivalent. II (4 credits)*
Theory and practice of polymer processing. Non-Newtonian flow, extrusion, injection-molding, fiber, film, and rubber processing. Kinetics of and structural development during solidification. Physical characterization of microstructure and macroscopic properties. Component manufacturing and recycling issues, compounding and blending.

**MacroSE 418 (Physics 418). Structural Macromolecular**
*Prerequisite: Physics Math 216, Physics 242 or by permission of instructor. I (3 credits)*
An intensive study of macromolecular structural problems and their solutions: thermodynamics and statistical mechanics of chain molecules; conformational influencing conformational transitions; denaturation; statistical nature of physical properties; nature of general organization and folding in macromolecules; case studies of structural problems in bio- and macro-molecules.

**MacroSE 511 (ChemE 511) (MSE 511). Rheology of Polymeric Materials**
*Prerequisite: a course in fluid mechanics or permission from instructor. (3 credits)*
An introduction to the relationships between the chemical structure of polymer chains and their rheological behavior. The course will make frequent reference to synthesis, processing, characterization, and use of polymers for high technology applications.

**MacroSE 512 (ChemE 512) (MSE 512). Polymer Physics**
*Prerequisite: senior or graduate standing in engineering or physical science. II (3 credits)*
Structure and properties of polymers as related to their composition, annealing and mechanical treatments. Topics include creep, stress relaxation, dynamic mechanical properties, viscoelasticity, transitions, fracture, impact response, dielectric properties, permeation, and morphology.

**MacroSE 514 (Mfg 514) (MSE 514). Composite Materials**
*Prerequisite: MSE 350. I alternate years (3 credits)*
Behavior, processing and design of composite materials, especially fiber composites. Emphasis is on the basic chemical and physical processes currently employed and expected to guide the future development of the technology.

**MacroSE 515 (MSE 515). Mechanical Behavior of Solid Polymeric Materials**
*Prerequisite: ME 211, MSE 412. II even years (3 credits)*
The mechanical behavior of polymers from linear viscoelastic to yield and fracture are covered. Specific topics include dynamic-mechanical relaxations, creep, yielding, crazing, fatigue, and fracture mechanics. The materials include toughened plastics, polymer alloys and blends, and composite materials. Structured design with plastics is also considered.

**MacroSE 517 (ME 517). Mechanics of Polymers I**
*Prerequisite: ME 511 (AM 511) or permission of instructor. II (3 credits)*
Constitutive equation for linear small strain viscoelastic response; constant rate and sinusoidal responses; time and frequency dependent material properties;

energy dissipation; structural applications including axial loading, bending, torsion, three dimensional response, thermo-viscoelasticity, correspondence principle, Laplace transform and numerical solution methods.

**MacroSE 535 (Chem 535). Physical Chemistry of Macromolecules**
*Prerequisite: Chem 463 or Chem 468. I (3 credits)*
The theory and application of useful methods for studying natural and synthetic polymers will be stressed. The methods discussed include osmotic pressure, sedimentation equilibrium, Brownian motion, diffusion, sedimentation transport, intrinsic viscosity, scattering of light and x-rays, optical and resonance spectra, flow and electric bi-refringence, depolarization of fluorescence, circular dichroism and magneto optical rotatory dispersion, electrophoresis, titration curves, kinetics of polymerization, suitable distribution functions for expressing heterogeneity, rigidity and viscosity of gels.

**MacroSE 536 (Chem 536). Laboratory in Macromolecular Chemistry**
*Prerequisite: Chem 535 or Physics 418 or permission of instruction. I alternate years (2 credits)*
Experimental methods for the study of macromolecular materials in solution and in bulk state.

**MacroSE 538 (Chem 538). Organic Chemistry of Macromolecules**
*Prerequisite: Chem 215, Chem 216, and Chem 230 or Chem 241/242, 260. I (3 credits)*
The preparation, reactions, and properties of high molecular weight polymeric materials of both natural and synthetic origin. Two lectures and reading.

**MacroSE 751 (Chem 751) (ChemE 751) (MSE 751) (Physics 751). Special Topics in Macromolecular Science**
*Prerequisite: permission of instructor. (2 credits)*

**MacroSE 790. Faculty Activities Research Survey**
This course introduces students to the research activities of MacroSE faculty with the intent of helping a student to choose his research advisor in the first term.

**MacroSE 800. Macromolecular Seminar I, II**
*(2 credits)*
Student presentation of selected seminar topics in macromolecular science and engineering.

**MacroSE 890. Introduction to Research Techniques**
*Prerequisite: permission of chairman. every term (1-8 credits)*
This course is used for research carried out to earn the master's degree.

**MacroSE 990. Dissertation Research Precandidacy**
*Prerequisite: permission. every term (1-8 credits)*
This course number is used for doctoral research by students not yet admitted to candidacy. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**MacroSE 995. Dissertation Research/Candidacy**
*Prerequisite: permission. every term (8 credits); (4 credits) in half-term*
This course number is used for doctoral research by students who have been admitted to candidacy. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

## Faculty

The research and teaching faculty of the Macromolecular Science and Engineering Center consists of members from several departments within the University.

