

MECHANICAL ENGINEERING

Emeriti: (Professors) James L. Adams, Peter Bradshaw, Daniel B. DeBra, Robert H. Eustis, Thomas J. R. Hughes, James P. Johnston,* Thomas R. Kane, William M. Kays, Joseph B. Keller, Robert McKim, Robert J. Moffat,* M. Godfrey Mungal, J. David Powell, Rudolph Sher, Charles R. Steele,* Milton D. Van Dyke, Douglass J. Wilde*;
(Professors, Research) Elliot Levinthal, Richard M. Christensen, Sidney Self, Felix Zajac

Mechanical Engineering Executive Committee: Mark Cappelli (Student Services and Undergraduate Curriculum), Mark R. Cutkosky, John K. Eaton (Vice Chairman), Kenneth E. Goodson, (Graduate Admissions), Christian Gerdes (Graduate Curriculum), Drew Nelson (Student Services and Undergraduate Curriculum), Friedrich B. Prinz (Chairman, Mechanical Engineering)

Group Chairs: Thomas P. Andriacchi (Biomechanical Engineering), Craig T. Bowman (Thermosciences), Mark R. Cutkosky (Design), Parviz Moin (Flow Physics and Computation Engineering), Peter M. Pinsky (Mechanics and Computation)

Laboratory Directors: David W. Beach (Product Realization Laboratory), J. Edward Carryer (Smart Product Design Laboratory), Mark R. Cutkosky (Manufacturing Sciences Lab), John K. Eaton (Heat Transfer and Turbulence Mechanics), Charbel Farhat (Army High Performance Computing Research Center, AHPARC), Kosuke Ishii (Manufacturing Modeling Laboratory), Thomas P. Andriacchi (Veterans Affairs Rehabilitation R&D Center), Larry J. Leifer (Center for Design Research), Reginald E. Mitchell (High Temperature Gas Dynamics), Parviz Moin (Center for Turbulence Research), Friedrich B. Prinz (Rapid Prototyping Laboratory)

Professors: Thomas P. Andriacchi, David M. Barnett, Craig T. Bowman, Brian J. Cantwell, Mark A. Cappelli, Dennis R. Carter, Mark R. Cutkosky, Scott Delp, John K. Eaton, Charbel Farhat, Kenneth E. Goodson, Ronald K. Hanson, Kosuke Ishii, David M. Kelley, Thomas W. Kenny, Charles H. Kruger, Larry J. Leifer, Sanjiva Lele, Parviz Moin, Drew V. Nelson, Peter M. Pinsky, Friedrich B. Prinz, Bernard Roth, Eric Shaqfeh, Sheri D. Sheppard

Associate Professors: Martin Z. Bazant, Christopher Edwards, J. Christian Gerdes, Marc Levenston, Reginald E. Mitchell, Heinz Pitsch, Juan G. Santiago

Assistant Professors: Wei Cai, Eric Darve, Gianluca Iaccarino, Ellen Kuhl, Adrian Lew, Gunter Niemeyer, Beth Pruitt, Xiaolin Zheng

Professor (Research): Kenneth Waldron

Professor (Teaching): David W. Beach

Courtesy Professors: Fu-Kuo Chang, Ralph Greco, Kenneth Salisbury, George S. Springer, Robert T. Street, Charles Taylor, Paul Yock

Senior Lecturers: Vadim Khayms, J. Craig Milroy

Lecturer: Matthew R. Ohline

Consulting Professors: Gary S. Beaupre, David M. Golden, Barry M. Katz, Stephen Walch, Edith Wilson

Consulting Associate Professors: J. Edward Carryer, Gary D. Lichtenstein, Paul Mitiguy, William Moggridge, Carol B. Muller, Sunil Puria, Paul Saffo, George Toye, Machiel Van der Loos

Consulting Assistant Professors: Michael Barry, Mark Bolas, Brendan J. Boyle, Dennis Boyle, William Burnett, Dev Patnaik, Sara Little Turnbull

* Recalled to active duty.

Student Services: Building 530, Room 125

Mail Code: 94305-3030

Student Services Phone: (650) 725-7695

Web Site: <http://me.stanford.edu>

Courses offered by the Department of Mechanical Engineering have the subject code ME, and are listed in the "Mechanical Engineering (ME) Courses" section of this bulletin.

The programs in the Department of Mechanical Engineering (ME) emphasize a mix of applied mechanics, biomechanical

engineering, computer simulations, design, and energy science and technology. Since mechanical engineering is a broad discipline, the undergraduate program can be a springboard for graduate study in business, law, medicine, political science, and other professions where understanding technology is important. Both undergraduate and graduate programs provide technical background for work in biomechanical engineering, environmental pollution control, ocean engineering, transportation, and other multidisciplinary problems that concern society. In all programs, emphasis is placed on developing systematic procedures for analysis, communication of work and ideas, practical and aesthetic aspects in design, and responsible use of technology.

The department has five groups: Biomechanical Engineering; Design; Flow Physics and Computation; Mechanics and Computation; and Thermosciences. Each maintains its own labs, shops, and offices.

The Biomechanical Engineering (BME) Group has teaching and research activities which focus primarily on musculoskeletal biomechanics, neuromuscular biomechanics, cardiovascular biomechanics, and rehabilitation engineering. Research in other areas including hearing, ocean, plant, and vision biomechanics exists in collaboration with associated faculty in biology, engineering, and medicine. The group has strong research interactions with the Mechanics and Computation and the Design groups, and the departments of Neurology, Radiology, and Surgery in the School of Medicine.

The Design Group emphasizes cognitive skill development for creative design. It is concerned with automatic control, computer-aided design, creativity, design aesthetics, design for manufacturability, design research, experimental stress analysis, fatigue and fracture mechanics, finite element analysis, human factors, kinematics, manufacturing systems, microcomputers in design, micro-electromechanics systems (MEMS), robotics, and vehicle dynamics. The group offers undergraduate and graduate programs in Product Design (jointly with the Department of Art and Art History) and is centrally involved in the Institute of Design; for further information, see <http://dschool.stanford.edu>.

The Flow Physics and Computation Group (FPC) is developing new theories, models, and computational tools for accurate engineering design analysis and control of complex flows (including acoustics, chemical reactions, interactions with electromagnetic waves, plasmas, and other phenomena) of interest in aerodynamics, electronics cooling, environment engineering, materials processing, planetary entry, propulsion and power systems, and other areas. FPC research emphasizes modeling and analysis of physical phenomena in engineering systems. Students and research staff are developing new methods and tools for generation, access, display, interpretation and post-processing of large databases resulting from numerical simulations of physical systems. Research in FPC ranges from advanced simulation of complex turbulent flows to active flow control. Faculty teach graduate and undergraduate courses in acoustics, aerodynamics, computational fluid mechanics, computational mathematics, fluid mechanics, combustion, and thermodynamics and propulsion.

The Mechanics and Computational Group covers biomechanics, continuum mechanics, dynamics, experimental and computational mechanics, finite element analysis, fluid dynamics, fracture mechanics, micromechanics, nanotechnology, and simulation based design. Qualified students can work as research project assistants, engaging in thesis research in association with the faculty director and fellow students. Projects include analysis, synthesis, and control of systems; biomechanics; flow dynamics of liquids and gases; fracture and micro-mechanics, vibrations, and nonlinear dynamics; and original theoretical, computational, and experimental investigations in the strength and deformability of elastic and inelastic elements of machines and structures.

The Thermosciences Group conducts experimental and analytical research on both fundamental and applied topics in the general area of thermal and fluid systems. Research strengths include high Reynolds number flows, microfluidics, combustion and reacting flows, multiphase flow and combustion, plasma sciences, gas physics and chemistry, laser diagnostics, microscale heat transfer, convective heat transfer, and energy systems. Research motivation comes from applications including air-breathing and space propulsion, bioanalytical systems, pollution control,

electronics fabrication and cooling, stationary and mobile energy systems, biomedical systems, and materials processing. Emphasis is on fundamental experiments leading towards advances in modeling, optimization, and control of complex systems.

Mission Statement—The goal of Stanford's undergraduate program in Mechanical Engineering is to provide each student with a balance of intellectual and practical experiences, accumulation of knowledge, and self-discovery to prepare the graduate to address societal needs. The program prepares each student for entry-level work as a mechanical engineer, graduate study in engineering, or graduate study in another field where a broad engineering background provides a foundation. With grounding in the principles and practice of mechanical engineering, graduates are ready to engage in learning about and employing new concepts, technologies, and methodologies.

FACILITIES

The department groups maintain modern laboratories that support undergraduate and graduate instruction and graduate research work.

The Structures and Composites Laboratory, a joint activity with the Department of Aeronautics and Astronautics, studies structures made of fiber-reinforced composite materials. Equipment for fabricating structural elements includes autoclave, filament winder, and presses. X-ray, ultrasound, and an electron microscope are available for nondestructive testing. The lab also has environmental chambers, a high speed impactor, and mechanical testers. Lab projects include designing composite structures, developing novel manufacturing processes, and evaluating environmental effects on composites.

Experimental facilities are available through the interdepartmental Structures and Solid Mechanics Research Laboratory, which includes an electrohydraulic materials testing system, a vehicle crash simulator, and a shake table for earthquake engineering and related studies, together with highly sophisticated auxiliary instrumentation. Facilities to study the micromechanics of fracture areas are available in the Micromechanics/Fracture Laboratory, and include a computer-controlled materials testing system, a long distance microscope, an atomic force microscope, and other instrumentation. Additional facilities for evaluation of materials are available through the Center for Materials Research, Center for Integrated Circuits, and the Ginzton Laboratory. Laboratories for biological experimentation are accessible through the School of Medicine. Individual accommodation is available for the work of each research student.

Major experimental and computational laboratories engaged in bioengineering work are located in the Biomechanical Engineering Group. Other Biomechanical Engineering Group activities and resources are associated with the Rehabilitation Research and Development Center of the Veterans Administration Palo Alto Health Care System. This major national research center has computational and prototyping facilities. In addition, the Rehabilitation Research and Development Center houses the Electrophysiology Laboratory, Experimental Mechanics Laboratory, Human Motor Control Laboratory, Rehabilitation Device Design Laboratory, and Skeletal Biomechanics Laboratory. These facilities support graduate course work as well as Ph.D. student research activities.

Computational and experimental work is also conducted in various facilities throughout the School of Engineering and the School of Medicine, particularly the Advanced Biomaterials Testing Laboratory of the Department of Materials Science and Engineering, the Orthopaedic Research Laboratory in the Department of Functional Restoration, and the Vascular Research Laboratory in the Department of Surgery. In collaboration with the School of Medicine, facilities throughout the Stanford Medical Center and the Veterans Administration Palo Alto Health Care System conduct biological and clinical work.

The Design Group has facilities for lab work in experimental mechanics and experimental stress analysis. Additional facilities, including MTS electrohydraulic materials test systems, are available in the Solid Mechanics Research Laboratory. Design Group students also have access to Center for Integrated Systems (CIS) and Ginzton Lab microfabrication facilities.

The group also maintains the Product Realization Laboratory (PRL), a teaching facility offering students integrated experiences in market definition, product design, and prototype manufacturing. The PRL provides coaching, design manufacturing tools, and networking opportunities to students interested in product development. The ME 310 Design Project Laboratory has facilities for CAD, assembly, and testing of original designs by master's students in the engineering design program. A Smart Product Design Laboratory supports microprocessor application projects. The Center for Design Research (CDR) has an excellent facility for concurrent engineering research, development, and engineering curriculum creation and assessment. Resources include a network of high-performance workstations. For worldwide web mediated concurrent engineering by virtual, non-collocated, design development teams, see the CDR web site at <http://cdr.stanford.edu>. In addition, CDR has several industrial robots for student projects and research. These and several NC machines are part of the CDR Manufacturing Sciences Lab. The Manufacturing Modeling Laboratory (MML) addresses various models and methods that lead to competitive manufacturing. MML links design for manufacturing (dfM) research at the Department of Mechanical Engineering with supply chain management activities at the Department of Management Science and Engineering. The Rapid Prototyping Laboratory consists of seven processing stations including cleaning, CNC milling, grit blasting, laser deposition, low temperature deposition, plasma deposition, and shot peening. Students gain experience by using ACIS and Pro Engineer on Hewlett Packard workstations for process software development. The Design Group also has a Product Design Loft in which students in the Joint Program in Design develop graduate thesis projects.

The Flow Physics and Computation Group has a 32 processor Origin 2000, 48-node and 85-node Linux cluster with high performance interconnection and an array of powerful workstations for graphics and data analysis. Several software packages are available, including all the major commercial CFD codes. FPC is strongly allied with the Center for Turbulence Research (CTR), a research consortium between Stanford and NASA, and the Center for Integrated Turbulence Simulations (CITS), which is supported by the Department of Energy (DOE) under its Accelerated Strategic Computing Initiative (ASCI). The Center for Turbulence Research has direct access to major national computing facilities located at the nearby NASA-Ames Research Center, including massively parallel super computers. The Center for Integrated Turbulence Simulations has access to DOE's vast supercomputer resources. The intellectual atmosphere of the Flow Physics and Computation Group is greatly enhanced by the interactions among CTR's and CITS's postdoctoral researchers and distinguished visiting scientists.

The Mechanics and Computation Group has a Computational Mechanics Laboratory that provides an integrated computational environment for research and research-related education in computational mechanics and scientific computing. The laboratory houses Silicon Graphics, Sun, and HP workstations and servers, including an 8-processor SGI Origin2000 and a 16-processor networked cluster of Intel-architecture workstations for parallel and distributed computing solutions of computationally intensive problems. Software is available on the laboratory machines, including commercial packages for engineering analysis, parametric geometry and meshing, and computational mathematics. The laboratory supports basic research in computational mechanics as well as the development of related applications such as simulation-based design technology.

The Thermosciences Group has four major laboratory facilities. The Heat Transfer and Turbulence Mechanics Laboratory concentrates on fundamental research aimed at understanding and improved prediction of turbulent flows and high performance energy conversion systems. The laboratory includes two general-purpose wind tunnels, a pressurized high Reynolds number tunnel, two supersonic cascade flow facilities, three specialized boundary layer wind tunnels, and several other flow facilities. Extensive diagnostic equipment is available including multiple particle-image velocimetry and laser-Doppler anemometry systems.

