MECHANICAL ENGINEERING

Emeriti: (Professors) James L. Adams, Holt Ashley, Peter Bradshaw, Arthur E. Bryson, Thomas J. Connolly, Daniel B. DeBra, Robert H. Eustis, George Herrmann, James P. Johnston, Thomas R. Kane, William M. Kays, Joseph B. Keller, Erastus H. Lee, A. Louis London, Robert McKim, Morton Mitchner, Robert J. Moffat, J. David Powell, William C. Reynolds, Rudolph Sher, Milton D. Van Dyke, Douglass J. Wilde; *Professors (Research)* Elliot Levinthal, Sidney Self

Chair: Ronald K. Hanson

Associate Chair for Student Services: M. Godfrey Mungal

Associate Chair for Faculty Affairs: Mark R. Cutkosky

Associate Chair for Graduate Curriculum and Admissions: Parviz Moin

Division Chairs: Thomas P. Andriacchi, Scott Delp (co-chairs, Biomechanical Engineering), Mark Cappelli (Thermosciences Division), Thomas J. R. Hughes (Mechanics and Computation); (the Design Division, and the Flow Physics and Computation Division operate without a chair)

Laboratory Directors: David W. Beach (Program Director, Manufacturing Systems Engineering and Product Realization Laboratory), J. Edward Carryer (Smart Product Design Laboratory), Mark R. Cutkosky (Manufacturing Sciences Lab and Manufacturing Models Laboratory), Dennis R. Carter (Veterans Affairs Rehabilitation R&D Center), John K. Eaton (Heat Transfer and Turbulence Mechanics), Larry J. Leifer (Center for Design Research and Stanford Learning Lab), Reginald E. Mitchell (High Temperature Gasdynamics), 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, Dennis R. Carter, Mark R. Cutkosky, John K. Eaton, Joel H. Ferziger, Huajian Gao, Ronald K. Hanson, Thomas J. R. Hughes, Charles H. Kruger, Larry J. Leifer, Parviz Moin, M. Godfrey Mungal, Drew V. Nelson, Peter M. Pinsky, Friedrich B. Prinz, Bernard Roth, Charles R. Steele

Associate Professors: Mark A. Cappelli, Scott L. Delp, Rolf A. Faste, Keneth E. Goodson, Kosuke Ishii, David M. Kelley, Thomas W. Kenny, Sanjiva Lele, Reginald E. Mitchell, Sheri D. Sheppard

Assistant Professors: Kyeongjae Cho, Christopher Edwards, J. Christian Gerdes, Jean H. Heegaard, Juan G. Santiago

Professors (Research): Richard Christensen, Paul Durbin, Kenneth Waldron, Kenneth Waldron, Felix E. Zajac

Professor (Teaching): David W. Beach

Courtesy Professors: George S. Springer, Paul Yock

Courtesy Associate Professor: Fu-Kuo Chang

Courtesy Assistant Professor (Research): Charles A. Taylor

Senior Lecturer: J. Craig Milroy

Lecturers: Eugene Alexander, Michael Barry, Albert Makino, Neal Moore, Richard Neptune, Matthew R. Ohline, Robert E. Smith, Nancy Squires

Consulting Professors: Gary Beupre, David M. Golden, Philip G. Hodge, Jr., Barry M. Katz, Victor D. Scheinman, Edith Wilson

Consulting Associate Professors: J. Edward Carryer, Brent Constantz, Paul Mitiguy, Carol B. Muller, Sunil Puria

Consulting Assistant Professors: Michael Barry, Brendan J. Boyle, William Burnett, Sara Little Turnbull, Scott Yerby

Visiting Professors: Dick Desautel, Javier Jimenez, Darryl, Thelen

Visiting Associate Professor: B. Gurumoorthy

Visiting Assistant Professor: Darryl Thelen

The programs in the Department of Mechanical Engineering (ME) are designed to provide background for a wide variety of careers. The discipline is very broad, but is generally understood to emphasize an appropriate mix of applied mechanics, biomechanical engineering, computer simulations, design, and energy science and technology. Graduates at all degree levels have traditionally entered into energy industries, product manufacturing industries, transportation, government laboratories and agencies dealing with these problems, and a variety of academic positions.