Ellen M. Arruda, *Associate Professor of Mechanical Engineering and Applied Mechanics and Macromolecular Science and Engineering*

Arthur J. Ashe III, *Professor of Chemistry and Macromolecular Science and Engineering*

Mark Banaszak-Holl, *Associate Professor of Chemistry, and Macromolecular Science and Engineering*

Stacy G. Bike, *Associate Professor of Chemical Engineering, and Macromolecular Science and Engineering*

Zhen Chen, *Assistant Professor of Chemistry, and Macromolecular Science and Engineering*

M. David Curtis, *Professor of Chemistry, and Macromolecular Science and Engineering*

Frank E. Filisko, *Professor of Materials Science and Engineering, and Macromolecular Science and Engineering*

Ronald Gibala, *Professor of Materials Science and Engineering, and Macromolecular Science and Engineering*

Erdogan Gulari, *Professor of Chemical Engineering, and Macromolecular Science and Engineering*

L. Jay Guo, *Assistant Professor of Electrical Engineering and Computer Science, and Macromolecular Science and Engineering*

Jerzy Kanicki, *Professor of Electrical Engineering and Computer Science, and Macromolecular Science and Engineering*

Samuel Krimm, *Biophysics Research Division, Professor of Physics, and Macromolecular Science and Engineering*

Katsuo Kurabayashi, *Assistant Professor of Mechanical Engineering and Applied Mechanics, and Macromolecular Science and Engineering*

Richard M. Laine, *Associate Professor of Materials Science and Engineering, Chemistry, and Macromolecular Science and Engineering*

Ronald G. Larson, *G.G. Brown Professor of Chemical Engineering and Chair, Chemical Engineering and Professor, Macromolecular Science and Engineering*

Peter X. Ma, *Assistant Professor of Biologic and Materials Sciences, and Macromolecular Science and Engineering*

David C. Martin, *Associate Professor of Materials Science and Engineering, and Interim Director, Macromolecular Science and Engineering*

Adam Matzger, *Assistant Professor of Chemistry, and Macromolecular Science and Engineering*

David J. Mooney, *Associate Professor of Biologic and Materials Science, Chemical Engineering, and Macromolecular Science and Engineering*

A. Ramamoorthy, *Assistant Professor of Chemistry, and Macromolecular Science and Engineering; Assistant Research Scientist, Biophysics Research Division*

Paul G. Rasmussen, *Professor of Chemistry, and Macromolecular Science and Engineering*

Richard E. Robertson, *Professor of Macromolecular Science and Engineering, and Professor of Materials Science and Engineering*

Michael J. Solomon, *Assistant Professor of Chemical Engineering, and Macromolecular Science and Engineering*

Suichi Takayama, *Assistant Professor of Biomedical Engineering, and Macromolecular Science and Engineering*

Alan S. Wineman, *Professor of Mechanical Engineering and Applied Mechanics, and Macromolecular Science and Engineering*

Albert F. Yee, *Professor of Materials Science and Engineering, and Professor of Macromolecular Science and Engineering*

Robert Zand, *Professor of Biological Chemistry, and Macromolecular Science and Engineering, Research Scientist (Biophysics)*

Robert M. Ziff, *Professor of Chemical Engineering, and Macromolecular Science and Engineering*

*Renee Hilgendorf (reneeh@umich.edu)*
*2168 H.H. Dow Building*
*2300 Hayward*
*Ann Arbor, Michigan 48109-2136*
*(734) 763-9790*
*(734) 763-4788 fax*
*mseuww.engin.umich.edu*

## Graduate degrees

Master of Science in Engineering (M.S.E.) in Materials Science and Engineering

Doctor of Philosophy (Ph.D.) in Materials Science and Engineering

### M.S.E. in Materials Science and Engineering

A total of 30 graduate-level credit hours of departmental and cognate subjects must be completed for this degree. At least 21 hours of the 30 hours must be formal course work which includes MSE 590 (one credit hour) and a minimum of two cognate courses. At least 15 of the required 30 credit hours must be chosen from Materials Science and Engineering department course offerings or their equivalents recommended by the graduate advisor. Each cognate course must be in a technical discipline and at least two credit hours. Students receiving financial aid from the department must take nine credit hours of MSE 690 and submit a master's thesis for approval by the department.

### Ph.D. in Materials Science and Engineering

A doctoral committee is appointed for each applicant to supervise the investigative work of the student and election of graduate courses of instruction and passing the qualifying examination. Candidacy is achieved when the student demonstrates competence in his/her field of knowledge through completion of courses and passing the preliminary examination.

The doctoral degree is conferred after the student presents the result of thier investigation in the form of a dissertation, and in recognition of marked ability and scholarship in a relatively broad field of knowledge.

The Department will furnish details of requirements upon request. Also, a pamphlet that describes the general procedure leading to the doctorate is available in the Graduate School Office, 1004 Rackhan Building, upon request.

## Facilities

The facilities for the program in materials science and engineering are housed primarily in the H.H. Dow Building. These include laboratories equipped for basic studies of the structures and properties of metals, polymers, ceramics and electronic materials; special purpose laboratories for studies of crystal plasticity, high-temperature alloys, and structural composites; and instrument laboratories containing optical and electron microscopes, x-ray diffraction and spectroscopic apparatus, and precision mechanical testing equipment.

**Note:** Please refer to pages 142-145 of this *Bulletin* for Materials Science and Engineering course descriptions and a listing of Materials Science and Engineering faculty.