The High Temperature Gas Dynamics Laboratory includes research on sensors, plasma sciences, cool and biomass combustion and gas pollutant formation, and reactive and non-reactive gas dynamics. Research facilities include diagnostic devices for combustion gases, a spray combustion facility, laboratory

combustors including a coal combustion facility and supersonic combustion facilities, several advanced laser systems, a variety of plasma facilities, a pulsed detonation facility, and four shock tubes and tunnels. The Thermosciences Group and the Design Group share the Microscale Thermal and Mechanical Characterization laboratory (MTMC). MTMC is dedicated to the measurement of thermal and mechanical properties in thin-film systems, including microfabricated sensors and actuators and integrated circuits, and features a nanosecond scanning laser thermometry facility, a laser interferometer, a near-field optical microscope, and an atomic force microscope. The activities at MTMC are closely linked to those at the Heat Transfer Teaching Laboratory (HTTL), where undergraduate and master's students use high-resolution probe stations to study thermal phenomena in integrated circuits and thermally-actuated microvalves. HTTL also provides macroscopic experiments in convection and radiative exchange.

The Energy Systems Laboratory is a teaching and research facility dedicated to the study of energy conversion systems. The lab includes three dynamometers for engine testing, a computer-controlled variable engine valve controller, a fuel-cell experimental station, a small rocket testing facility, and a small jet engine thrust stand.

The Guidance and Control Laboratory, a joint activity with the Department of Aeronautics and Astronautics and the Department of Mechanical Engineering, specializes in construction of electromechanical systems and instrumentation, particularly where high precision is a factor. Work ranges from robotics for manufacturing to feedback control of fuel injection systems for automotive emission control. The faculty and staff work in close cooperation with both the Design and Thermosciences Groups on device development projects of mutual interest.

Many computation facilities are available to department students. Three of the department's labs are equipped with super-minicomputers. Numerous smaller minicomputers and microcomputers are used in the research and teaching laboratories.

Library facilities at Stanford beyond the general library include Engineering, Mathematics, and Physics department libraries.

UNDERGRADUATE PROGRAMS IN MECHANICAL ENGINEERING

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

Undergraduates seeking to major in Mechanical Engineering should see the curriculum outlined in the "School of Engineering" section of this bulletin. The University's basic requirements for the bachelor's degree are discussed in the "Undergraduate Degrees" section of this bulletin. Courses taken for the departmental major (math; science; science, technology, and society; engineering fundamentals; and engineering depth) must be taken for a letter grade if the instructor offers the option.

A Product Design program offered by the Design Group leads to the B.S. in Engineering (Product Design). An individually designed major in Biomechanical Engineering offered by the Biomechanical Engineering Group leads to the B.S. in Engineering (Biomechanical Engineering); this may be appropriate for students preparing for medical school or graduate bioengineering studies.

Grade Requirements—To be recommended by the department for a B.S. in Mechanical Engineering, a student must achieve the minimum grade point average (GPA) set by the School of Engineering (2.0 in engineering fundamentals and mechanical engineering depth).

For information about an ME minor, see the "School of Engineering" section of this Bulletin.

HONORS PROGRAM

The Department of Mechanical Engineering offers a program leading to a B.S. in Mechanical Engineering with honors. This program offers a unique opportunity for qualified undergraduate engineering majors to conduct independent study and research at an advanced level with a faculty mentor.

Mechanical Engineering majors who have a grade point average (GPA) of 3.5 or higher in the major may apply for the honors program. Students who meet the eligibility requirement and wish to be considered for the honors program must submit a written

application to the Mechanical Engineering student services office no later than the second week of Autumn Quarter in the senior year. The application to enter the program can be obtained from the ME student services office, and must contain a one-page statement describing the research topic and include an unofficial Stanford transcript. In addition, the application must be approved by a Mechanical Engineering faculty member who agrees to serve as the thesis adviser for the project. Thesis advisers must be members of Stanford's Academic Council.

In order to receive department honors, students admitted to the program must:

1. maintain the 3.5 GPA required for admission to the honors program.
2. under the direction of the thesis adviser, complete at least 9 units of ME 191H, Honors Thesis, during the senior year.
3. submit a completed thesis draft to the adviser by mid-May. Further revisions and final endorsement by the adviser are to be finished by the first week of June, when two bound copies are to be submitted to the Mechanical Engineering student services office.
4. present the thesis at the Mechanical Engineering Poster Session held in mid-April.

COGNATE COURSES

ARTSTUDI 60. Design I: Fundamental Visual Language
 ARTSTUDI 160. Design II: The Bridge
 CHEMENG 25. Biotechnology
 CS 106A. Programming Methodology
 ENGR 14. Applied Mechanics: Statics
 ENGR 15. Dynamics
 ENGR 25. Biotechnology
 ENGR 30. Engineering Thermodynamics
 ENGR 31. Chemical Principles with Application to Nanoscale Science and Technology
 ENGR 40. Introductory Electronics
 ENGR 70A. Programming Methodology
 ENGR 102M. Technical/Professional Writing for Mechanical Engineers
 ENGR 105. Feedback Control Design
 ENGR 205. Introduction to Control Design Techniques

COTERMINAL B.S./M.S. PROGRAM

Stanford undergraduates who wish to continue their studies for the Master of Science degree in the coterminal program must have earned a minimum of 120 units towards graduation. This includes allowable Advanced Placement (AP) and transfer credit. Applicants must submit their application no later than the quarter prior to the expected completion of their undergraduate degree. This is normally Winter Quarter (February 3 is the deadline) prior to Spring Quarter graduation. The application must provide evidence of potential for strong academic performance as a graduate student. The M.E. department graduate admissions committee makes decisions on each application. Typically, a GPA of at least 3.5 in engineering, science, and math is expected. Applicants must have completed two of 80, 112, 113, 131A, and 131B, and must take the Graduate Record Examination (GRE) before action is taken on the application. Coterminal information, applications deadlines, and forms can be obtained from the ME student services office.

For University coterminal degree program rules and University application forms, see <http://registrar.stanford.edu/shared/publications.htm#Coterm>.

GRADUATE PROGRAMS IN MECHANICAL ENGINEERING

ADMISSION AND FINANCIAL ASSISTANCE

To be eligible for admission to the department, a student must have a B.S. degree in engineering, physics, or a comparable science program. To apply for the Ph.D. degree, applicants must have already completed an M.S. degree. Applications for Ph.D. and HCP (Honors Co-op) programs are accepted throughout the year. M.S. applications for fellowship aid must be received by the first Tuesday in December. The department annually awards, on a competitive basis, a limited number of fellowships, teaching assistantships, and

research assistantships to incoming graduate students. Research assistantships are used primarily for post-master's degree students and are awarded by individual faculty research supervisors, not by the department.

Mechanical engineering is a varied profession, ranging from primarily aesthetic aspects of design to highly technical scientific research. Disciplinary areas of interest to mechanical engineers include biomechanics, energy conversion, fluid mechanics, materials, nuclear reactor engineering, propulsion, rigid and elastic body mechanics, systems engineering, scientific computing, and thermodynamics, to name a few. No mechanical engineer is expected to have a mastery of the entire spectrum.

A master's degree program leading to the M.S. is offered in Mechanical Engineering, and a master's degree program leading to the M.S. is offered in Engineering with a choice of the following fields of study: Biomechanical Engineering, Product Design, and an individually designed major. Fields of study are declared on Axess.

POST-MASTER'S DEGREE PROGRAMS

The department offers two post-master's degrees: Engineer and Doctor of Philosophy. Post-master's research generally requires some evidence that a student has research potential before a faculty member agrees to supervision and a research assistantship appointment. It is most efficient to carry out preliminary research during the M.S. degree program, if interested in a post-master's degree.

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

The basic University requirements for the M.S. degree are discussed in the "Graduate Degrees" section of this bulletin.

The master's program consists of 45 units of course work taken at Stanford. No thesis is required, although many students become involved in research projects during the master's program, particularly to explore their interests in working towards a Ph.D. degree. Students whose undergraduate backgrounds are entirely devoid of some of the major subject disciplines of engineering (for example, applied mechanics, applied thermodynamics, fluid mechanics, ordinary differential equations) may need to take some undergraduate courses to fill obvious gaps and prepare themselves to take graduate courses in these areas. Such students may require more than three quarters to fulfill the master's degree requirements, as the makeup courses may only be used as unrestricted electives (see item 4 below) in the M.S. degree program. However, it is not the policy to require fulfillment of mechanical engineering B.S. degree requirements to obtain an M.S. degree.

MECHANICAL ENGINEERING

The master's degree program requires 45 units of course work taken as a graduate student at Stanford. No thesis is required. However, students who want some research experience during the master's program may participate in research through ME 391 and 392.

Requirements are subject to change and students are encouraged to refer to the most recent *Mechanical Engineering Graduate Student Handbook* provided by the student services office and located at me.stanford.edu. The department's requirements for the M.S. in Mechanical Engineering are as follows:

Mathematical Fundamentals: two math courses for a total of at least 6 units from the following list are required: ME 300A, 300B, 300C; CME 302; MATH 106, 109; CS 205; EE 261, 263; STATS 110, 141; ENGR 155C. Other MATH and CME courses with catalog numbers of 200 and above also fulfill the math requirement. Mathematics courses must be taken for a letter grade.

4. **Depth in Mechanical Engineering:** a set of graduate-level courses in Mechanical Engineering to provide depth in one area. The faculty have approved these sets as providing depth in specific areas as well as a significant component of applications of the material in the context of engineering synthesis. These sets are outlined in the *Mechanical Engineering Graduate Student Handbook*. Depth courses must be taken for a letter grade.
5. **Breadth in Mechanical Engineering:** two additional graduate level courses (outside the depth) from the depth/breadth charts listed in the *Mechanical Engineering Graduate*

Handbook. Breadth courses must be taken for a letter grade.

6. **Sufficient Mechanical Engineering Course Work:** students must take a minimum of 24 units of course work in mechanical engineering topics. For the purposes of determining mechanical engineering topics, any course on approved lists for the math, depth, and breadth requirements counts towards these units. In addition, any graduate-level course with an ME course number is considered a mechanical engineering topic.
7. **Approved Electives** (to bring the total number of units to at least 39): electives must be approved by an adviser. Graduate engineering, math, and science courses are normally approved. Approved electives must be taken for a letter grade. No more than 6 of the 39 units may come from ME 391/392 (or other independent study/research courses), and no more than 3 may come from seminars. Students planning a Ph.D. should discuss with their advisers the option of taking 391 or 392 during the master's program. ME 391/392 (and other independent study courses) may only be taken on a credit/no credit basis.
8. **Unrestricted electives** (to bring the total number of units submitted for the M.S. degree to 45): students are encouraged to take these units outside engineering, mathematics, or the sciences. Students should consult their advisers on course loads and on ways to use the unrestricted electives to make a manageable program. Unrestricted electives may be taken CR/NC.
9. Within the courses satisfying the requirements above, there must be at least one graduate-level course with a laboratory component. Courses which satisfy this requirement are: ENGR 206, 341; ME203, 210, 220, 218A,B,C,D, 310A,B,C, 317A,B, 318, 323, 324, 348, 354, 367, 382A,B, 385. ME 391/392 (or other independent study courses) may satisfy this requirement if 3 units are taken for work involving laboratory experiments.

Candidates for the M.S. in Mechanical Engineering are expected to have the approval of the faculty, and a minimum grade point average (GPA) of 2.75 in the 45 units presented for fulfillment of degree requirements (exclusive of independent study courses). All courses used to fulfill mathematics, depth, breadth, approved electives, and lab studies must be taken for a letter grade (excluding seminars, independent study, and courses for which a letter grade is not an option for any student).

Students falling below a GPA of 2.5 at the end of 20 units may be disqualified from further registration. Students failing to meet the complete degree requirements at the end of 60 units of graduate registration are disqualified from further registration. Courses used to fulfill deficiencies arising from inadequate undergraduate preparation for mechanical engineering graduate work may not be applied to the 45 units required for completion of the MS degree.

ENGINEERING

As described in the "School of Engineering" section of this bulletin, each department in the school may sponsor students in a more general degree, the M.S. in Engineering. Sponsorship by the Department of Mechanical Engineering (ME) requires (1) filing a petition for admission to the program by no later than the day before instruction begins, and (2) that the center of gravity of the proposed program lies in ME. No more than 18 units used for the proposed program may have been previously completed. The program must include at least 9 units of graduate-level work in the department other than ME 300A,B,C, seminars, and independent study. The petition must be accompanied by a statement explaining the program objectives and how it is coherent, contains depth, and fulfills a well-defined career objective. The grade requirements are the same as for the M.S. in Mechanical Engineering.

COGNATE COURSES

AA 244A. Free and Forced Motion of Structures
ANTHRO 332. Transformative Design
CHEMENG 444. Quantum Simulations of Molecules and Materials
CME 210. Multiscale Methods in Engineering
CS 223A. Introduction to Robotics

CS 327A. Advanced Robotics
 ENGR 207A. Linear Control Systems I
 ENGR 207B. Linear Control Systems II
 ENGR 209A. Analysis and Control of Nonlinear Systems
 ENGR 231. Transformative Design
 ENGR 240. Introduction to Micro and Nano Electromechanical Systems (M/NEMS)
 ENGR 341. Micro/Nano Systems Design and Fabrication Laboratory
 MS&E 250A. Engineering Risk Analysis
 MS&E 264. Sustainable Product Development and Manufacturing
 MS&E 289. Clicks and Bricks: Creating Customer Experiences

PRODUCT DESIGN IN MECHANICAL ENGINEERING

The Joint Program in Design focuses on the synthesis of technology with human needs and values to create innovative product experiences. This program is a joint offering of the departments of Mechanical Engineering and Art and Art History. It provides a design education that integrates technical, human, aesthetic, and business concerns. The resulting two-year degree of M.S. in Engineering (Product Design subplan) is considered a terminal degree for the practice of design.

<i>Subject and Catalog Number</i>	<i>Units</i>
ARTSTUDI 60. Design I: Fundamental Visual Language	3
ARTSTUDI 160. Design II: The Bridge	3
ME203. Manufacturing and Design	4
ME216A. Advanced Product Design: Needfinding	4
ME216B. Advanced Product Design: Implementation	4
ME312. Advanced Product Design: Formgiving	4
ME313. Human Value and Innovation in Design*	3
ME316A,B,C. Product Design Master's Project†	12
ME365 Structure of Design Research*	1-3
ARTSTUDI 360A,B,C. Master's Project†	6
Approved Electives**	14-16
Total Units	60

* Must be taken for a letter grade only

† ME 316A,B,C and ARTSTUDI 360A,B,C are taken concurrently for three quarters during the second year.

** Approved electives fulfill career objectives of the students. Students may focus their energy in engineering, business, psychology, or other areas relevant to design. Most students elect a broad approach that spans these domains and increases their cultural awareness. Approved electives must be discussed with the student's adviser.

Admission requirements are the same as for the M.S. in Mechanical Engineering described above, with additional requirements of a minimum of one year's experience after the bachelor's degree, and a portfolio showing strong evidence of design ability and aesthetic skills and sensitivity.