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 a good understanding of technology is often important. Both undergraduate and graduate programs provide excellent technical background for work in biomechanical engineering, environmental pollution control, ocean engineering, transportation, and on other multidisciplinary problems that concern our society. Throughout the various programs, considerable emphasis is placed on developing systematic procedures for analysis, effective communication of one's work and ideas, practical and aesthetic aspects in design, and responsible use of technology. This can provide a student with an approach and a philosophy of great utility, irrespective of an ultimate career.

The department has five divisions: Biomechanical Engineering, Design, Flow Physics and Computation Division (jointly with the Department of Aeronautics and Astronautics), Mechanics and Computation, and Thermosciences. Each maintains its own labs, shops, and offices.

The Biomechanical Engineering (BME) Division 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 exist in collaboration with associated faculty in biology, engineering, and medicine. The Biomechanical Engineering Division has particularly strong research interactions with the Mechanics and Computation Division, the Design Division, and the departments of Functional Restoration, Radiology, and Surgery in the School of Medicine.

The Design Division emphasizes cognitive skill development for creative design. It is concerned with automatic control, computer-aided design, creativity, design aesthetics, design research, experimental stress analysis, fatigue and fracture mechanics, finite element analysis, human factors, kinematics, manufacturing systems, microcomputers in design, micro-electromechanics systems (MEMS), optimization, design for manufacturability, and robotics. The Design Division offers undergraduate and graduate programs in Product Design (jointly with the Department of Art and Art History). The division offers a master's program in Manufacturing Systems Engineering jointly with the Department of Management Science and Engineering, and the Graduate School of Business.

The Flow Physics and Computation Division (FPC) is a joint laboratory of the departments of Aeronautics and Astronautics, and Mechanical Engineering. FPC is contributing 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. A significant emphasis of FPC research is on physical modeling and analysis of physical phenomena in engineering systems. FPC 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. The FPC 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 Division 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 working 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 micromechanics, 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 Division offers courses and specialized work in applied thermodynamics, combustion, energy systems, fluid mechanics, gas physics and chemistry, heat transfer, laser diagnostics, materials processing, plasma sciences, propulsion, and sensors.

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 in order to prepare the graduate to address a variety of societal needs. The program prepares each student for entry-level work as a mechanical engineer, for graduate study in engineering, or for graduate study in another field where a broad and fundamental engineering background provides a desirable foundation. With solid grounding in the principles and practice of mechanical engineering, graduates are ready to engage in a lifetime of learning about and employing new concepts, technologies, and methodologies, whatever their ultimate career choice.

FACILITIES

The department divisions 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 include 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 available through the School of Medicine. Individual accommodation is provided for the work of each research student.

Many Biomechanical Engineering Division 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 Material 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, biologically and clinically oriented work is conducted in various facilities throughout the Stanford Medical Center and the Veterans Administration Palo Alto Health Care System.

The Design Division 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 Division students also have access to Center for Integrated Systems (CIS) and Ginzton Lab microfabrication facilities.

The division also maintains the Product Realization Laboratory, a teaching facility offering students integrated experiences in market definition, product design, and prototype manufacturing. The PR Lab provides coaching, design and 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 World Wide Web mediated concurrent engineering by virtual, non-colocated, design-development teams, see the CDR URL (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 Division also has a unique "Product Design Loft," in which students in the joint program in Design develop graduate thesis projects.

Flow Physics and Computation Division has a 32 processor Origin 2000 super computer and an array of powerful workstations for graphics and advanced data analysis. 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 Division is greatly enhanced by the interactions among CTR's and CITS's staff of postdoctoral researchers and distinguished visiting scientists.

The Mechanics and Computation Division 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 solution of computationally intensive problems. A wide spectrum of software is available on the laboratory machines, including major 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 Division has two major labs. The Heat Transfer and Turbulence Mechanics (HTTM) Laboratory concentrates on fundamental research aimed at understanding and improved prediction of turbulent flows and thermal and fluid sciences at the microscales. The High Temperature Gas-Dynamics Laboratory (HTGL) is engaged in research activities in combustion, laser-based diagnostics and sensors, plasma sciences, pollutant formation, and reactive and non-reactive gas dynamics. The experimental capability of the HTGL includes a central laboratory computer with dedicated minicomputers, 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 and Design Division 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.