# MECHANICAL ENGINEERING

*Cynthia Quann-White (cynthiaq@umich.edu)*
*2206 G.G. Brown Building*
*2350 Hayward*
*Ann Arbor, Michigan 48109-2125*
*(734) 763-9223*
*(734) 647-7303 fax*
*www.engin.umich.edu/dept/meam/*

## Graduate Degrees

Master of Science in Engineering (M.S.E.) in Mechanical Engineering

Doctor of Philosophy (Ph.D.) in Mechanical Engineering

### M.S.E. in Mechanical Engineering

The requirement for this degree is 30 credit hours of approved graduate course work. At least 18 hours must be taken in mechanical engineering, 6 hours in mathematics, and 6 cognate credits. Up to 6 credit hours of research or 9 credit hours of thesis can be taken as part of a 30-credit-hour requirement. Details of course requirements and fields of specialization will be furnished by the department upon request.

### Ph.D. in Mechanical Engineering

A doctoral committee is appointed for each applicant to supervise the investigative work of the student and election of graduate courses of instruction and passing the qualifying examination. Candidacy is achieved when the student demonstrates competence in his/her field of knowledge through completion of courses and passing the preliminary examination.

The doctoral degree is conferred after the student presents the result of thier investigation in the form of a dissertation, and in recognition of marked ability and scholarship in a relatively broad field of knowledge.

The Department will furnish details of requirements upon request. Also, a pamphlet that describes the general procedure leading to the doctorate is available in the Graduate School Office, 1004 Rackham Building, upon request.

## Facilities

The laboratories of the Department of Mechanical Engineering and Applied Mechanics, located in the George Granger Brown Laboratories, Walter E. Lay Automotive Laboratory, and H.H. Dow buildings on the North Campus, provide facilities for both instruction and research. The George Granger Brown Laboratories Building contains the thermodynamics, heat transfer, and fluid mechanics laboratories; a drop-tower for zero-g heat transfer studies and a large centrifuge for high-g investigations; a two-phase flow loop; holographic measurements laboratory; and thermal systems research. Also located in this building are the biomechanics laboratory; robotics laboratory; the manufacturing processes and integrated manufacturing laboratories; laser processing laboratories; and the materials laboratories, which provide facilities for investigations in such areas as adaptive controls, welding, acoustic emission, brittle fracture, heat treating, plasticity, friction and wear, surface phenomena, and mechanical properties.

The Walter E. Lay Automotive Laboratory houses the mechanical analysis laboratory with a wide variety of electromechanical instrumentation and computers for the experimental analysis of dynamics of mechanical systems; the cavitation and multiphase flow laboratory for theoretical and experimental investigations into many aspects of such phenomena; the automatic controls laboratory for demonstrating and investigating principles and applications of control systems; the combustion laboratory with a gas chromatograph and an infrared spectrometer; and the facilities for automotive engineering, which include a number of well-instrumented test cells for reciprocating engines, a test cell for a small aircraft gas turbine, as well as a number of single cylinder engines.

The Integrated Manufacturing Systems Laboratory (IMSL) in the H.H. Dow Building is one of the premiere manufacturing research laboratories in the U.S., with facilities to support machining, computer-aided manufacturing, and precision engineering.

**Note:** Please refer to pages 148-157 of this *Bulletin* for Mechanical Engineering course descriptions and a listing of Mechanical Engineering faculty.

*NAME-grad-apps@umich.edu*
*221 Naval Architecture and Marine Engineering Building*
*2600 Draper Road*
*Ann Arbor, Michigan 48109-2145*
*(734) 936-0566*
*(734) 936-8820 fax*
*http://www.engin.umich.edu/dept/name*

## Graduate Degrees

Master of Science (M.S.) in Naval Architecture and Marine Engineering

Master of Science in Engineering (M.S.E.) in Naval Architecture and Marine Engineering

Joint Master of Science in Engineering (M.S.E.) Master of Business Administration (M.B.A.) in Naval Architecture and Marine Engineering

Master of Engineering (M.Eng.) in Concurrent Marine Design

Professional Degrees: Naval Architect (N.A.) and Marine Engineer (M.E.)

Doctor of Philosophy (Ph.D.) in Naval Architecture and Marine Engineering

### M.S. and M.S.E. in Naval Architecture and Marine Engineering

The applicant should have a bachelor's degree in a mechanics-oriented engineering discipline, such as naval architecture and marine engineering, aerospace, mechanical, applied mechanics, or civil engineering. Applicants with bachelor's degrees in other engineering disciplines, mathematics, or physics may have to take additional courses beyond the 30-credit-hour minimum.

A minimum of 30 credit hours is required for the degree, of which at least 18 hours are taken in naval architecture and marine engineering. A student is required to take NA 500, plus at least two of five core courses. Half of the program must consist of 500-level (or higher) courses. Three or more hours must be in graduate-level mathematics courses. Two courses of at least 2 credit hours each must be taken outside the department.

The student is free to set up his/her own program of course work that meets the above requirements. The two primary areas of graduate study and research are marine mechanics, and marine systems design. In each of these broad areas of focus there are a number of sub-areas of specialization possible through the choice of electives. Examples of such areas are hydrodynamics, structures, coastal processes, computer-aided marine design, concurrent marine design, marine structures, marine systems management and offshore engineering.