Students with non-engineering undergraduate degrees in design, art, architecture, or similar majors, may apply to the Department of Art and Art History for a similar graduate design program leading to an M.F.A. in Design. Students with non-engineering degrees who wish to earn the M.S. degree should consult with the program adviser.

BIOMECHANICAL ENGINEERING IN MECHANICAL ENGINEERING

Students interested in graduate studies in biomechanical engineering can choose one of the programs below.

M.S. in Mechanical Engineering: students who apply and are admitted to the M.S. in Mechanical Engineering program can elect to take biomechanical engineering courses as part of their requirements. These courses may be applied towards the student's engineering breadth or technical electives.

10. *M.S. in Engineering, Biomechanical Engineering subplan:* this program allows students more flexibility in taking courses in the life sciences and generally emphasizes a more interdisciplinary curriculum. Minimum grade point average (GPA) requirements are the same as for the M.S. in Mechanical Engineering. Details of this program can be found in the *Mechanical Engineering Graduate Student Handbook*.

A Ph.D. in Biomechanical Engineering is not offered. Students from either master's degree path (Mechanical Engineering or Engineering, Biomechanical Engineering subplan) receive their Ph.D. degrees in Mechanical Engineering.

ENGINEER IN MECHANICAL ENGINEERING

The basic University requirements for the degree of Engineer are discussed in the "Graduate Degrees" section of this bulletin.

This degree requires an additional year of study beyond the M.S. degree and includes a research thesis. The program is designed for students who wish to do professional engineering work upon graduation and who want to engage in more specialized study than is afforded by the master's degree alone.

Admission standards are substantially the same as indicated under the master's degree. However, since thesis supervision is required and the availability of thesis supervisors is limited, admission is not granted until the student has personally engaged a faculty member to supervise a research project. This most often involves a paid research assistantship awarded by individual faculty members (usually from the funds of sponsored research projects under their direction). Thus, individual arrangement between student and faculty is necessary. Students studying for the M.S. degree at Stanford who wish to continue to the Engineer degree ordinarily make such arrangements during the M.S. degree program. Students holding master's degrees from other universities are invited to apply and may be admitted providing they are sufficiently well qualified and have made thesis supervision and financial aid arrangements.

Department requirements for the degree include a thesis; up to 18 units of credit are allowed for thesis work (ME 400). In addition to the thesis, 27 units of approved advanced course work in mathematics, science, and engineering are expected beyond the requirements for the M.S. degree; the choice of courses is subject to approval of the adviser. Students who have not fulfilled the Stanford M.S. degree requirements are required to do so, with allowance for approximate equivalence of courses taken elsewhere; up to 45 units may be transferable.

Candidates for the degree must have faculty approval and have a minimum grade point average (GPA) of 3.0 for all courses (exclusive of thesis credit and other independent study courses) taken beyond those required for the master's degree.

DOCTOR OF PHILOSOPHY IN MECHANICAL ENGINEERING

The basic University requirements for the Ph.D. degree are discussed in the "Graduate Degrees" section of this bulletin. The Ph.D. degree is intended primarily for students who desire a career in research, advanced development, or teaching; for this type of work, a broad background in math and the engineering sciences, together with intensive study and research experience in a specialized area, are the necessary requisites.

The department allows but does not require a minor field from another department. However, if a minor is waived, the candidate must show breadth of training by taking courses in one or more related fields or departments as noted below.

Ph.D. students must have a master's degree, and must fulfill the requirements for the Stanford M.S. degree in Mechanical Engineering.

In special situations dictated by compelling academic reasons, Academic Council members who are not members of the department's faculty may serve as the principal dissertation adviser when approved by the department. In such cases, a member of the department faculty must serve as program adviser and as a member of the reading committee, and agree to accept responsibility that department procedures are followed and standards maintained.

Admission involves much the same consideration described under the Engineer degree. Since thesis supervision is required, admission is not granted until the student has personally engaged a member of the faculty to supervise a research project. Once a student has obtained a research supervisor, this supervisor becomes thereafter the student's academic adviser. Research supervisors may require that the student pass the departmental qualifying examination before starting research and before receiving a paid research assistantship. Note that research assistantships are awarded by faculty research supervisors and not by the department.

Prior to being formally admitted to candidacy for the Ph.D. degree, the student must demonstrate knowledge of engineering fundamentals by passing a qualifying examination. The academic level and subject matter of the examination correspond approximately to the M.S. program described above. Typically, the

exam is taken shortly after the student completes the M.S. degree requirements. The student is required to have a minimum graduate Stanford GPA of 3.5 to be eligible for the exam (grades from independent study courses are not included in the GPA calculation). Once the student's faculty sponsor has agreed that the exam should be scheduled, the student must submit an application folder containing several items including a curriculum vitae, research project abstract, and preliminary dissertation proposal. Information, examination dates, and deadlines may be obtained from the department's student services office or at http://me.stanford.edu/current/grad1/phd_qual.html.

Ph.D. candidates must complete a minimum of 27 units (taken for a letter grade) of approved formal course work (excluding research, directed study, and seminars) in advanced study beyond the M.S. degree. The courses should consist primarily of graduate courses in engineering and sciences, although the candidate's adviser may approve a limited number of upper-level undergraduate courses and courses outside of engineering and sciences, as long as such courses contribute to a strong and coherent program. In addition to this 27-unit requirement, all Ph.D. candidates must participate each quarter in one of the following (or equivalent) seminars: ME 389, 390, 393, 394, 395, 396 397; AA 297; ENGR 298, 311A/B.

The Ph.D. thesis normally represents at least one full year of research work and must be a substantial contribution to the field. Students may register for course credit for thesis work (ME 500) to help fulfill University academic unit requirements, but there is no minimum limit on registered dissertation units, as long as students are registered in at least 8 units per quarter prior to TGR. Candidates should note that only completed course units are counted toward the requirement. Questions should be directed to the department student services manager.

The department has a breadth requirement for the Ph.D. degree. This may be satisfied either by a formal minor in another department or by at least 9 units of course work that is approved by the principal dissertation adviser.

The final University oral examination (dissertation defense) is conducted by a committee consisting of a chair from another department and four faculty members of the department or departments with related interests. Usually, the committee includes the candidate's adviser, reading committee members, plus two more faculty. The examination consists of two parts. The first is open to the public and is scheduled as a seminar talk, usually for one of the regular meetings of a seminar series. The second is conducted in private and covers subjects closely related to the dissertation topic.

PH.D. MINOR

Students who wish a Ph.D. minor in ME should consult with the ME student services office. A minor in ME may be obtained by completing 20 units of approved graduate-level ME courses. Courses approved for the minor must form a coherent program and must be chosen from those satisfying requirement 2 for the M.S. in Mechanical Engineering.

MECHANICAL ENGINEERING (ME) COURSES

For information on graduate programs in the Department of Mechanical Engineering, see the "Mechanical Engineering" and "School of Engineering" sections of this bulletin.

MECHANICAL ENGINEERING COURSE CATALOG NUMBERING SYSTEM

The department uses the following course numbering system:

10- 99	Freshman and Sophomore
100-199	Junior and Senior
200-299	Advanced Undergraduate and Beginning Graduate
300-399	Graduate
400-499	Advanced Graduate
500	Ph.D. Thesis

UNDERGRADUATE COURSES IN MECHANICAL ENGINEERING

Lab sections in experimental engineering are assigned in groups. If the lab schedule permits, students are allowed, with due regard to priority of application, to arrange their own sections and lab periods. Enrollment with the instructor concerned, on the day before instruction begins or the first day of University instruction, is essential in order that the lab schedule may be prepared. Enrollment later than the first week is not permitted.

ME 10N. Form and Function of Animal Skeletons

Stanford Introductory Seminar. Preference to freshmen. The biomechanics and mechanobiology of the musculoskeletal system in human beings and other vertebrates on the level of the whole organism, organ systems, tissues, and cell biology. Field trips to labs. GER:DB-EngrAppSci

3 units, Win (Carter, D)

ME 17N. Robotics Imitating Nature

Stanford Introductory Seminar. Preference to freshmen. The dream of constructing robots that duplicate the functional abilities of humans and/or other animals has been promulgated primarily by science fiction writers. But biological systems provide models for the designers of robots. Building electromechanical devices that perform locomotory and sensing functions similar to those of an animal as a way of learning about how biological systems function. Walking and running machines, and the problem of giving a robot the capability to respond to its environment. GER:DB-EngrAppSci

3 units, Spr (Waldron, K)

ME 18Q. Teamology: Creative Teams and Individual Development

Stanford Introductory Seminar. Preference to sophomores. Roles on a problem solving team that best suit individual creative characteristics. Two teams are formed for teaching experientially how to develop less conscious abilities from teammates creative in those roles. Reinforcement teams have members with similar personalities; problem solving teams are composed of people with maximally different personalities.

3 units, Aut (Wilde, D)

ME 21N. Renaissance Machine Design

Stanford Introductory Seminar. Preference to freshmen. Technological innovations of the 1400s that accompanied the proliferation of monumental art and architecture by Brunelleschi, da Vinci, and others who designed machines and invented novel construction, fresco, and bronze-casting techniques. The social and political climate, from the perspective of a machine designer, that made possible and demanded engineering expertise from prominent artists. Hands-on projects to provide a physical understanding of Renaissance-era engineering challenges and introduce the pleasure of creative engineering design. Technical background not required. GER:DB-EngrAppSci

3 units, Spr (Cutkosky, M)

ME 25N. Global Warming and Climate Change: Fact or Fiction

Stanford Introductory Seminar. Preference to freshmen. Scientific arguments concerning debates between the view that anthropogenic activities are not causing global warming versus the view that these activities are responsible for a global warming that results in significant climate change. Consequences of increased demand for energy. Prerequisites: high school physics, chemistry, and biology.

3 units, Win (Bowman, C)

ME 26N. Think Like a Designer

Stanford Introductory Seminar. Preference to freshmen. Techniques designers use to create innovative solutions across domains. Project-based. Emphasis is on approaches to problem identification and problem solving. Topics include need finding, structured brainstorming, synthesis, rapid prototyping, and visual communication. Field trips to a local design firm, a robotics lab, and a machining lab. The pleasures of creative design and hands-on development of tangible solutions.

3 units, Aut (Banerjee, S)

ME 70. Introductory Fluids Engineering

Elements of fluid mechanics as applied to engineering problems. Equations of motion for incompressible ideal flow. Hydrostatics. Control volume laws for mass, momentum, and energy. Bernoulli equation. Dimensional analysis and similarity. Flow in ducts. Boundary layer flows. Lift and drag. Lab experiment demonstrations. Prerequisites: ENGR 14 and 30. GER:DB-EngrAppSci

4 units, Win (Cappelli, M), Spr (Santiago, J)

ME 80. Mechanics of Deformable Bodies

Mechanics of materials and deformation of structural members. Topics include stress and deformation analysis under axial loading, torsion and bending, column buckling and pressure vessels. Introduction to stress transformation and multiaxial loading. Prerequisite: ENGR 14. GER:DB-EngrAppSci

3 units, Aut (Levenston, M), Spr (Pruitt, B)

ME 101. Visual Thinking

Lecture/lab. Visual thinking and language skills are developed and exercised in the context of solving design problems. Exercises for the mind's eye. Rapid visualization and prototyping with emphasis on fluent and flexible idea production. The relationship between visual thinking and the creative process. Enrollment limited to 60. GER:DB-EngrAppSci

3 units, Aut (Staff), Win (Staff), Spr (Staff)

ME 103D. Engineering Drawing and Design

Designed to accompany 203. The fundamentals of engineering drawing including orthographic projection, dimensioning, sectioning, exploded and auxiliary views, and assembly drawings. Homework drawings are of parts fabricated by the student in the lab. Assignments in 203 supported by material in 103D and sequenced on the assumption that the student is enrolled in both courses simultaneously.

1 unit, Aut (Milroy, J), Win (Milroy, J)

ME 104. The Designer's Voice

How to develop a point of view about a design career in order to articulate a design vision, inspire a design studio, or infect a business with a culture of design thinking. Focus is on the integration of work and worldview, professional values, design language, and the development of the designer's voice. Role play, guest speakers, individual mentoring and coaching, student journals. Restricted to undergraduate Product Design seniors.

1 unit, Aut (Burnett, W)

ME 110. Design Sketching

Freehand sketching, rendering, and design development. Students develop a design sketching portfolio for review by program faculty. May be repeated for credit.

1 unit, Aut (Staff), Win (Staff), Spr (Staff)

ME 110B. Advanced Design Sketching

Freehand sketching, rendering, design development, and some computer use, guided by instructors. Concurrent assignments in 116 provide subject matter. Prerequisite: 110A or consent of instructor based on drawing skill.

1 unit, not given this year

ME 112. Mechanical Systems Design

Lecture/lab. Characteristics of machine elements including gears, bearings, and shafts. Design for fatigue life. Electric motor fundamentals. Transmission design for maximizing output power or efficiency. Mechanism types, linkage analysis and kinematic synthesis. Team-based design projects emphasizing the balance of physical with virtual prototyping based on engineering analysis. Lab for dissection of mechanical systems and project design reviews. Prerequisites: 80, 101. Recommended: 203, ENGR 15. GER:DB-EngrAppSci

4 units, Win (Cutkosky, M)

ME 113. Mechanical Engineering Design

Goal is to create designs and models of new mechanical devices. Design is experienced by students as they work on a team design project obtained from industry or other organizations. Prerequisites: 80, 101, 112. GER:DB-EngrAppSci

4 units, Spr (Waldron, K)

ME 115A. Introduction to Design Methods

Lecture/lab. Problem finding and solving, intermediate creativity methods, and effective techniques for researching and presenting product concepts. Individual- and team-based design projects emphasizing advanced visual thinking and prototyping skills. Prerequisite: 101.