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 Divisions 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 are outstanding. In addition to the general library, there are Engineering, Mathematics, Physics, and other department libraries of which engineering students make frequent use.

UNDERGRADUATE PROGRAMS

BACHELOR OF SCIENCE

Specializing in mechanical engineering (ME) during the undergraduate period may be done by following the curriculum outlined earlier under 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 is offered by the Design Division and leads to the B.S. Engineering (Product Design). An individually designed major in Biomechanical Engineering (B.S.E.: Biomechanical Engineering), offered by the Biomechanical Engineering Division, may be appropriate for some 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 engineering depth).

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

COTERMINAL B.S./M.S. PROGRAM

Stanford undergraduates who wish to continue their studies for the Master of Science degree in the coterminal program should apply for entrance after the beginning of the eighth quarter of undergraduate work and before the end of the 11th quarter. The application must provide evidence of potential for strong academic performance as a graduate student. The application is evaluated and acted on by the graduate admissions committee of the department. Typically, a GPA of at least 3.25 in engineering, science, and math is expected. Applicants must have completed two of 111, 112, 113, 131A, 131B, 131C, and must take the Graduate Record Examination (GRE) before action is taken on the application. Product designers must have completed 116A to be considered, and are required to work at least one year before rejoining the program. Coterminal information and forms can be obtained from the ME Student Services office.

GRADUATE PROGRAMS

ADMISSION AND FINANCIAL ASSISTANCE

To be eligible for admission to the department, a student must have a B.S. degree in engineering (the Ph.D. degree requires the completion of the M.S.), physics, or a comparable science program. Applications for all degree programs are accepted throughout the year, although applications for fellowship aid must be received by January 14. 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. Preference for teaching assistantships is generally given to students who obtain the bachelor's or master's degrees at Stanford.

Mechanical engineering is a varied profession, ranging from primarily aesthetic aspects of design to highly technical scientific research. Discipline 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.

Master's degree programs are offered in Mechanical Engineering (M.S.:ME), Engineering (Manufacturing Systems Engineering, M.S.E.:MSE), Engineering (Biomechanical Engineering, M.S.E.:BME), Engineering (Product Design, M.S.E.:PD), and Engineering (M.S.E.).

The following sections list specific requirements for the master's degrees listed above.

MASTER OF SCIENCE

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

The master's program normally consists of three quarters of full-time course work. No thesis is required, although many students become involved in research projects during the master's year, particularly to explore their interests in working for the 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 in 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 make-up courses may not be used for other than the 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 in order to obtain an M.S. degree; furthermore, students who have already fulfilled certain categories of the M.S. degree requirements as a result of undergraduate work may find they have sufficient time (see item '3' below) to obtain the M.S. degree in the normal three quarters.

MECHANICAL ENGINEERING

The master's degree program requires 45 units of course work taken as a graduate student. At least 36 of the units must be taken at Stanford; any units transferred from other universities (up to 9 are allowed) must be in graduate-level courses taken while registered as a graduate student and may not be applied toward fulfillment of item '2' below. No thesis is required. However, students who desire some research experience during the master's year may participate in research through ME 290, 291, and 292.

The department's requirements for the M.S. in Mechanical Engineering are:

1. *Mathematical Competence in Two of the Following Areas:* complex variables, linear algebra, modern algebra, numerical analysis, partial differential equations, statistics, or vector and tensor analysis, as

demonstrated by completion of two courses from Computer Science 137, 205, 237A,B,C; Mathematics 106, 109, 113, 131, 132; ME 200-208; Statistics 110, 161. Requirement: 6 units.

Students who completed comparable graduate-level courses as undergraduates and who can demonstrate their competence to instructors may be exempted from this requirement by their advisers and the ME Student Services office, and place the units in the approved elective category.