### Joint M.S.E./M.B.A. in Naval Architecture and Marine Engineering

The Department of Naval Architecture and Marine Engineering and the School of Business Administration offer a joint degree program for qualified persons to pursue concurrent work in business administration and naval architecture and marine engineering studies leading to the M.B.A. and M.S.E. degrees. The program is arranged so that all requirements for both degrees can be completed in two years of enrollment, depending on undergraduate NAME background and the specialty area of the NAME master's program. The degrees are awarded simultaneously.

The program can begin with studies in either school. However, because of the sequential nature of the core courses in the M.B.A. program, most students will find it advantageous to start with year one in the Business School. During the remainder of the program, courses might be taken in both schools. Students who wish to begin in NAME should consult a counselor in the Business School to formulate an appropriate plan of study.

Students admitted to this joint program must satisfy the following degree requirements:

- 31.5 credit hours M.B.A. core
- 13.5 elective hours in business administration
- 18 hours of graduate-level NAME courses, including NA 500 and any two of NA 510, NA 520, NA 540, NA 570, and NA 580.
- 3 or more credit hours of mathematics
- Up to 9 hours acceptable to program advisor, some of which could be part of the business electives. Interested students must file separate applications and be admitted to both schools. The application fee can be paid to either of the two schools.

### M.Eng. in Concurrent Marine Design

The M.Eng. in Concurrent Marine Design is a professionally oriented graduate degree designed to meet the needs of the marine industry. It focuses on providing entry- and mid-level marine professionals with knowledge and practical experience dealing with the design of marine vehicles, structures, and systems for both performance and production. The integrating philosophy for this degree is that of concurrent engineering – the simultaneous consideration of the design of both the product and the production methods considering the full life-cycle costs and operation of the product.

World competitiveness demands a new and simultaneous approach where performance and production are considered concurrently with the goal of an associated reduction in the design/build time. This approach requires integrating support of a product model-based computer environment with simulation of both product and process performance. This degree program deals with the linkages within early marine design among life-cycle economics, performance, and manufacturing processes.

A prerequisite for this program of study is the equivalent of a Bachelor of Science in Engineering degree in naval architecture and marine engineering, naval architecture, mechanical engineering, civil engineering, aerospace engineering, or an equivalent field. Relevant marine industrial experience totaling at least one year is required; two years is preferred. Significant assignments will be considered as a substitute. Prerequisite courses are Foundations of Ship Design (NA 470), and Introduction to Probability and Statistics (Stat 412), or their equivalents.

The degree requires 30 credits of graduate courses beyond the prerequisites, of which 24 must be graded (not pass/fail), 15 credits must be at the 500-level and above, and 15 of the 24 graded credits must be in engineering courses. The minimum grade point average for graduation is 5.0/9.0 ("B" average).

In addition to the prerequisite courses, each student is required to meet the following course distribution requirements:

- Ship Production Planning and Control (NA 460); Marine Product Modeling (NA 561); and Advanced Marine Design (NA 570).
- At least 6 credits from a list of advanced engineering courses in related fields. Optimization, Market Forecasts and Management of Marine Systems (NA 580) or Concurrent Marine Design Management (NA 562) and at least one more relevant non-engineering course.
- Six (6) credits of industrial-based Concurrent Marine Design Team Project (NA 579).

The above requirements are intended to provide the student with the educational background demanded by an engineering design environment capable of integrating basic engineering principles with manufacturing agility and life-cycle costs. The program helps prepare the student for participation and leadership in cross-function design teams involved in marine systems design.

### Professional Degrees: Naval Architect (N.A.) or Marine Engineer (M.E.)

The professional degree programs require a minimum of 30 credit hours of work beyond the master's level, or its equivalent, taken at the University of Michigan with an average grade of "B" or better. A minimum of 20 credits must be in formal course work.

Requirements for the professional degree include:

- At least 24 credits beyond the master of science in engineering degree requirements in the area of the program.
- Of the 24 credits in the program, at least six credits devoted to a professional degree thesis involving a research, design, or development study. In general, the thesis project is intended to provide results which are immediately and directly applicable to design practice in naval architecture or marine engineering in the context of concurrent marine design. The thesis project must include a prospectus presentation and a written report. A committee of faculty members will supervise the work, evaluate the report, and conduct a final oral examination of the work.
- At least three graduate-level courses in cognate fields other than mathematics.
- At least nine credits in mathematics beyond the bachelor of science in engineering mathematics requirement of the department.

Successful completion of a comprehensive examination is required and normally takes place near the end of the course work. It emphasizes the application of engineering science in practice and the student should demonstrate maturity in formulating and solving problems at the level of advanced engineering practice. The professional degree comprehensive examination, owing to its different level and emphasis, may not be substituted for the first part of the Ph.D. preliminary examination.

### Doctor of Philosophy (Ph.D.) in Naval Architecture and Marine Engineering

The doctoral degree is conferred in recognition of marked ability and scholarship in some relatively broad field of knowledge. A part of the work consists of regularly scheduled graduate courses of instruction in the chosen field and in such cognate subjects as may be required by the committee. In addition, the student must pursue independent investigation in a subdivision of the selected field and must present the results of the investigation in the form of a dissertation.