3 units, Win (Staff)

ME 115B. Human Values in Design

Lecture/lab. Problem finding, problem solving, intermediate creativity methods, and techniques for researching and presenting product concepts. Individual- and team-based design projects emphasizing advanced visual thinking and prototyping skills. Prerequisite: 115A. GER:DB-EngrAppSci

3 units, Spr (Lee, M; Wong, A)

ME 116. Advanced Product Design: Formgiving

Small- and medium-scale design projects are carried to a high degree of aesthetic refinement. Emphasis is on form development, design process, and model making. Prerequisites: ME 115B, ARTSTUDI 160. GER:DB-EngrAppSci

4 units, Aut (Staff)

ME 120. History and Philosophy of Design

Major schools of 19th- and 20th-century design (Arts-and-Crafts movement, Bauhaus, Industrial Design, and postmodernism) are analyzed in terms of their continuing cultural relevance. The relation of design to art, technology, and politics; readings from principal theorists, practitioners, and critics; recent controversies in industrial and graphic design, architecture, and urbanism. Enrollment limited to 40. GER:DB-EngrAppSci

3-4 units, Spr (Katz, B)

ME 131A. Heat Transfer

The principles of heat transfer by conduction, convection, and radiation with examples from the engineering of practical devices and systems. Topics include transient and steady conduction, conduction by extended surfaces, boundary layer theory for forced and natural convection, boiling, heat exchangers, and graybody radiative exchange. Prerequisites: 70, ENGR 30. Recommended: intermediate calculus, ordinary differential equations. GER:DB-EngrAppSci

3-4 units, Aut (Asheghi, M)

ME 131B. Fluid Mechanics: Compressible Flow and Turbomachinery

Engineering applications involving compressible flow: aircraft and rocket propulsion, power generation; application of mass, momentum, energy and entropy balance to compressible flows; variable area isentropic flow, normal shock waves, adiabatic flow with friction, flow with heat addition. Operation of flow systems: the propulsion system. Turbomachinery: pumps, compressors, turbines. Angular momentum analysis of turbomachine performance, centrifugal and axial flow machines, effect of blade geometry, dimensionless performance of turbomachines; hydraulic turbines; steam turbines; wind turbines. Compressible flow turbomachinery: the aircraft engine. Prerequisites: 70, ENGR 30. GER:DB-EngrAppSci

4 units, Win (Lele, S)

ME 140. Advanced Thermal Systems

Capstone course. Thermal analysis and engineering emphasizing integrating heat transfer, fluid mechanics, and thermodynamics into a unified approach to treating complex systems. Mixtures, humidity, chemical and phase equilibrium, and availability. Labs apply principles through hands-on experience with a turbojet engine, PEM fuel cell, and hybrid solid/oxygen rocket motor. Use of MATLAB as a computational tool. Prerequisites: ENGR 30, ME 70, and 131A,B. GER:DB-EngrAppSci

5 units, Spr (Mitchell, R)

ME 150. Internal Combustion Engines

Internal combustion engines including conventional and turbocharged spark ignition, and diesel engines. Lectures: basic engine cycles, engine components, methods of analysis of engine performance, pollutant emissions, and methods of engine testing. Lab involves hands-on experience with engines and test hardware. Limited enrollment. Prerequisites: 140. GER:DB-EngrAppSci

3 units, not given this year

ME 161. Dynamic Systems

(Same as ME 261. Graduate students only enroll in 261.) Modeling, analysis, and measurement of mechanical and electromechanical systems. Numerical and closed form solutions of ordinary differential equations governing the behavior of single and multiple degree of freedom systems. Stability, resonance, amplification and attenuation, and control system design. Prerequisite: background in dynamics and calculus such as ENGR 15 and MATH 43. Recommended: CME 102, and familiarity with differential equations, linear algebra, and basic electronics. GER:DB-EngrAppSci

3-4 units, Aut (Mitiguy, P)

ME 190. Ethical Issues in Mechanical Engineering

Moral rights and responsibilities of engineers in relation to society, employers, colleagues, and clients; cost-benefit-risk analysis, safety, and informed consent; whistle blowing; engineers as expert witnesses, consultants, and managers; ethical issues in engineering design, manufacturing, and operations, and engineering work in foreign countries; and ethical implications of the social and environmental contexts of contemporary engineering. Case studies and field research. Enrollment limited to 25 Mechanical Engineering majors.

4 units, Spr (McGinn, R)

ME 191. Engineering Problems and Experimental Investigation

Directed study and research for undergraduates on a subject of mutual interest to student and staff member. Student must find faculty sponsor and have approval of adviser.

1-5 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

ME 191H. Honors Research

Student must find faculty honors adviser and apply for admission to the honors program.

1-5 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

ME 196. Design and Manufacturing Forum

(Same as ME 396.) Guest speakers address issues of interest to design and manufacturing engineers. Sponsored by Stanford Engineering Club for Automation and Manufacturing (SECAM). May be repeated for credit

1 unit, Win (Reis, R), Spr (Reis, R)

ME 281. Biomechanics of Movement

(Same as BIOE 281.) Experimental techniques to study human and animal movement including motion capture systems, EMG, force plates, medical imaging, and animation. The mechanical properties of muscle and tendon, and quantitative analysis of musculoskeletal geometry. Projects and demonstrations emphasize applications of mechanics in sports, orthopedics, and rehabilitation. GER:DB-EngrAppSci

3 units, Aut (Delp, S)

ME 338B. Continuum Mechanics

Constitutive theory; equilibrium constitutive relations; material frame indifference and material symmetry; finite elasticity; formulation of the boundary value problem; linearization and well-posedness; symmetries and configurational forces; numerical considerations.

3 units, alternate years, not given this year

GRADUATE COURSES IN MECHANICAL ENGINEERING

Primarily for graduate students; undergraduates may enroll with consent of instructor.

ME 201. Dim Sum of Mechanical Engineering

Introduction to research in mechanical engineering for M.S. students and upper-division undergraduates. Weekly presentations by current ME Ph.D. and second-year fellowship students to show research opportunities across the department. Strategies for getting involved in a research project. (Sheppard)

1 unit, Aut (Kuhl, E; Gardella, I)

ME 203. Design and Manufacturing

Prototype development techniques as an intrinsic part of the design process. Machining, welding, and casting. Manufacturing processes. Design aspects developed in an individual term project chosen, designed, and fabricated by students. Labs, field trips. Undergraduates majoring in Mechanical Engineering or Product Design must take course for 4 units. Limited enrollment with consent of instructor. Corequisite: 103D or CAD experience. Corequisite for WIM for Mechanical Engineering and Product Design majors: ENGR 102M. Recommended: 101.

4 units, Aut (Beach, D), Win (Beach, D)

ME 204. Bicycle Design and Frame-Building

Lecture/lab. The engineering and artistic execution of designing and building a bicycle frame. Fundamentals of bicycle dynamics, handling, and sizing. Manufacturing processes. Films, guest lecturers, field trips. Each student designs and fabricates a custom bicycle frame. Limited enrollment. Prerequisite: 203 or equivalent.

3 units, Spr (Connolly, R)

ME 206A. Entrepreneurial Design for Extreme Affordability

(Same as OIT 333.) Bass Seminar. Project course jointly offered by School of Engineering and Graduate School of Business. Students apply engineering and business skills to design product prototypes, distribution systems, and business plans for entrepreneurial ventures in developing countries for challenges faced by the world's poor. Topics include user empathy, appropriate technology design, rapid prototype engineering and testing, social technology entrepreneurship, business modeling, and project management. Weekly design reviews; final course presentation. Industry and adviser interaction. Limited enrollment via application; see <http://extreme.stanford.edu>.

4 units, Win (Patell, J; Beach, D)

ME 206B. Entrepreneurial Design for Extreme Affordability
(Same as OIT 334.) Bass Seminar. Project course jointly offered by School of Engineering and Graduate School of Business. Students apply engineering and business skills to design product prototypes, distribution systems, and business plans for entrepreneurial ventures in developing countries for challenges faced by the world's poor. Topics include user empathy, appropriate technology design, rapid prototype engineering and testing, social technology entrepreneurship, business modeling, and project management. Weekly design reviews; final course presentation. Industry and adviser interaction. Limited enrollment via application; see <http://extreme.stanford.edu>.

4 units, Spr (Patell, J; Beach, D)

ME 207. Negotiation

(Same as CEE 151, CEE 251, MS&E 285.) Negotiation styles and processes to help students conduct and review negotiations. Workshop format integrating intellectual and experiential learning. Exercises, presentations, live and field examples, and individual and small group reviews. Application required before first day of class; see Coursework.

3 units, Aut (Christensen, S), Spr (Christensen, S)

ME 208. Patent Law and Strategy for Innovators and Entrepreneurs

How to build a patent portfolio and avoid patent infringement. How to conduct a patent search. How to file a provisional patent application.

2-3 units, Aut (Schox, J)

ME 210. Introduction to Mechatronics

Technologies involved in mechatronics (intelligent electro-mechanical systems), and techniques to apply this technology to mechatronic system design. Topics include: electronics (A/D, D/A converters, op-amps, filters, power devices); software program design, event-driven programming; hardware and DC stepper motors, solenoids, and robust sensing. Large, open-ended team project. Limited enrollment. Prerequisites: ENGR 40, CS 106, or equivalents.

4 units, Win (Messana, M; Ohline, R)

ME 212. Calibrating the Instrument

For first-year graduate students in the Joint Program in Design. Means for calibrating the designer's mind/body instrument through tools including improvisation, brainstorming, creative imaging, educational kinesiology, and Brain Gym. Current design issues; guest speakers; shared stories; and goal setting.

1 unit, Aut (Edmark, J)

ME 216A. Advanced Product Design: Needfinding

Human needs that lead to the conceptualization of future products, environments, systems, and services. Field work in public and private settings; appraisal of personal values; readings on social ethnographic issues; and needfinding for a corporate client. Emphasis is on developing the flexible thinking skills that enable the designer to navigate the future. Prerequisites for undergraduates: 116 and 203, or consent of the instructor. Prerequisites for graduate students: 203 and 313, or consent of the instructor.

3-4 units, Win (Barry, M; Pamaik, D)

ME 216B. Advanced Product Design: Implementation

Summary project using knowledge, methodology, and skills obtained in Product Design major. Students implement an original design concept and present it to a professional jury. Prerequisite: 216A.

4 units, Spr (Burnett, W; Howard, R)

ME 218A. Smart Product Design Fundamentals

Lecture/lab. Team design project series on programmable electromechanical systems design. Topics: transistors as switches, digital and analog circuits, operational amplifiers, comparators, software design, programming in C. Lab fee. Limited enrollment.

4-5 units, Aut (Carryer, J)

ME 218B. Smart Product Design Applications

Lecture/lab. Second in team design project series on programmable electromechanical systems design. Topics: user I/O, timer systems, interrupts, signal conditioning, software design for embedded systems, sensors, actuators, noise, and power supplies. Lab fee. Limited enrollment. Prerequisite: 218A or passing the smart product design fundamentals proficiency examination.

4-5 units, Win (Carryer, J)

ME 218C. Smart Product Design Practice

Lecture/lab. Advanced level in series on programmable electromechanical systems design. Topics: inter-processor communication, system design with multiple microprocessors, architecture and assembly language programming for the PIC microcontroller, controlling the embedded software tool chain, A/D and D/A techniques, electronic manufacturing technology. Team project. Lab fee. Limited enrollment. Prerequisite: 218B.

4-5 units, Spr (Carryer, J)

ME 218D. Smart Product Design: Projects

Lecture/lab. Industrially sponsored project is the culmination of the Smart Product Design sequence. Student teams take on an industrial project requiring application and extension of knowledge gained in the prior three quarters, including prototyping of a final solution with hardware, software, and professional documentation and presentation. Lectures on electronic and software design, and electronic manufacturing techniques. Topics: chip level design of microprocessor systems, real time operating systems, alternate microprocessor architectures, and PCB layout and fabrication.

4 units, Aut (Carryer, J)

ME 219. The Magic of Materials and Manufacturing

Lecture/lab. Methods for market-quantity manufacturing of parts and products from a product designer's point of view. Materials including metals, plastics, ceramics, fibers, and foams, and processes that manipulate, exploit, transform, and modify these materials. Visual descriptions of processes, product examples, relevant material details, cost information, and manufacturability rules-of-thumb. Imagining and creating new products. Manufacturing site visits; laboratory projects. Enrollment limited to 20.

3 units, Spr (Beach, D; Johnson, K)

ME 220. Introduction to Sensors

Sensors are widely used in scientific research and as an integral part of commercial products and automated systems. The basic principles for sensing displacement, force, pressure, acceleration, temperature, optical radiation, nuclear radiation, and other physical parameters. Performance, cost, and operating requirements of available sensors. Elementary electronic circuits which are typically used with sensors. Lecture demonstration of a representative sensor from each category elucidates operating principles and typical performance. Lab experiments with off-the-shelf devices.

3-4 units, Spr (Staff)

ME 222. Design for Sustainability

Lecture/lab. Role of design in building a sustainable world. How to include sustainability in the design process considering environmental, cultural, and social impacts. Focus is on a proactive design approach, and the tools and techniques needed to translate theory into artifact.

2-3 units, Spr (Bishop, S; Boyle, D)

ME 227. Vehicle Dynamics and Control

The application of dynamics, kinematics, and control theory to the analysis and design of ground vehicle behavior. Simplified models of ride, handling, and braking, their role in developing intuition, and limitations in engineering design. Suspension design fundamentals. Performance and safety enhancement through automatic control systems. In-car laboratory assignments for model validation and kinesthetic understanding of dynamics. Limited enrollment. Prerequisites: ENGR 105, consent of instructor.

3 units, Spr (Gerdes, C)

ME 233. Making it Big: Crossing the Entrepreneur's Gap

Students take novel designs into entrepreneurial production and prepare for market production. Education, resources, and community to help cross the gap, found ideas and make them real in volume. Topics include entrepreneurial production methods and initiation, vendor selection and engagement, cost, design transfer, quality and testing, and manufacturing planning and execution. Leadership roles in entrepreneurial and large production-oriented companies. Case studies, project reviews, final presentation, industry interaction.

3 units, Aut (Theeuwes, M)

ME 238. Patent Prosecution

(Same as LAW 321.) Stages of the patent application process: identifying, capturing, and evaluating inventions; performing a patentability investigation, analyzing the documents, and the scope of the patent protection; composing claims that broadly cover the invention; creating a specification that supports the claims; filing a patent application with the U.S. Patent and Trademark Office; and analyzing an office action and preparing an appropriate response. Current rules and case law. Strategic decisions within each stage, such as: how does a patent application advance the patent portfolio; and in what countries should a patent application be filed?

2 units, Win (Schox, J)

ME 257. Turbine and Internal Combustion Engines

(Same as ME 357.) Principles of design analysis for aircraft gas turbines and automotive piston engines. Analysis for aircraft engines performed for Airbus A380 type aircraft. Design parameters determined considering aircraft aerodynamics, gas turbine thermodynamics, compressible flow physics, and material limitations. Additional topics include characteristics of main engine components, off-design analysis, and component matching. Performance of automotive piston engines including novel engine concepts in terms of engine thermodynamics, intake and exhaust flows, and in-cylinder flow.

3 units, Win (Pitsch, H)

ME 260. Fuel Cell Science and Technology

Emphasis on proton exchange membrane (PEM) and solid oxide fuel cells (SOFC), and principles of electrochemical energy conversion. Topics in materials science, thermodynamics, and fluid mechanics. Prerequisites: MATH 43, PHYSICS 55, and ENGR 30 or ME 140, or equivalents.