A student becomes an applicant for the doctorate when admitted to the Horace H. Rackham School of Graduate Studies and accepted in a field of specialization. Candidacy is achieved when the student demonstrates competence in her/his broad field of knowledge through the completion of course work, and passing comprehensive exams, and the presentation of a Ph.D. prospectus.

There is no general course requirement for the doctorate. However, during the course of a student's graduate study, nine credit hours of math and 56 total classroom credit hours are expected as a minimum. The comprehensive exam consists of a Part I written exam covering general mechanics, and a Part II oral exam in the student's area of specialization. The prospectus is a written research proposal describing the proposed Ph.D. thesis area that is also presented orally. A special doctoral committee is appointed for each applicant to supervise the work of the student both in election of courses and in preparation of the dissertation.

Requirements regarding foreign language and non-technical courses are left to individual departments or programs, and to the Graduate School. A prospective doctoral student should consult the program advisor regarding specific details.

A pamphlet that describes the general procedure leading to the doctorate is available in the Graduate School office, 1004 Rackham Building, upon request.

## Facilities

The department operates the Marine Hydrodynamics Laboratory (MHL) located on Central Campus. The laboratory houses a 110 x 6.7 x 3.2 meter towing tank, a low turbulence, free-surface water channel, a gravity-capillary water wave facility, a 35-meter gravity wave tank, and a propeller tunnel for student use. The laboratory is equipped with appropriate shops and state-of-the-art instrumentation, much of which was developed in-house.

In addition to the MHL, the department also has an Ocean Engineering Laboratory and a Computer Aided Marine Design Laboratory. The Ocean Engineering Laboratory (OEL) is involved in full-scale field measurements such as beach erosion measurements, measurements of thermal fronts and pollution transport on the Great Lakes, and active remote sensing of the ocean surface from satellites and aircraft. In addition, the OEL is the home of the University's underwater Remote Operated Vehicle for Education and Research (M-ROVER), that is used for submerged vehicle/dynamics studies in the undergraduate curriculum and for exploration and research of the Great Lakes and the oceans.

The Computer Aided Marine Design Laboratory is equipped with several types of high-end graphics work stations in order to develop computer aided design tools and scientific visualization techniques. Both facilities are used for teaching and student and faculty research.

**Note:** Please refer to pages 161-165 of this *Bulletin* for Naval Architecture and Marine Engineering course descriptions and a listing of Naval Architecture and Marine Engineering faculty.

*www.ners.engin.umich.edu*

## Graduate Degrees

Master of Science (M.S.) in Nuclear Science

Master of Science in Engineering (M.S.E.) in Nuclear Engineering and Radiological Sciences

Master of Science (M.S.) in Scientific Computing

Doctor of Philosophy (Ph.D.) in Nuclear Science

Doctor of Philosophy (Ph.D.) in Nuclear Engineering and Radiological Sciences

### M.S. in Nuclear Science and M.S.E. in Nuclear Engineering and Radiological Sciences

Students entering the program in Nuclear Engineering and Radiological Sciences must have a bachelor's degree from an accredited engineering program. The nuclear science program is available to those with bachelor's degrees from recognized programs in physics, chemistry, or mathematics who wish to work in the field of nuclear engineering and radiological sciences.

Students planning to enter the M.S. degree program who do not have an undergraduate degree in Nuclear Engineering and Radiological Sciences should take courses in atomic and nuclear physics and in advanced mathematics for engineers (Math 450 or equivalent). Students without these prerequisites will be requested to make up the deficiencies in addition to the 30 hours required for the M.S. degree. An upper-level course in electronic circuits (EECS 314 and Physics 455 or equivalent), a course in fluid mechanics (CEE 325 or equivalent), a course in computer programming (Eng 101, EECS 285, or equivalent) are recommended as desirable preparation.

The requirements for the master's degree are 30 hours of course work at the graduate level, including 20 hours from nuclear engineering and radiological sciences and two courses outside the department. At least four of the nuclear engineering and radiological sciences courses, excluding NERS 599 and NERS 799, must be at the 500-level or higher. All M.S. degree students must take a formal 400-level or higher lab course while enrolled as a graduate student. The student, with approval of the program advisor, may substitute a master's project report for 2 to 6 credit hours of graduate course work, with the NERS 599 credits not to exceed 3 credit hours per full term. In this case, the student will be required to make a seminar presentation of the master's project, in addition to a written final report. Additional courses are selected with the help of the program advisor from courses in nuclear engineering and radiological sciences, cognate fields of engineering, mathematics, physics, chemistry, and others. Where the entering student presents evidence of satisfactory completion of work equivalent to any of the nuclear engineering and radiological sciences courses, substitution of other courses will be arranged by the program advisor.

### M.S. in Scientific Computing

The M.S. degree in Scientific Computing has been developed to meet the needs of industrial engineers who wish to return to school to upgrade their skills in numerical computation. The second target group is students, with or without industrial experience, who wish to study intensively scientific computing as a supplement to a previous or concurrent master's or doctoral degree program.

### Ph.D. in Nuclear Science and Ph.D. in Nuclear Engineering and Radiological Sciences

The doctoral degree is conferred in recognition of marked ability and scholarship in some relatively broad field of knowledge. A part of the work consists of regularly scheduled graduate courses of instruction in the chosen field and in such cognate subjects as may be required by the committee. In addition, the student must pursue independent investigation in a subdivision of the selected field and must present the result of the investigation in the form of a dissertation.

A student becomes an applicant for the doctorate when admitted to the Horace H. Rackham School of Graduate Studies and accepted in a field of specialization. Candidacy is achieved when the student demonstrates competence in her/his broad field of knowledge through completion of a prescribed set of courses and passing a comprehensive examination.

There is no general course or credit requirement for the doctorate. In most areas, a student must pass a comprehensive examination in a major field of specialization and be recommended for candidacy for the doctorate. A special doctoral committee is appointed for each applicant to supervise the work of the student both as to election of courses and in preparation of the dissertation.

Requirements regarding foreign language and non-technical courses are left to individual departments or programs, and to the Graduate School. A prospective doctoral student should consult the program advisor regarding specific details.

A pamphlet that describes the general procedure leading to the doctorate is available in the Graduate School office, 1004 Rackham Building, upon request.

## Facilities

The Department of Nuclear Engineering and Radiological Sciences occupies the Mortimer E. Cooley Building, which contains departmental offices, faculty offices, classrooms, and several of the labs listed below. Other laboratories of the department are housed in the Phoenix Memorial Laboratory and the Naval Architecture and Marine Engineering (NAME) Building. The Department of Nuclear Engineering and Radiological Sciences has a number of special facilities and laboratories that allow students to get hands-on experience with systems that manipulate matter at a fundamental level. These include:

Ford Nuclear Reactor

Glow Discharge Laboratory

High Temperature Corrosion Laboratory

Intense Energy Beam Interaction Laboratory

Materials Preparation Laboratory

Metastable Materials Laboratory

Michigan Ion Beam Laboratory

Radiation Detection Laboratory

Radiation Imaging Laboratory

Radioactive Waste Management-Laboratory

Radiological Health Engineering

Nuclear Engineering and Radiological Sciences

Nuclear Science and Nuclear Engineering

## Contact Information

### Nuclear Science and Nuclear Engineering

Peggy Jo Gramer (pjgrammer@umich.edu)
1916 Mortimer E. Cooley Building
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Ann Arbor, Michigan 48109-2104
(734) 615-8810
(734) 763-4540 fax

### Scientific Computing

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1919 Mortimer E. Cooley Building
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Ann Arbor, Michigan 48109-2104
(734) 936-3130
(734) 763-4540 fax

**Note:** Please refer to pages 168-172 of this *Bulletin* for Nuclear Engineering and Radiological Sciences course descriptions and a listing of Nuclear Engineering and Radiological Sciences faculty.

# DIRECTORY-UNIVERSITY OF MICHIGAN

## General University Offices (area code 734)

Campus Information Center ........ 763-INFO

Academic Affairs (Provost's Office), 3074 Fleming Bldg. ........ 764-9290

Admissions, Undergraduate, 1220 Student Activities Bldg. (SAB) ........ 764-7433

Career Planning and Placement, 3200 SAB ........ 764-7460

Cashier's Office, 1015 Literature, Science, and the Arts Bldg. (LS&A) ........ 764-8230

1400 Pierpont Commons ........ 936-4936

Employment:

- Student, 2503 SAB ........ 763-4128
- Hospital, 300 N. Ingalls Bldg. (NIB), Room 8A04 ........ 747-2375
- Campus, G250 Wolverine Tower ........ 764-7280

Academic Outreach, 837 Greene Street ........ 764-5300

Financial Aid, 2011 SAB ........ 763-6600

Graduate School, 106 Rackham Bldg.

- Domestic Admissions ........ 764-8129
- International Admissions, ........ 764-8129

76-GUIDE, 24-hr. Telephone Counseling Svc.
SOS Crisis Center, 114 N. River ........ 764-8433 (76-GUIDE)

Housing, 1011 SAB:

- Residence Halls Assignments ........ 763-3164
- Family Housing Assignments ........ 763-3164
- Off-Campus Housing ........ 763-3205
- Off-Campus Housing (cooperatives), 337 E. William ........ 662-4414
- Off-Campus Housing (fraternities, sororities), 4115 Michigan Union ........ 936-3686
- Fees, payment of, Cashier's Office, 1015 LS&A Bldg. ........ 764-8230

International Center: Central Campus, 603 E. Madison ........ 764-9310

North Campus, Pierpont Commons, Room B510 ........ 936-4180

Ombuds, 3000 Michigan Union ........ 763-3545

Office of New Student Programs:
Orientation, University Mentorship Program, and Welcome to Michigan
3511 SAB ........ 764-6413

President's Office, 2074 Fleming Bldg. ........ 764-6270

Secretary of the University, 2012 Fleming, ........ 763-5553

Student Financial Operations: Room, Board, and Tuition, 2226 SAB ........ 764-7447

Student Activities and Leadership, 2205 Michigan Union ........ 763-5900

Student Legal Services, 2304 Michigan Union ........ 763-9920

University Health Service, 207 Fletcher

- http://www.uhs.umich.edu
- Appointments ........ 764-8325
- Information ........ 764-8320

Veterans Affairs, 555 LS&A Bldg. ........ 764-1575

## U-M College of Engineering Offices (area code 734)

General Information: ........ 647-7000

http://www.engin.umich.edu/

Academic Services (Withdrawal/Disenrollment), 1401 LEC ........ 647-7111

Computer Aided Engineering Network (CAEN), Hotline, 2320 Media Union ........ 763-5041