3 units, Spr (Prinz, F)

ME 261. Dynamic Systems

(Same as ME 161. Graduate students only enroll in 261.) Modeling, analysis, and measurement of mechanical and electromechanical systems. Numerical and closed form solutions of ordinary differential equations governing the behavior of single and multiple degree of freedom systems. Stability, resonance, amplification and attenuation, and control system design. Prerequisite: background in dynamics and calculus such as ENGR 15 and MATH 43. Recommended: CME 102, and familiarity with differential equations, linear algebra, and basic electronics.

3-4 units, Aut (Mitiguy, P)

ME 265. Technology Licensing and Commercialization

How to profit from technology; processes and strategies to commercialize functional or artistic inventions and creations (not limited to mechanical engineering). Business and legal aspects of determining what can be owned and licensed, how to determine commercial value, and what agreements are necessary. Contract and intellectual property law; focus is on provisions of license agreements and their negotiation.

3 units, Spr (Hustein, J)

ME 280. Skeletal Development and Evolution

The mechanobiology of skeletal growth, adaptation, regeneration, and aging is considered from developmental and evolutionary perspectives. Emphasis is on the interactions between mechanical and chemical factors in the regulation of connective tissue biology. Prerequisites: 80, or Human Biology core, or Biology core.

3 units, Spr (Carter, D)

ME 284A. Cardiovascular Bioengineering

(Same as BIOE 284A.) Via Internet. Bioengineering principles applied to the cardiovascular system. Anatomy of human cardiovascular system, comparative anatomy, and allometric scaling principles. Cardiovascular molecular and cell biology. Overview of continuum mechanics. Form and function of blood, blood vessels, and the heart from an engineering perspective. Normal, diseased, and engineered replacement tissues.

3 units, Aut (Taylor, C)

ME 284B. Cardiovascular Bioengineering

(Same as BIOE 284B.) Via Internet. Continuation of ME 284A. Integrative cardiovascular physiology, blood fluid mechanics, and transport in the microcirculation. Sensing, feedback, and control of the circulation. Overview of congenital and adult cardiovascular disease, diagnostic methods, and treatment strategies. Engineering principles to evaluate the performance of cardiovascular devices and the efficacy of treatment strategies.

3 units, Win (Taylor, C)

ME 287. Soft Tissue Mechanics

Structure/function relationships and mechanical properties of soft tissues, including nonlinear elasticity, viscoelasticity, and poroelasticity. Undergraduates require consent of instructor.

3 units, Win (Levenston, M)

ME 289. Biomechanical Engineering Research Seminar

BME research conducted at Stanford for incoming students. Graduate students and postdoctoral fellows present research emphasizing motivation of research questions, project design, methods, and preliminary results.

1 unit, not given this year

ME 294. Medical Device Design

In collaboration with the School of Medicine. Introduction to medical device design for undergraduate and graduate engineering students. Design and prototyping. Labs; medical device environments may include hands-on device testing; and field trips to operating rooms and local device companies. Limited enrollment. Prerequisite: 203.

3 units, Aut (Staff)

ME 297. Forecasting the Future of Engineering

Goal is to develop a 25-year forecast of the future of engineering including the challenges engineers are likely to be asked to solve, and how engineers can be prepared to meet these challenges. Students prepare a long-range forecast of a specific science/engineering sector and a proposed initiative tying new engineering capabilities with global challenges.

3 units, Win (Saffo, P; Benjamin, C)

ME 298. Silversmithing and Design

Skills involved in working with precious metals at a small scale. Investment casting and fabrication techniques such as reticulation, granulations, filigree, and mokume gane.

3-4 units, Win (Shaughnessy, S; Knox, A)

ME 299A. Practical Training

For master's students. Educational opportunities in high technology research and development labs in industry. Students engage in internship work and integrate that work into their academic program. Following internship work, students complete a research report outlining work activity, problems investigated, key results, and follow-up projects they expect to perform. Meets the requirements for curricular practical training for students on F-1 visas. Student is responsible for arranging own internship/employment and faculty sponsorship. Register under faculty sponsor's section number. All paperwork must be completed by student and faculty sponsor, as the Student Services Office does not sponsor CPT. Students are allowed only one quarter of CPT per degree program.

1 unit, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

ME 299B. Practical Training

For Ph.D. students. Educational opportunities in high technology research and development labs in industry. Students engage in internship work and integrate that work into their academic program. Following internship work, students complete a research report outlining work activity, problems investigated, key results, and follow-up projects they expect to perform. Meets the requirements for curricular practical training for students on F-1 visas. Student is responsible for arranging own internship/employment and faculty sponsorship. Register under faculty sponsor's section number. All paperwork must be completed by student and faculty sponsor, as the student services office does not sponsor CPT. Students are allowed only one quarter of CPT per degree program.

1 unit, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

ME 300A. Linear Algebra with Application to Engineering Computations

(Same as CME 200.) Solving matrix-vector systems. Direct and iterative solvers for non-singular linear systems of equations; their accuracy, convergence properties, and computational efficiency. Under- and over-determined systems, and nonlinear systems of equations. Eigenvalues, eigenvectors, and singular values; their application to engineering problems. Concepts such as basis, linear independence, column space, null space, rank, norms and condition numbers, projections, and matrix properties. Recommended: familiarity with computer programming; mathematics background equivalent to MATH 103, 130.

3 units, Aut (Gerritsen, M)

ME 300B. Partial Differential Equations in Engineering

(Same as CME 204.) Geometric interpretation of partial differential equation (PDE) characteristics; solution of first order PDEs and classification of second-order PDEs; self-similarity; separation of variables as applied to parabolic, hyperbolic, and elliptic PDEs; special functions; eigenfunction expansions; the method of characteristics. If time permits, Fourier integrals and transforms, Laplace transforms. Prerequisite: CME 200/ME 300A, equivalent, or consent of instructor.

3 units, Win (Shaqfeh, E)

ME 300C. Introduction to Numerical Methods for Engineering

(Same as CME 206.) Numerical methods from a user's point of view. Lagrange interpolation, splines. Integration: trapezoid, Romberg, Gauss, adaptive quadrature; numerical solution of ordinary differential equations: explicit and implicit methods, multistep methods, Runge-Kutta and predictor-corrector methods, boundary value problems, eigenvalue problems; systems of differential equations, stiffness. Emphasis is on analysis of numerical methods for accuracy, stability, and convergence. Introduction to numerical solutions of partial differential equations; Von Neumann stability analysis; alternating direction implicit methods and nonlinear equations. Prerequisites: CME 200/ME 300A, CME 204/ME 300B.

3 units, Spr (Moin, P)

ME 304. The Designer's Voice

How to develop a point of view about a design career in order to articulate a design vision, inspire a design studio, or infect a business with a culture of design thinking. Focus is on the integration of work and worldview, professional values, design language, and the development of the designer's voice. Role play, guest speakers, individual mentoring and coaching, student journals. Restricted to Joint Product in Design graduate students.

1 unit, Win (Burnett, W)

ME 308. Spatial Motion

The geometry of motion in Euclidean space. Fundamentals of theory of screws with applications to robotic mechanisms, constraint analysis, and vehicle dynamics. Methods for representing the positions of spatial systems of rigid bodies with their inter-relationships; the formulation of Newton-Euler kinetics applied to serial chain systems such as industrial robotics.

3 units, alternate years, not given this year

ME 309. Finite Element Analysis in Mechanical Design

Basic concepts of finite elements, with applications to problems confronted by mechanical designers. Linear static, modal, and thermal formulations; nonlinear and dynamic formulations. Students implement simple element formulations. Application of a commercial finite element code in analyzing design problems. Issues: solution methods, modeling techniques, features of various commercial codes, basic problem definition. Individual projects focus on the interplay of analysis and testing in product design/development. Prerequisite: MATH 103, or equivalent. Recommended: 80, or equivalent in structural and/or solid mechanics; some exposure to principles of heat transfer.

3 units, Spr (Kuhl, E)

ME 310A. Project-Based Engineering Design, Innovation, and Development

Three quarter sequence; for engineering graduate students intending to lead projects related to sustainability, automotive, biomedical devices, communication, and user interaction. Student teams collaborate with academic partners in Europe, Asia, and Latin America on product innovation challenges presented by global corporations to design requirements and construct functional prototypes for consumer testing and technical evaluation. Design loft format such as found in Silicon Valley consultancies. Typically requires international travel. Prerequisites: undergraduate engineering design project; consent of instructor.

5 units, Aut (Leifer, L; Cutkosky, M)

ME 310B. Project-Based Engineering Design, Innovation, and Development

(Same as ENGR 310B.) Three quarter sequence; for engineering graduate students intending to lead projects related to sustainability, automotive, biomedical devices, communication, and user interaction. Student teams collaborate with academic partners in Europe, Asia, and Latin America on product innovation challenges presented by global corporations to design requirements and construct functional prototypes for consumer testing and technical evaluation. Design loft format such as found in Silicon Valley consultancies. Typically requires international travel. Prerequisites: undergraduate engineering design project; consent of instructor.

5 units, Win (Leifer, L; Cutkosky, M)

ME 310C. Project-Based Engineering Design, Innovation, and Development

Three quarter sequence; for engineering graduate students intending to lead projects related to sustainability, automotive, biomedical devices, communication, and user interaction. Student teams collaborate with academic partners in Europe, Asia, and Latin America on product innovation challenges presented by global corporations to design requirements and construct functional prototypes for consumer testing and technical evaluation. Design loft format such as found in Silicon Valley consultancies. Typically requires international travel. Prerequisites: undergraduate engineering design project; consent of instructor.

5 units, Spr (Leifer, L; Cutkosky, M)

ME 312. Advanced Product Design: Formgiving

Lecture/lab. Small- and medium-scale design projects carried to a high degree of aesthetic refinement. Emphasis is on form development, design process, and model making. Prerequisites: 203, 313. Corequisite: ARTSTUDI 160.

3-4 units, Win (Burnett, W)

ME 313. Human Values and Innovation in Design

Introduction to the philosophy, spirit, and tradition of the product design program. Hands-on design projects used as vehicles for design thinking, visualization, and methodology. The relationships among technical, human, aesthetic, and business concerns. Drawing, prototyping, and design skills. Focus is on tenets of design philosophy: point of view, user-centered design, design methodology, and iterative design.

3 units, Aut (Banerjee, S)

ME 314. Good Products, Bad Products

The characteristics of industrial products that cause them to be successes or failures: the straightforward (performance, economy, reliability), the complicated (human and cultural fit, compatibility with the environment, craftsmanship, positive emotional response of the user), the esoteric (elegance, sophistication, symbolism). Engineers and business people must better understand these factors to produce more successful products. Projects, papers, guest speakers, field trips.

3-4 units, Win (Beach, D)

ME 315. The Designer in Society

For graduate students. Career objectives and psychological orientation compared with existing social values and conditions. Emphasis is on assisting individuals in assessing their roles in society. Readings on political, social, and humanistic thought are related to technology and design. Experiential, in-class exercises, and term project. Enrollment limited to 24.

3 units, Spr (Roth, B)

ME 316A. Product Design Master's Project

For graduate Product Design or Design (Art) majors only. Students create and present two master's theses under the supervision of engineering and art faculty. Theses involve the synthesis of aesthetics and technological concerns in the service of human need and possibility. Product Design students register for 4 units; Art students for 2 units. Prerequisites: ME 216B, ME 365 Corequisite: ARTSTUDI 360.

2-4 units, Aut (Banerjee, S; Burnett, W; Kelley, D; Barry, M)

ME 316B. Product Design Master's Project

Continuation of 316A.

2-4 units, Win (Banerjee, S; Burnett, W; Barry, M; Kelley, D)

ME 316C. Product Design Master's Project

Continuation of 316B.

2-4 units, Spr (Banerjee, S; Burnett, W; Kelley, D; Barry, M)

ME 317A. Design for Manufacturability: Product Definition for Market Success

Systematic methodologies to define, develop, and produce world-class products. Student team projects to identify opportunities for improvement and develop a comprehensive product definition. Topics include value engineering, quality function deployment, design for assembly and producibility, design for variety and supply chain, design for life-cycle quality, and concurrent engineering. Students must take 317B to complete the project and obtain a letter grade. On-campus enrollment limited to 20; SCPD class size limited to 50, and each site must have at least 3 students to form a project team.

4 units, Win (Ishii, K)

ME 317B. Design for Manufacturability: Quality by Design for Customer Value

Building on 317A, focus is on the implementation of competitive product design. Student groups apply structured methods to optimize the design of an improved product, and plan for its manufacture, testing, and service. The project deliverable is a comprehensive product and process specification. Topics: concept generation and selection (Pugh's Method), FMEA applied to the manufacturing process, design for robustness, Taguchi Method, SPC and six sigma process, tolerance analysis, flexible manufacturing, product testing, rapid prototyping. Enrollment limited to 40, not including SCPD students. Minimum enrollment of two per SCPD viewing site; single student site by prior consent of instructor. On-campus class limited to 20. For SCPD students, limit is 50 and each site must have a minimum of three students to form a project team and define a project on their own. Prerequisite: 317A.

4 units, Spr (Ishii, K)

ME 318. Computer-Aided Product Creation

Design course focusing on an integrated suite of computer tools: rapid prototyping, solid modeling, computer-aided machining, and computer numerical control manufacturing. Students choose, design, and manufacture individual products, emphasizing individual design process and computer design tools. Field trips demonstrate Stanford Product Realization Lab's relationship to the outside world. Structured lab experiences build a basic CAD/CAM/CNC proficiency. Limited enrollment. Prerequisite: consent of instructor.

4 units, Aut (Staff), Win (Staff), Spr (Staff)

ME 322. Kinematic Synthesis of Mechanisms

The rational design of linkages. Techniques to determine linkage proportions to fulfill design requirements using analytical, graphical, and computer based methods.

3 units, Win (Roth, B)

ME 323. Modeling and Identification of Mechanical Systems for Control

Lecture/Lab. The art and science behind developing mathematical models for control system design. Theoretical and practical system modeling and parameter identification. Frequency domain identification, parametric modeling, and black-box identification. Analytical work and laboratory experience with identification, controller implementation, and the implications of unmodeled dynamics and non-linearities. Prerequisites: linear algebra and system simulation with MATLAB/SIMULINK; ENGR 105.

3 units, Aut (Gerdes, C)

ME 324. Precision Engineering

Advances in engineering are often enabled by more accurate control of manufacturing and measuring tolerances. Concepts and technology enable precision such that the ratio of overall dimensions to uncertainty of measurement is large relative to normal engineering practice. Typical application areas: non-spherical optics, computer information storage devices, and manufacturing metrology systems. Application experience through design and manufacture of a precision engineering project, emphasizing the principles of precision engineering. Structured labs; field trips. Prerequisite: consent of instructors.