Engineering Career Resource Center (students and alumni), 230 Chrysler Center ........ 647-7160

Engineering Council (UMEC), 1230 EECS Bldg. ........ 764-8511

Engineering Learning Resource Center (ELRC), G264 LEC ........ 647-7127

Engineering Advising Center,1009 LEC ........ 647-7106

Graduate Professional Programs (D.Eng., M.Eng., M.S. in TIDM), 245 Chrysler Center ........ 647-7024

International Programs Office, 245 Chrysler Center ........ 647-7026

Minority Engineering Program Office (MEPO), 1463 LEC ........ 647-7120

**Recruitment, Transfer Admissions and Scholarships**

Robert H. Lurie Engineering Center (LEC) Room 1108 ........ 647-7101
(includes recruitment of first-year and transfer undergraduate students; undergraduate transfer admission—cross-campus, external and international, and admission of students with guest or special status)

Scholarships, 1432 LEC ........ 647-7113

Student Leadership and Academic Services ........ 647-7155

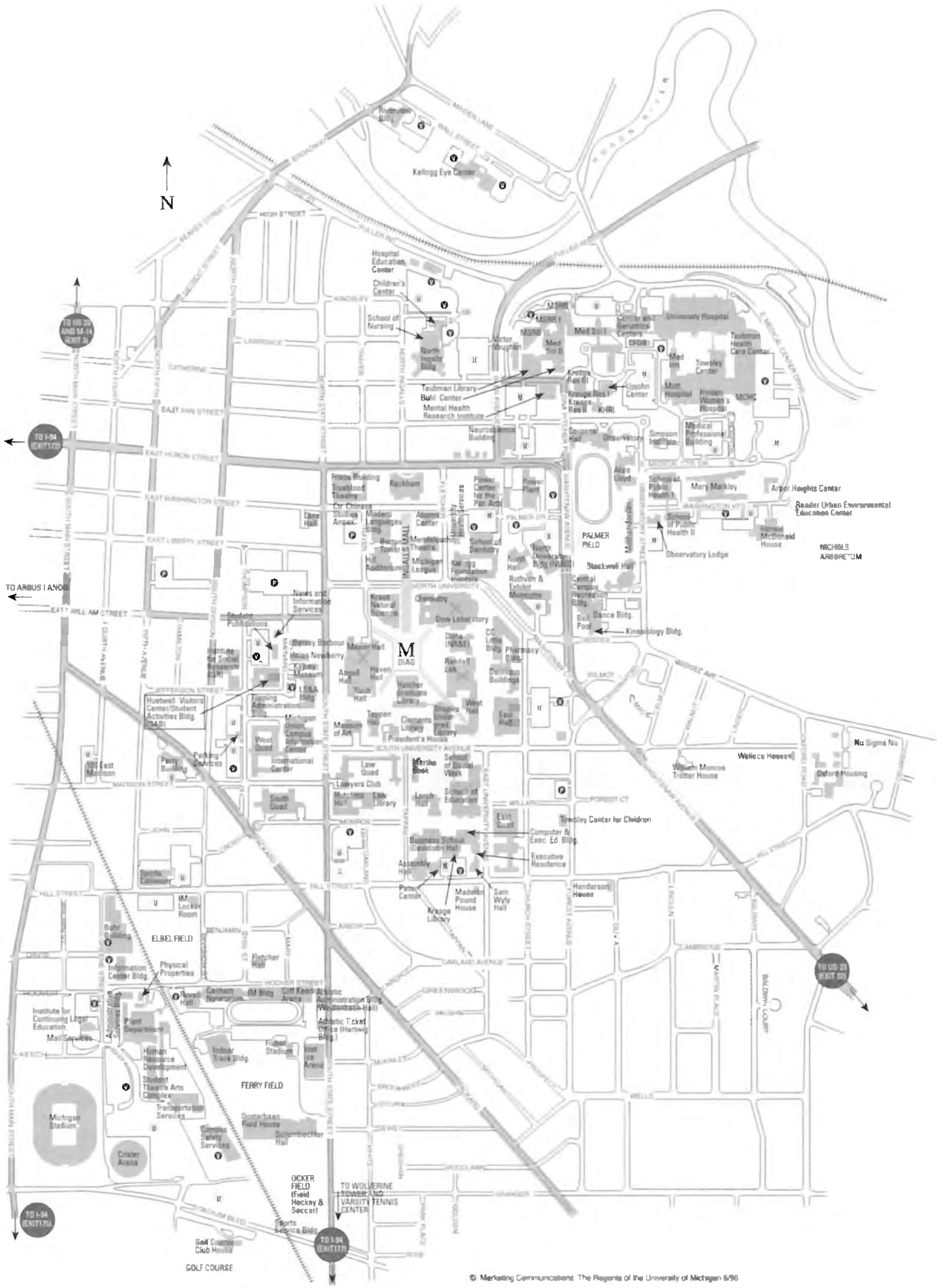
Society of Minority Engineering Students (SMES), 1232 EECS Bldg. ........ 764-7252

Society of Women Engineers (SWE), 1226 EECS Bldg. ........ 763-5027

Undergraduate Education ........ 647-7150

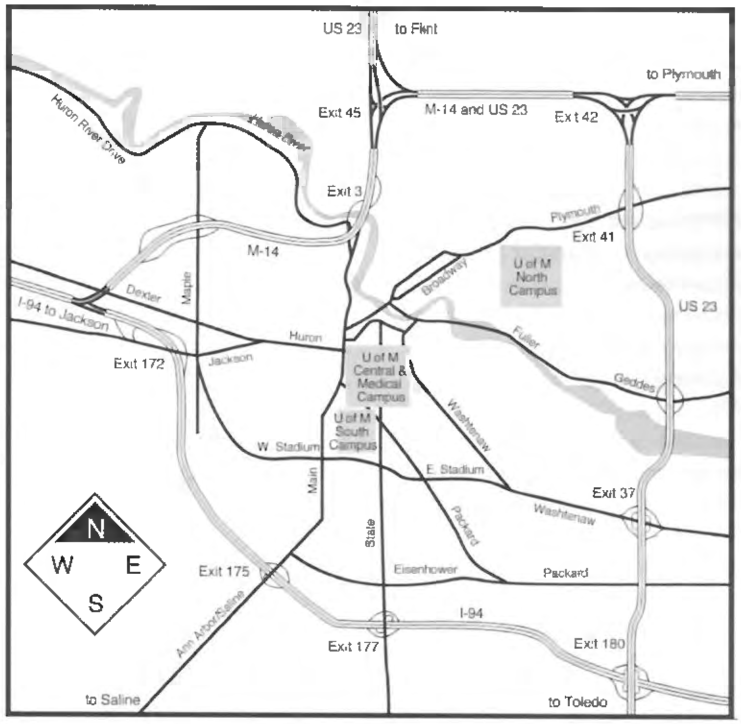
Women in Engineering Office, 1240 LEC ........ 647-7012

# CENTRAL CAMPUS MAP

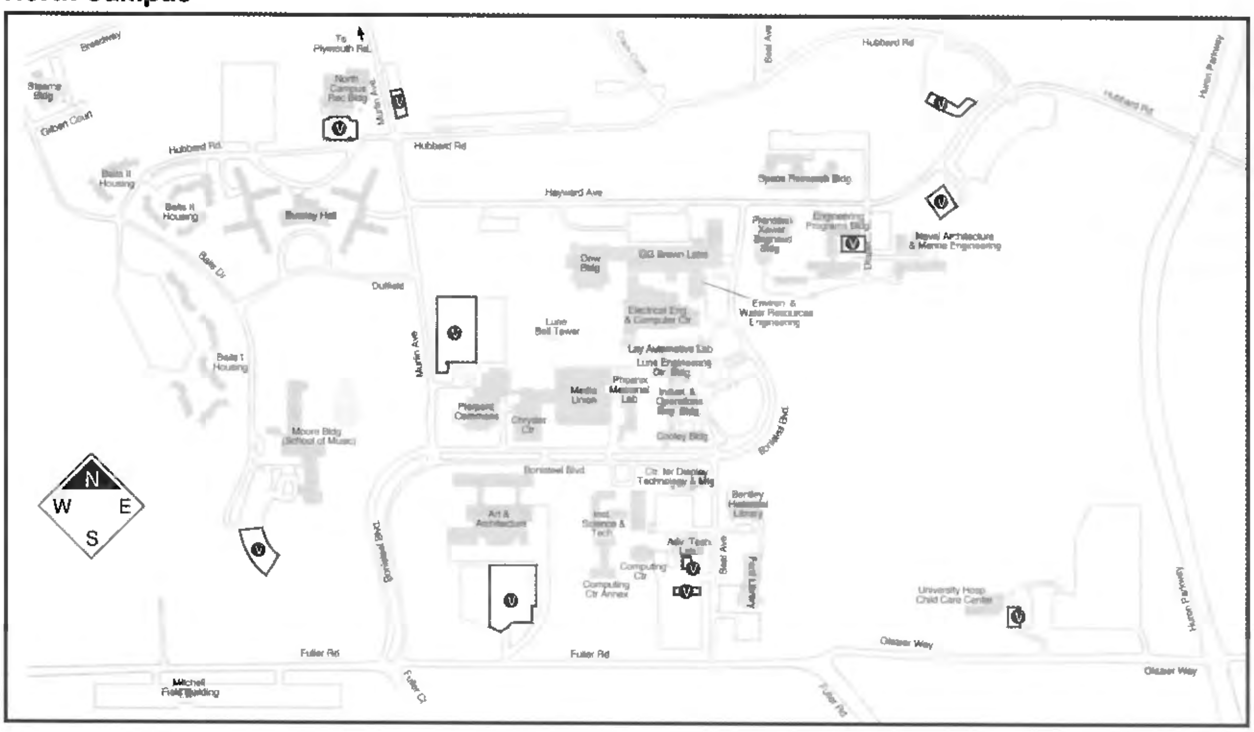


# NORTH CAMPUS MAP

## Ann Arbor Area




## University of Michigan North Campus



# INDEX

## A



## B

# INDEX

# INDEX

## M



## N

# INDEX

# INDEX

# NOTES

# NOTES

University of Michigan
College of Engineering

**Recruitment, Transfer Admissions, and Scholarships**
Robert H. Lurie Engineering Center
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734 647-7126 fax
http://www.engin.umich.edu