4 units, Spr (Beach, D; DeBra, D)

ME 326. Telerobotics and Human-Robot Interactions

Focus is on dynamics and controls. Evaluation and implementation of required control systems. Topics include master-slave systems, kinematic and dynamic similarity; control architecture, force feedback, haptics, sensory substitutions; stability, passivity, sensor resolution, servo rates; time delays, prediction, wave variables. Hardware-based projects encouraged, which may complement ongoing research or inspire new developments. Limited enrollment. Prerequisites: ENGR 205, 320 or CS 223A, or consent of instructor. (Niemever)

3 units, not given this year

ME 329. Physical Solid Mechanics

Quantum mechanics, statistical mechanics, and solid state physics for engineering students. The theory describes physical processes at nanoscale in solid materials. Atomic structures of solids and their electronic structures. Statistical mechanics provides a theoretical framework for thermodynamics to connect the nanoscale processes to macroscopic properties of solids.

3 units, alternate years, not given this year

ME 330. Advanced Kinematics

Kinematics from mathematical viewpoints. Introduction to algebraic geometry of point, line, and plane elements. Emphasis is on basic theories which have potential application to mechanical linkages, computational geometry, and robotics.

3 units, Aut (Roth, B)

ME 331A. Classical Dynamics

(Same as AA 242A.) Accelerating and rotating reference frames. Kinematics of rigid body motion; Euler angles, direction cosines. D'Alembert's principle, equations of motion. Inertia properties of rigid bodies. Dynamics of coupled rigid bodies. Lagrange's equations and their use. Dynamic behavior, stability, and small departures from equilibrium. Prerequisite: ENGR 15 or equivalent.

3 units, Win (Mitiguy, P)

ME 331B. Advanced Dynamics

(Same as AA 242B.) Formulation of equations of motion with Newton/Euler equations; angular momentum principle; D'Alembert principle; power, work, and energy; Kane's method; and Lagrange's equations. Numerical solutions of nonlinear algebraic and differential equations governing the behavior of multiple degree of freedom systems. Computed torque control.

3 units, Spr (Mitiguy, P)

ME 333. Mechanics

Goal is a common basis for advanced mechanics courses. Formulation of the governing equations from a Lagrangian perspective. Examples include systems of particles and linear elastic solids. Waves in discrete and continuous media. Linear elasticity formulation in the static and dynamic cases, and elementary measures of stress and strain. Tensor and variational calculus. (Lew)

3 units, Aut (Lew, A)

ME 335A. Finite Element Analysis

Fundamental concepts and techniques of primal finite element methods. Method of weighted residuals, Galerkin's method, and variational equations. Linear elliptic boundary value problems in one, two, and three space dimensions; applications in structural, solid, and fluid mechanics and heat transfer. Properties of standard element families and numerically integrated elements. Implementation of the finite element method. Active column equation solver, assembly of equations, and element routines. The mathematical theory of finite elements.

3 units, Aut (Pinsky, P)

ME 335B. Finite Element Analysis

Finite element methods for linear dynamic analysis. Eigenvalue, parabolic, and hyperbolic problems. Mathematical properties of semi-discrete (t-continuous) Galerkin approximations. Modal decomposition and direct spectral truncation techniques. Stability, consistency, convergence, and accuracy of ordinary differential equation solvers. Asymptotic stability, over-shoot, and conservation laws for discrete algorithms. Mass reduction. Applications in heat conduction, structural vibrations, and elastic wave propagation. Computer implementation of finite element methods in linear dynamics. Implicit, explicit, and implicit-explicit algorithms and code architectures.

3 units, Win (Pinsky, P)

ME 335C. Introduction to Boundary Element Analysis

The boundary integral equation and boundary element method with applications to potential theory and elastostatics. Green's function methods for transforming partial differential equations to integral equations with boundary conditions built in. Implementation of the method and treatments of weakly and strongly (Cauchy principal values) singular kernels. Coupling with finite element methods. Additional topics may include fracture mechanics, contact mechanics, and transient diffusion.

3 units, Spr (Pinsky, P)

ME 336. Crystalline Anisotropy

(Same as MATSCI 359.) Matrix and tensor analysis with applications to the effects of crystal symmetry on elastic deformation, thermal expansion, diffusion, piezoelectricity, magnetism, thermodynamics, and optical properties of solids, on the level of J. F. Nye's Physical Properties of Crystals. Homework sets use Mathematica.

3 units, Win (Barnett, D)

ME 337. Mechanics of Growth

Introduction to continuum theory and numerical solutions or biomechanical problems. Kinematics of finite growth. Balance equations in open system thermodynamics. Constitutive equations for biological tissues. Enhanced finite element models in biomechanics. Analytical solutions for simple model problems. Numerical solutions for more advanced problems such as: bone remodeling; wound healing; muscle regeneration; tumor growth; atherosclerosis; in-stent restenosis; and tissue engineering.

3 units, not given this year

ME 338A. Continuum Mechanics

Nonlinear continuum mechanics for solids and fluids. Kinematics of finite deformations. Measures of strain and stress. Finite rotations. Linearized kinematics and infinitesimal measures of deformations. Rates. Conservation laws for mass, momenta, and energy. Boundary value problem in continuum mechanics. Prerequisites: 333 and 300, or equivalent background with consent of instructor.

3 units, Win (Kuhl, E)

ME 339. Mechanics of the Cell

Kinematical description of basic structural elements used to model parts of the cell: rods, ropes, membranes, and shells. Formulation of constitutive equations: nonlinear elasticity and entropic contributions. Elasticity of polymeric networks. Applications to model basic filaments of the cytoskeleton: actin, microtubules, intermediate filaments, and complete networks. Applications to biological membranes. (Jacobs)

3 units, Aut (Kuhl, E)

ME 340A. Theory and Applications of Elasticity

Elasticity theory and application to material structures at microscale. Theories: stress, strain, and energy; equilibrium and compatibility conditions; boundary value problem. Solution methods: stress function, Green's function, Fourier transformation. Numerical exercises using Matlab. Applications to defects in solids, thin films, and biomembranes.

3 units, Spr (Cai, W)

ME 340B. Elasticity in Microscopic Structures

Elasticity theory and applications to structures in micro devices, material defects, and biological systems. Theoretical basis: stress, strain, and energy; equilibrium and compatibility conditions; boundary value problem formulation. Solution methods: stress function, Green's function, and Fourier transformation; moderate numerical exercises using Matlab. Methods and solutions applied to the elastic behaviors of thin films and MEMS structures, cracks and dislocations, and cell filaments and membranes.

3 units, not given this year

ME 341. Biomechanics of Hearing, Speech, and Balance

Theory and practice of building mathematical models to understand physical phenomena; integration of imaging, physiology, and biomechanics. Research literature, examples from hearing science, speech production, and the vestibular system. Dualisms in modeling include: general principles versus detailed models; analytic versus computational models; forward versus inverse approaches; and the interplay between theory and experiments.

3 units, alternate years, not given this year

ME 342A. MEMS Laboratory

Practice and theory of MEMS device design and fabrication, orientation to fabrication facilities, and introduction to techniques for design and evaluation of MEMS devices in the context of designed projects. Emphasis on MEMS design (need finding, brainstorming, evaluation, and design methodology), characterization, and fabrication, including photolithography, etching, oxidation, diffusion, and ion implantation. Limited enrollment. Prerequisite: engineering or science background and consent of instructor.

3-4 units, not given this year

ME 342D. MEMS Laboratory Assignments

Prerequisite: consent of instructor.

1-2 units, not given this year

ME 343. An Introduction to Waves in Elastic Solids

One-dimensional motion of an elastic continuum, the linearized theory of elasticity and elastodynamic theory, elastic waves in an unbounded medium, plane harmonic waves in elastic half-spaces including reflection and refraction, slowness, energy velocity and anisotropic effects. Text is first five chapters of Achenbach's Wave Propagation in Elastic Solids. (Barnett)

3 units, not given this year

ME 344A. Computational Nanotechnology

Atomistic simulations as computational tools to design nanoscale materials and devices. Nanoparticles and nanowires introduced as main classes of nano building blocks. Computational modeling of carbon nanomaterials (fullerenes and nanotubes); nanoparticles and quantum dots; semiconductor and metal nanowires; and molecular wires. Atomistic modeling programs with graphical user interface used to gain hands-on experience of nanomaterials design.

3 units, not given this year

ME 344B. Nanomaterials Modeling

Atomistic and quantum mechanical simulation methods. Focus is quantum simulation of nanomaterials. Review of concepts and practical techniques of atomistic simulations; finite difference algorithms and practical computational issues for molecular dynamics and Monte Carlo simulations. Graphical user interface, designing nanomaterials through analysis and feedback processes, configuration optimization, dynamic mode analysis, and electronic structure analysis. Hands-on experience in computational design of nanomaterials, and fundamentals of simulations.

3 units, not given this year

ME 345. Fatigue Design and Analysis

The mechanism and occurrences of fatigue in service. Methods for predicting fatigue life and for protecting against premature fatigue failure. Use of elastic stress and inelastic strain analyses to predict crack initiation life. Use of linear elastic fracture mechanics to predict crack propagation life. Effects of stress concentrations, manufacturing processes, load sequence, irregular loading, multi-axial loading. Subject is treated from the viewpoints of the engineer seeking up-to-date methods of life prediction and the researcher interested in improving understanding of fatigue behavior. Prerequisite: undergraduate mechanics of materials.

3 units, not given this year

ME 346A. Introduction to Statistical Mechanics

Concepts and tools of classical statistical mechanics and applications to molecular systems. Thermodynamics and probability theory. Statistical ensembles. Information and entropy. Free energy and transition between metastable states. Brownian motion, Langevin dynamics, and Fokker-Planck equation. Non-equilibrium systems: correlation and response functions, fluctuation-dissipation theorem. Applications to self-assembly, thin film growth, and structural transformation.

3 units, Win (Staff)

ME 346B. Introduction to Molecular Simulations

Algorithms of molecular simulations and underlying theories. Molecular dynamics, time integrators, modeling thermodynamic ensembles (NPT, NVT), free energy, constraints. Monte Carlo simulations, parallel tempering. Stochastic equations, Langevin and Brownian dynamics. Applications in solids, liquids, and biomolecules (proteins). Programming in Matlab and C++. Prerequisites: ME 346A or equivalent, Matlab, and C++.

3 units, Spr (Darve, E)

ME 346C. Advanced Techniques for Molecular Simulations

Advanced methods for computer simulation of proteins. Symplectic time integrators, multiple-time stepping, energy conservation. Long-range force calculation, particle mesh Ewald, fast multipole method, multigrid. Free energy methods, umbrella sampling, acceptance ratio, thermodynamic integration, non equilibrium methods, adaptive biasing force. Prerequisites: ME 346A,B or equivalent, Matlab, and C++.

3 units, alternate years, not given this year

ME 347. Mathematical Theory of Dislocations

The mathematical theory of straight and curvilinear dislocations in linear elastic solids. Stress fields, energies, and Peach-Koehler forces associated with these line imperfections. Anisotropic effects, Green's function methods, and the geometrical techniques of Brown and Indenborn-Orlov for computing dislocation fields and for studying dislocation interactions. Continuously distributed dislocations and cracks and inclusions.

3 units, not given this year

ME 348. Experimental Stress Analysis

Theory and applications of photoelasticity, strain gages, and holographic interferometry. Comparison of test results with theoretical predictions of stress and strain. Other methods of stress and strain determination (optical fiber strain sensors, thermoelasticity, Moire, residual stress determination).

3 units, not given this year

ME 351A. Fluid Mechanics

Exact and approximate analysis of fluid flow covering kinematics, global and differential equations of mass, momentum, and energy conservation. Forces and stresses in fluids. Euler's equations and the Bernoulli theorem applied to inviscid flows. Vorticity dynamics. Topics in irrotational flow: stream function and velocity potential for exact and approximate solutions; superposition of solutions; complex potential function; circulation and lift. Some boundary layer concepts.

3 units, Aut (Iaccarino, G)

ME 351B. Fluid Mechanics

Laminar viscous fluid flow. Governing equations, boundary conditions, and constitutive laws. Exact solutions for parallel flows. Creeping flow limit, lubrication theory, and boundary layer theory including free-shear layers and approximate methods of solution; boundary layer separation. Introduction to stability theory and transition to turbulence, and turbulent boundary layers. Prerequisite: 351A.

3 units, Win (Eaton, J)

ME 352A. Radiative Heat Transfer

The fundamentals of thermal radiation heat transfer; blackbody radiation laws; radiative properties of non-black surfaces; analysis of radiative exchange between surfaces and in enclosures; combined radiation, conduction, and convection; radiative transfer in absorbing, emitting, and scattering media. Advanced material for students with interests in heat transfer, as applied in high-temperature energy conversion systems. Take 352B,C for depth in heat transfer. Prerequisites: graduate standing and undergraduate course in heat transfer. Recommended: computer skills.

3 units, Aut (Mitchell, R)

ME 352B. Fundamentals of Heat Conduction

Physical description of heat conduction in solids, liquids, and gases. The heat diffusion equation and its solution using analytical and numerical techniques. Data and microscopic models for the thermal conductivity of solids, liquids, and gases, and for the thermal resistance at solid-solid and solid-liquid boundaries. Introduction to the kinetic theory of heat transport, focusing on applications for composite materials, semiconductor devices, micromachined sensors and actuators, and rarefied gases. Prerequisite: consent of instructor.

3 units, Win (Goodson, K)

ME 352C. Convective Heat Transfer

Prediction of heat and mass transfer rates based on analytical and numerical solutions of the governing partial differential equations. Heat transfer in fully developed pipe and channel flow, pipe entrance flow, laminar boundary layers, and turbulent boundary layers. Superposition methods for handling non-uniform wall boundary conditions. Approximate models for turbulent flows. Comparison of exact and approximate analyses to modern experimental results. General introduction to heat transfer in complex flows. Prerequisite: 351B or equivalent.

3 units, Spr (Eaton, J)

ME 354. Experimental Methods in Fluid Mechanics

Experimental methods associated with the interfacing of laboratory instruments, experimental control, sampling strategies, data analysis, and introductory image processing. Instrumentation including point-wise anemometers and particle image tracking systems. Lab. Prerequisites: previous experience with computer programming and consent of instructor. Limited enrollment.

4 units, not given this year

ME 355. Compressible Flow

Topics include quasi-one-dimensional isentropic flow in variable area ducts, normal shock waves, oblique shock and expansion waves, flow in ducts with friction and heat transfer, unsteady one-dimensional flow, and steady two-dimensional supersonic flow.

3 units, Spr (Bowman, C)

ME 357. Turbine and Internal Combustion Engines

(Same as ME 257.) Principles of design analysis for aircraft gas turbines and automotive piston engines. Analysis for aircraft engines performed for Airbus A380 type aircraft. Design parameters determined considering aircraft aerodynamics, gas turbine thermodynamics, compressible flow physics, and material limitations. Additional topics include characteristics of main engine components, off-design analysis, and component matching. Performance of automotive piston engines including novel engine concepts in terms of engine thermodynamics, intake and exhaust flows, and in-cylinder flow.

3 units, Win (Pitsch, H)

ME 358. Heat Transfer in Microdevices

Application-driven introduction to the thermal design of electronic circuits, sensors, and actuators that have dimensions comparable to or smaller than one micrometer. The impact of thin-layer boundaries on thermal conduction and radiation. Convection in microchannels and microscopic heat pipes. Thermal property measurements for microdevices. Emphasis is on Si and GaAs semiconductor devices and layers of unusual, technically-promising materials such as chemical-vapor-deposited (CVD) diamond. Final project based on student research interests. Prerequisite: consent of instructor.

3 units, Spr (Ashghi, M)

ME 359A. Advanced Design and Engineering of Space Systems I

The application of advanced theory and concepts to the development of spacecraft and missile subsystems; taught by experts in their fields. Practical aspects of design and integration. Mission analysis, systems design and verification, radiation and space environments, orbital mechanics, space propulsion, electrical power and avionics subsystems, payload communications, and attitude control. Subsystem-oriented design problems focused around a mission to be completed in groups. Tours of Lockheed Martin facilities. Limited enrollment. Prerequisites: undergraduate degree in related engineering field or consent of instructor.

4 units, not given this year

ME 359B. Advanced Design and Engineering of Space Systems II

Continuation of 359A. Topics include aerospace materials, mechanical environments, structural analysis and design, finite element analysis, mechanisms, thermal control, probability and statistics. Tours of Lockheed Martin facilities. Limited enrollment. Prerequisites: undergraduate degree in related field, or consent of instructor.

4 units, not given this year

ME 361. Turbulence

Governing equations. Averaging and correlations. Reynolds equations and Reynolds stresses. Free shear flows, turbulent jet, turbulent length and time scales, turbulent kinetic energy and kinetic energy dissipation, and kinetic energy budget. Kolmogorov's hypothesis and energy spectrum. Wall bounded flows, channel flow and boundary layer, viscous scales, and law of the wall. Turbulence modeling, gradient transport and eddy viscosity, mixing length model, two-equation models, Reynolds-stress model, and large-eddy simulation.

3 units, Spr (Pitsch, H)

ME 362A. Physical Gas Dynamics

Concepts and techniques for description of high-temperature and chemically reacting gases from a molecular point of view. Introductory kinetic theory, chemical thermodynamics, and statistical mechanics as applied to properties of gases and gas mixtures. Transport and thermodynamic properties, law of mass action, and equilibrium chemical composition. Maxwellian and Boltzmann distributions of velocity and molecular energy. Examples and applications from areas of current interest such as combustion and materials processing.

3 units, Aut (Cappelli, M)

ME 362B. Nonequilibrium Processes in High-Temperature Gases

Chemical kinetics and energy transfer in high-temperature gases. Collision theory, transition state theory, and unimolecular reaction theory. Prerequisite: 362A or consent of instructor.

3 units, Win (Hanson, R)

ME 363. Partially Ionized Plasmas and Gas Discharges

Introduction to partially ionized gases and the nature of gas discharges. Topics: the fundamentals of plasma physics emphasizing collisional and radiative processes, electron and ion transport, ohmic dissipation, oscillations and waves, interaction of electromagnetic waves with plasmas. Applications: plasma diagnostics, plasma propulsion and materials processing. Prerequisite: 362A or consent of instructor.

3 units, Spr (Cappelli, M)

ME 364. Optical Diagnostics and Spectroscopy

The spectroscopy of gases and laser-based diagnostic techniques for measurements of species concentrations, temperature, density, and other flow field properties. Topics: electronic, vibrational, and rotational transitions; spectral lineshapes and broadening mechanisms; absorption, fluorescence, Rayleigh and Raman scattering methods; collisional quenching. Prerequisite: 362A or equivalent.

3 units, not given this year

ME 365. The Structure of Design Research

Restricted to second-year Joint Program in Design graduate students; prerequisite for ME 316A,B,C. How to shape individual research plans, identify tools for design research, and develop a vocabulary for research through design. Students present proposals for master's theses. Case studies.

1-3 units, Spr (Banerjee, S)

ME 367. Optical Diagnostics and Spectroscopy Laboratory

Principles, procedures, and instrumentation associated with optical measurements in gases and plasmas. Absorption, fluorescence and emission, and light-scattering methods. Measurements of temperature, species concentration, and molecular properties. Lab. Enrollment limited to 16. Prerequisite: 362A or 364.

4 units, Spr (Hanson, R)

ME 368A. Biodesign Innovation: Needs Finding and Concept Creation

(Same as BIOE 374A, MED 272A, OIT 581.) Two quarter sequence. Inventing new medical devices and instrumentation, including: methods of validating medical needs; techniques for analyzing intellectual property; basics of regulatory (FDA) and reimbursement planning; brainstorming and early prototyping. Guest lecturers and practical demonstrations.

2 units, Win (Yock, P; Zenios, S; Brinton, T; Milroy, C)

ME 368B. Biodesign Innovation: Concept Development and Implementation

(Same as BIOE 374B, MED 272B, OIT 583.) Two quarter sequence. How to take a medical device invention forward from early concept to technology translation and development. Topics include prototyping; patent strategies; advanced planning for reimbursement and FDA approval; choosing translation route (licensing versus start-up); ethical issues including conflict of interest; fundraising approaches and cash requirements; essentials of writing a business or research plan; strategies for assembling a development team.

2 units, Spr (Yock, P; Zenios, S; Brinton, T; Milroy, C)

ME 369A. Biodesign Innovation, Project A

(Same as BIOE 375A, MED 273A, OIT 582.) Interdisciplinary student teams select a medical need, characterize it fully, develop a needs statement, invent potential conceptual approaches to solving the need, and pursue initial prototyping and planning for regulatory and reimbursement pathways. Guest experts. Corequisite: MED 272A/BIOE 374A/ME 368A/OIT 581.

2 units, Win (Yock, P; Zenios, S; Milroy, C; Brinton, T)

ME 369B. Biodesign Innovation, Project B

(Same as BIOE 375B, MED 273B, OIT 584.) Interdisciplinary teams select the most promising invention from BIOE 375A and move into prototyping and project planning. Teams develop strategies for patenting, FDA submission, third-party reimbursement, licensing agreement or launching a start-up, including cash forecasting and business plan. Prerequisites: MED 375A/ME 369A/BIOE 375A/OIT 582. Corequisite: MED 272B/ME 368B/BIOE 374B/OIT 583.

2 units, Spr (Yock, P; Milroy, J; Brinton, T; Zenios, S)

ME 370A. Energy Systems I: Thermodynamics

Thermodynamic analysis of energy systems emphasizing systematic methodology for and application of basic principles to generate quantitative understanding. Availability, mixtures, reacting systems, phase equilibrium, chemical availability, and modern computational methods for analysis. Prerequisites: undergraduate engineering thermodynamics and computer skills such as Matlab.

3 units, Aut (Bowman, C)

ME 370B. Energy Systems II: Modeling and Advanced Concepts

Development of quantitative device models for complex energy systems, including fuel cells, reformers, combustion engines, and electrolyzers, using thermodynamic and transport analysis. Student groups work on energy systems to develop conceptual understanding, and high-level, quantitative and refined models. Advanced topics in thermodynamics and special topics associated with devices under study. Prerequisite: 370A.

4 units, Win (Edwards, C)

ME 370C. Energy Systems III: Projects

Refinement and calibration of energy system models generated in ME 370B carrying the models to maturity and completion. Integration of device models into a larger model of energy systems. Prerequisites: 370A.B. consent of instructor.

4 units, Spr (Edwards, C)

ME 371. Combustion Fundamentals

Heat of reaction, adiabatic flame temperature, and chemical composition of products of combustion; kinetics of combustion and pollutant formation reactions; conservation equations for multi-component reacting flows; propagation of laminar premixed flames and detonations. Prerequisite: 362A or 370A, or consent of instructor.

3 units, Win (Zheng, X)

ME 372. Combustion Applications

The role of chemical and physical processes in combustion; ignition, flammability, and quenching of combustible gas mixtures; premixed turbulent flames; laminar and turbulent diffusion flames; combustion of fuel droplets and sprays. Prerequisite: 371.

3 units, Spr (Zheng, X)

ME 377. Experiences in Innovation and Design Thinking

Lecture/lab. Immersive experiences in innovation and design thinking, blurring the boundaries among technology, business, and human values. Tenets of design thinking including being human-centered, prototype-driven, and mindful of process. Topics include design processes, innovation methodologies, need finding, human factors, rapid prototyping, team dynamics, storytelling, and project management. Hands-on projects, in-class exercises, and guest lectures. Students and faculty from areas including business, earth sciences, education, engineering, humanities and sciences, law, and medicine. Preparation for advanced d.school courses. Limited enrollment. Application required. See <http://dschool.stanford.edu/projects/classes/me377.html>.

3-4 units, Aut (Kembel, G), Win (Kembel, G), Spr (Kembel, G)

ME 377A. Experiences in Innovation and Design Thinking

Design processes, innovation methodologies, need finding, human factors, rapid prototyping, team dynamics, storytelling, and project management. Preparation for real-world innovation and other d.school projects. Hands-on exercises and team projects focusing on process, frameworks, and methods.

2-3 units, not given this year

ME 377B. Experiences in Innovation and Design Thinking

Design processes, innovation methodologies, need finding, human factors, rapid prototyping, team dynamics, storytelling, and project management. Preparation for real-world innovation and other d.school projects. Hands-on exercises and team projects focusing on process, frameworks, and methods.

2-3 units, not given this year

ME 377C. Experiences in Innovation and Design Thinking

Design processes, innovation methodologies, need finding, human factors, rapid prototyping, team dynamics, storytelling, and project management. Preparation for real-world innovation and other d.school projects. Hands-on exercises and team projects focusing on process, frameworks, and methods.

2-3 units, not given this year

ME 381. Orthopaedic Bioengineering

Engineering approaches applied to the musculoskeletal system in the context of surgical and medical care. Fundamental anatomy and physiology. Material and structural characteristics of hard and soft connective tissues and organ systems, and the role of mechanics in normal development and pathogenesis. Engineering methods used in the evaluation and planning of orthopaedic procedures, surgery, and devices.

3 units, not given this year

ME 382A. Medical Device Design

Real world problems and challenges of biomedical device design and evaluation. Students engage in industry sponsored projects resulting in new designs, physical prototypes, design analyses, computational models, and experimental tests, gaining experience in: the formation of design teams; interdisciplinary communication skills; regulatory issues; biological, anatomical, and physiological considerations; testing standards for medical devices; and intellectual property.

4 units, Win (Andriacchi, T)

ME 382B. Medical Device Design

Continuation of industry sponsored projects from 382A. With the assistance of faculty and expert consultants, students finalize product designs or complete detailed design evaluations of new medical products. Bioethics issues and strategies for funding new medical ventures.

4 units, Spr (Andriacchi, T)

ME 385. Tissue Engineering Lab

Hands-on experience in the fabrication of living engineered tissues. Techniques include sterile technique, culture of mammalian cells, creation of cell-seeded scaffolds, and the effects of mechanical loading on the metabolism of living engineered tissues. Theory, background, and practical demonstration for each technique. Lab.

1-2 units, not given this year

ME 386. Neuromuscular Biomechanics

(Same as BIOE 386.) The interplay between mechanics and neural control of movement. State of the art assessment through a review of classic and recent journal articles. Emphasis is on the application of dynamics and control to the design of assistive technology for persons with movement disorders.

3 units, not given this year

ME 390. Thermosciences Research Project Seminar

Review of work in a particular research program and presentations of other related work.

1 unit, not given this year

ME 391. Engineering Problems

Directed study for graduate engineering students on subjects of mutual interest to student and staff member. May be used to prepare for experimental research during a later quarter under 392. Faculty sponsor required.

1-5 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

ME 392. Experimental Investigation of Engineering Problems

Graduate engineering students undertake experimental investigation under guidance of staff member. Previous work under 391 may be required to provide background for experimental program. Faculty sponsor required.

1-5 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

ME 393. Topics in Biologically Inspired or Human Interactive Robotics

Application of observations from human and animal physiology to robotic systems. Force control of motion including manipulation, haptics, and locomotion. Weekly literature review forum led by student. May be repeated for credit. (Cutkosky, Waldron, Niemeyer)

1 unit, Aut (Staff)

ME 394. Design Forum

Introduction to the design faculty and research labs. Faculty describe their work and research interests followed by open discussion.

1 unit, not given this year

ME 395. Seminar in Solid Mechanics

Required of Ph.D. candidates in solid mechanics. Guest speakers present research topics related to mechanics theory, computational methods, and applications in science and engineering. May be repeated for credit. See <http://mc.stanford.edu>.

1 unit, Aut (Pruitt, B), Win (Pruitt, B; Kuhl, E), Spr (Kuhl, E)

ME 396. Design and Manufacturing Forum

(Same as ME 196.) Guest speakers address issues of interest to design and manufacturing engineers. Sponsored by Stanford Engineering Club for Automation and Manufacturing (SECAM). May be repeated for credit

1 unit, Win (Reis, R), Spr (Reis, R)

ME 397. Design Theory and Methodology Seminar

What do designers do when they do design? How can their performance be improved? Topics change each quarter. May be repeated for credit.

1-3 units, Aut (Leifer, L; Mabogunje, A; Sonalkar, N), Win (Leifer, L; Mabogunje, A), Spr (Leifer, L; Mabogunje, A)

ME 398. Biomechanical Research Symposium

Guest speakers present contemporary research on experimental and theoretical aspects of biomechanical engineering and bioengineering. May be repeated for credit.

1 unit, Aut, Win, Spr (Levenston, M)

ME 399. Fuel Cell Seminar

Interdisciplinary research in engineering, chemistry, and physics. Talks on fundamentals of fuel cells by speakers from Stanford, other academic and research institutions, and industry. The potential to provide high efficiency and zero emissions energy conversion for transportation and electrical power generation.

1 unit, not given this year

ME 400. Thesis (Engineer Degree)

Investigation of some engineering problems. Required of Engineer degree candidates

2-15 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

ME 405. Asymptotic Methods and Applications

Asymptotic versus convergent expansions, approximation of integrals, method of matched asymptotics, WKB method and turning points, method of multiple scales. Applications: viscous and potential flow, wave propagation, combustion, and electrostatics. Prerequisites: ME 300B, graduate-level fluid mechanics.

3 units, not given this year

ME 406. Turbulence Physics and Modeling Using Numerical Simulation Data

Prerequisite: consent of instructor.

2 units, Sum (Moin, P)

ME 408. Spectral Methods in Computational Physics

Data analysis, spectra and correlations, sampling theorem, nonperiodic data, and windowing; spectral methods for numerical solution of ordinary and partial differential equations; accuracy and computational cost; fast Fourier transform, Galerkin, collocation, and Tau methods; spectral and pseudospectral methods based on Fourier series and eigenfunctions of singular Sturm-Liouville problems; Chebyshev, Legendre, and Laguerre representations; convergence of eigenfunction expansions; discontinuities and Gibbs phenomenon; aliasing errors and control; efficient implementation of spectral methods; spectral methods for complicated domains; time differencing and numerical stability.

3 units, Win (Moin, P)

ME 410A. Foresight and Innovation

The art, science, and practice of design innovation. Tools such as critical foresight and anticipatory research design thinking that assist organizations in improving the quality and speed of research and design innovation programs. The path from idea to market. How to communicate a developing idea through scenarios, business pitches, and product prototypes. Prerequisite: consent of instructor.

1-5 units, Aut (Leifer, L; Cockayne, W)

ME 410B. Foresight and Innovation

The art, science, and practice of design innovation. Tools such as critical foresight and anticipatory research that assist organizations in improving the quality and speed of research and design innovation programs. The path from idea to market. How to communicate a developing idea through scenarios, business pitches, and product prototypes.

1-5 units, Win (Leifer, L; Cockayne, W)

ME 410C. Foresight and Innovation

The art, science, and practice of design innovation. Tools such as critical foresight and anticipatory research that assist organizations in improving the quality and speed of research and design innovation programs. The path from idea to market. How to communicate a developing idea through scenarios, business pitches, and product prototypes.

1-5 units, Spr (Leifer, L; Cockayne, W)

ME 410X. Foresight Project Experience with Corporate Partners

Participation in a global foresight research team with real-world industrial partners. Foresight and anticipatory research developed become part of the student's portfolio. May be repeated for credit. Limited enrollment. Prerequisite: consent of instructor.

1-5 units, Aut (Leifer, L; Cockayne, W), Win (Leifer, L; Cockayne, W), Spr (Leifer, L; Cockayne, W), Sum (Leifer, L; Cockayne, W)

ME 412. Engineering Functional Analysis and Finite Elements

(Same as CME 356.) Concepts in functional analysis to understand models and methods used in simulation and design. Topology, measure, and integration theory to introduce Sobolev spaces. Convergence analysis of finite elements for the generalized Poisson problem. Extensions to convection-diffusion-reaction equations and elasticity. Upwinding. Mixed methods and LBB conditions. Analysis of nonlinear and evolution problems. Prerequisites: 335A,B, CME 200, CME 204, or consent of instructor. Recommended: 333, MATH 171.

3 units, Win (Lew, A)

ME 413. Quantum Confinement Structures: Physics and Fabrication

Quantum mechanics principles and the thermodynamics of confinement structures. Focus is on potential applications such as solar cells and catalysis. Student presentations. Lab demonstrations. Prerequisite: background in quantum mechanics and statistical thermodynamics.

3 units, Spr (Prinz, F)

ME 414. Solid State Physics Issues for Mechanical Engineering Experiments

Principles of statistical mechanics, quantum mechanics, and solid-state physics. Provides graduate mechanical engineering students with understanding needed to work on devices or technologies which rely on solid-state physics.

3 units, Sum (Kenny, T)

ME 417. Total Product Integration Engineering

For students aspiring to be product development executives and leaders in research and education. Advanced methods and tools beyond the material covered in 217: quality design across global supply chain, robust product architecture for market variety and technology advances, product development risk management. Small teams or individuals conduct a practical project that produces a case study or enhancement to produce development methods and tools. Enrollment limited to 12. Prerequisites: 317A,B.

4 units, Aut (Ishii, K)

ME 420. Applied Electrochemistry: Micro- and Nanoscale

Concepts of physical chemistry such as thermodynamic equilibrium, reaction kinetics, and mass transport mechanisms from which the fundamentals of electrochemistry are derived. Theory of electrochemical methods for material analyses and modifications with emphasis on scaling behaviors. Electrochemical devices such as sensors, actuators, and probes for scanning microscopes, and their miniaturization concepts. Examples of these devices built, characterized, and applied in labs using technologies such as scanning probe techniques. Projects focus on current problems in biology, material science, microfabrication, and energy conversion.

3 units, not given this year

ME 421. Thought Leaders Seminar for European Entrepreneurship and Innovation

Real-world experiences and challenges in startups, corporations, universities, nonprofit research institutes, and government ministries and agencies. Speakers include entrepreneurs, leaders from global technology companies, university researchers, venture capitalists, legal experts, senior policy makers, and European guests. May be repeated for credit.

1 unit, Win (Leifer, L; Lee, B), Spr (Leifer, L; Lee, B)

ME 438. Computational Molecular Modeling Project

Project-based class. Topics for projects include parallel methods for molecular dynamics, multiple time stepping algorithms, free energy computation, molecular pathways analysis, long-time scale behavior of numerical integrators, and multigrid based fast electrostatic algorithms. Students can propose their own projects. Final report and oral presentation. May be repeated for credit.

3 units, Sum (Darve, E)

ME 450. Advances in Biotechnology

Guest academic and industrial speakers. Latest developments in fields such as bioenergy, green process technology, production of industrial chemicals from renewable resources, protein pharmaceutical production, industrial enzyme production, stem cell applications, medical diagnostics, and medical imaging. Biotechnology ethics, business and patenting issues, and entrepreneurship in biotechnology.

3 units, not given next year

ME 451A. Advanced Fluid Mechanics

Topics: kinematics (analysis of deformation, critical points and flow topology, Helmholtz decomposition); constitutive relations (viscous and visco-elastic flows, non-inertial frames); vortex dynamics; circulation theorems, vortex line stretching and rotation, vorticity generation mechanisms, vortex filaments and Biot-Savart formula, local induction approximation, impulse and kinetic energy of vortex systems, vorticity in rotating frame. Prerequisite: graduate courses in compressible and viscous flow.

3 units, not given this year

ME 451B. Advanced Fluid Mechanics

Waves in fluids: surface waves, internal waves, inertial and acoustic waves, dispersion and group velocity, wave trains, transport due to waves, propagation in slowly varying medium, wave steepening, solitons and solitary waves, shock waves. Instability of fluid motion: dynamical systems, bifurcations, Kelvin-Helmholtz instability, Rayleigh-Benard convection, energy method, global stability, linear stability of parallel flows, necessary and sufficient conditions for stability, viscosity as a destabilizing factor, convective and absolute instability. Focus is on flow instabilities. Prerequisites: graduate courses in compressible and viscous flow.

3 units, not given this year

ME 451C. Advanced Fluid Mechanics

Compressible flow: governing equations, Crocco-Vazsonyi's equations, creation and destruction of vorticity by compressibility effects, shock waves. Modal decomposition of compressible flow, linear and nonlinear modal interactions, interaction of turbulence with shock waves. Energetics of compressible turbulence, effects of compressibility on free-shear flows, turbulent boundary layers, Van Driest transformation, recovery temperature, and shock/boundary layer interaction. Strong Reynolds analogy, modeling compressible turbulent flows. Prerequisites: 355, 361A, or equivalents.

3 units, Aut (Lele, S)

ME 453A. Finite Element-Based Modeling and Simulation of Linear Fluid/Structure Interaction Problems

Basic physics behind many fluid/structure interaction phenomena. Finite element-based computational approaches for linear modeling and simulation in the frequency domain. Vibrations of elastic structures. Linearized equations of small movements of inviscid fluids. Sloshing modes. Hydroelastic vibrations. Acoustic cavity modes. Structural-acoustic vibrations. Applications to liquid containers and underwater signatures. Prerequisite: graduate course in the finite element method or consent of instructor.

3 units, not given this year

ME 453B. Computational Fluid Dynamics Based Modeling of Nonlinear Fluid/Structure Interaction Problems

Basic physics behind many high-speed flow/structure interaction phenomena. Modern computational approaches for nonlinear modeling and simulation in the time domain. Dynamic equilibrium of restrained and unrestrained elastic structures. Corotational formulation for large structural displacements and rotations. Arbitrary Lagrangian-Eulerian description of inviscid and viscous flows. Time-accurate CFD on moving and deforming grids. Discrete geometric conservation laws. Discretization of transmission conditions on non-matching discrete fluid/structure interfaces. Coupled fluid/mesh-motion/structure time integration schemes. Application to divergence, flutter, and buffeting. Prerequisites: graduate course in the finite element method, and in computational fluid dynamics.

3 units, not given this year

ME 455. Complex Fluids and Non-Newtonian Flows

Definition of a complex liquid and microrheology. Division of complex fluids into suspensions, solutions, and melts. Suspensions as colloidal and non-colloidal. Extra stress and relation to the stresslet. Suspension rheology including Brownian and non-Brownian fibers. Microhydrodynamics and the Fokker-Planck equation. Linear viscoelasticity and the weak flow limit. Polymer solutions including single mode (dumbbell) and multimode models. Nonlinear viscoelasticity. Intermolecular effects in nondilute solutions and melts and the concept of reptation. Prerequisites: low Reynolds number hydrodynamics or consent of instructor.

3 units, not given this year

ME 457. Fluid Flow in Microdevices

Physico-chemical hydrodynamics. Creeping flow, electric double layers, and electrochemical transport such as Nernst-Planck equation; hydrodynamics of solutions of charged and uncharged particles. Device applications include microsystems that perform capillary electrophoresis, drug dispensation, and hybridization assays. Emphasis is on bioanalytical applications where electrophoresis, electro-osmosis, and diffusion are important. Prerequisite: consent of instructor.

3 units, Win (Santiago, J)

ME 458. Advanced Topics in Electrokinetics

Electrokinetic theory and electrokinetic separation assays. Electroneutrality approximation and weak electrolyte electrophoresis theory. Capillary zone electrophoresis, field amplified sample stacking, isoelectric focusing, and isotachopheresis. Introduction to general electrohydrodynamics (EHD) theory including the leaky dielectric concept, the Ohmic model formulation, and electrokinetic flow instabilities. Prerequisite: ME 457.

3-5 units, Spr (Santiago, J)

ME 461. Advanced Topics in Turbulence

Turbulence phenomenology; statistical description and the equations governing the mean flow; fluctuations and their energetics; turbulence closure problem, two-equation turbulence models, and second moment closures; non-local effect of pressure; rapid distortion analysis and effect of shear and compression on turbulence; effect of body forces on turbulent flows; buoyancy-generated turbulence; suppression of turbulence by stratification; turbulent flows of variable density; effect of rotation on homogeneous turbulence; turbulent flows with strong vortices. Prerequisites: 351B and 361A, or consent of instructor.

3 units, not given this year

ME 463. Advanced Topics in Plasma Science and Engineering
Research areas such as plasma diagnostics, plasma transport, waves and instabilities, and engineering applications.

3 units, not given this year

ME 468. Experimental Research in Advanced User Interfaces
(Same as COMM 168, COMM 268, COMM 368. Undergraduates register for 168; master's students for 268; doctoral students for 368.) Project-based course involves small groups designing and implementing an experiment concerning voice and agent user interfaces. Each group is involved in a different, publishable research project. May be repeated for credit. Prerequisite: consent of instructor.

1-5 units, Win (Nass, C), Spr (Nass, C)

ME 469A. Computational Methods in Fluid Mechanics
Finite volume methods on structured and unstructured grids. Advanced methods for the solution of systems of equations. ADI schemes, preconditioned conjugate gradient and generalized minimum residual algorithms, multigrid methods, and deferred-correction approaches. Projection, fractional step, and artificial compressibility methods. Turbulent flows: direct numerical simulation, large eddy simulation, and Reynolds-averaged Navier-Stokes methods. Prerequisite: ME 300C/CME 206 or equivalent.

3 units, Win (Iaccarino, G)

ME 469B. Computational Methods in Fluid Mechanics
Advanced CFD codes. Geometry modeling, CAD-CFD conversion. Structured and unstructured mesh generation. Solution methods for steady and unsteady incompressible Navier-Stokes equations. Turbulence modeling. Conjugate (solid/fluid) heat transfer problems. Development of customized physical models. Batch execution for parametric studies. Final project involving solution of a problem of student's choosing. Prerequisite: ME 300C/CME 206.

3 units, not given this year

ME 470. Uncertainty Quantification
Uncertainty analysis in computational science. Probabilistic data representation, propagation techniques and validation under uncertainty. Mathematical and statistical foundations of random variables and processes for uncertainty modeling. Focus is on state-of-the-art propagation schemes, sampling techniques, and stochastic Galerkin methods. The concept of model validation under uncertainty and the determination of confidence bounds estimates. Prerequisite: basic probability and statistics at the level of CME 106 or equivalent.

3 units, Spr (Iaccarino, G)

ME 471. Turbulent Combustion
Basis of turbulent combustion models. Assumption of scale separation between turbulence and combustion, resulting in Reynolds number independence of combustion models. Level-set approach for premixed combustion. Different regimes of premixed turbulent combustion with either kinematic or diffusive flow/chemistry interaction leading to different scaling laws and unified expression for turbulent velocity in both regimes. Models for non-premixed turbulent combustion based on mixture fraction concept. Analytical predictions for flame length of turbulent jets and NO_x formation. Partially premixed combustion. Analytical scaling for lift-off heights of lifted diffusion.

3 units, Aut (Pitsch, H)

ME 484. Computational Methods in Cardiovascular Bioengineering

(Same as BIOE 484.) Lumped parameter, one-dimensional nonlinear and linear wave propagation, and three-dimensional modeling techniques applied to simulate blood flow in the cardiovascular system and evaluate the performance of cardiovascular devices. Construction of anatomic models and extraction of physiologic quantities from medical imaging data. Problems in blood flow within the context of disease research, device design, and surgical planning.

3 units, Spr (Figueroa Alvarez, C)

ME 485. Modeling and Simulation of Human Movement
(Same as BIOE 485.) Direct experience with the computational tools used to create simulations of human movement. Lecture/labs on animation of movement; kinematic models of joints; forward dynamic simulation; computational models of muscles, tendons, and ligaments; creation of models from medical images; control of dynamic simulations; collision detection and contact models. Prerequisite: 281, 331A,B, or equivalent.

3 units, Spr (Delp, S)

ME 491. Ph.D. Teaching Experience

Required of Ph.D. students. May be repeated for credit.

3 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

ME 500. Thesis (Ph.D.)

2-15 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)