2. Eighteen units of graduate-level courses in ME consisting of:
    a) *A Specialty in Mechanical Engineering:* a set of graduate-level courses in mechanical engineering to provide depth in one area. These sets have been approved by the faculty as providing depth in specific areas as well as a significant component of applications of the material in the context of engineering synthesis. These courses are listed in the *Mechanical Engineering Graduate Handbook*.
    b) *Breadth in Mechanical Engineering*: at least two additional graduate-level courses outside the depth area to bring the total number to at least 18 ME units in courses numbered 207 and above, excluding 290-301 and math courses. Courses 200-206, 288-301, and 311 may not be counted in these categories.
3. *Approved Electives* (to bring the total number of units to 39): all these units must have adviser approval. Graduate engineering, math, and science courses are normally approved, and upper-level undergraduate courses may be approved if consistent with the student's objectives. Of the 39 units, no more than 6 may come from ME 291 and 292, and no more than 3 may come from the other courses numbered 290-299 or other seminars. Students planning a Ph.D. degree should discuss with their adviser the desirability of taking 291 or 292 during the master's year.
4. *Unrestricted Electives* (to bring the total number of units submitted for the M.S. degree to 45): students are encouraged to use these units outside of 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.
5. Within the courses satisfying the requirements above, there must be at least one graduate-level course dealing with lab studies. Courses which satisfy this requirement are 207A,B, 217B, 218A, 224, 225A, 226B, 248, 254, 267, 282A, 282B, 303, 310A,B,C.

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 in fulfillment of degree requirements. All courses used to fulfill requirements 1, 2, 3, and 5 above must be graded (excluding seminars and courses for which a Satisfactory/No Credit grade is given to all students).

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 60 units required for graduate registration.

PRODUCT DESIGN

The focus of the Joint Program in Design is the intersection of technology with human needs and aspirations. This program is a joint offering of the Department of Mechanical Engineering and the Department of Art and Art History. The resulting two-year degree of MS in Engineering (Product Design) is considered a terminal degree for the practice of design.

Course No. and Subject	*Units*
Art & Art History 160, 169/269, 268	6
Art & Art History 360A,B,C. Master's Project*	6
ME 211A,B,C. Master's Project*	12
ME 212. Calibrating the Instrument	2
ME 303. Manufacturing and Design	4
ME 313. Ambidextrous Thinking	3
ME 316A,B,C. Advanced Product Design	12
Approved Electives†	9
Free Electives†	6
Total	60

---

* Taken jointly each quarter.s

† These electives allow a student to pursue studies suited to personal needs. A list of pre-approved product design electives is outlined in the *Mechanical Engineering Graduate Handbook.*

Note: Stanford BS (Product Design) degree holders admitted to the program design a 45-unit program with their adviser.

Admission requirements are the same as for the M.S.:ME described above, with the 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, etc., may apply to the Department of Art and Art History for a similar graduate design program administered by that department and 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.

MANUFACTURING SYSTEMS ENGINEERING

The M.S. in Engineering (Manufacturing Systems Engineering) addresses the need for engineers who combine management and design skills focused on manufacturing. There is a critical need for individuals who can deal directly with product design for manufacturability; design of manufacturing tools; financial, organizational, and strategic management issues; and elements of automation technology such as computer-aided design, computer-aided manufacturing robotics, and microprocessor control.

Manufacturing Systems Engineering (MSE) is offered jointly by two departments: Mechanical Engineering, and Management Science and Engineering. The program seeks high-quality students with strong educational backgrounds in engineering and provides a demanding curriculum strong in both hardware aspects and engineering management. Students must apply directly to the MSE program by submitting an application to the Department of Mechanical Engineering.

The hardware and engineering-design aspects of the program include:

ME 207A,B. Integrated Design in Marketing and Manufacturing
ME 217A,B. Design for Manufacturability
ME 218A,B,C. Smart Product Design
ME 310A. Tools for Team-Based Design
ME 310B,C. Design Project Experience with Corporate Partners
ME 313. Ambidextrous Thinking
ME 319. Robotics and Vision Lab

The engineering management subjects include:

Manag. Sci. & Engr. 203. Organization Behavior and Management
Manage. Sci. & Engr. 225. Manufacturing Systems Design
Manage. Sci. & Engr. 261. Inventory Control and Production Systems
Manage. Sci. & Engr. 262. Supply Chain Management
Manage. Sci. & Engr. 266. Management of New Product Development
Manage. Sci. & Engr. 268. Manufacturing Strategy
Manage. Sci. & Engr. 269. Marketing for Technology-Based Companies

Hardware and engineering design courses provide hands-on knowledge of these functions and the trade-offs that must be made to take advantage of the relationships between design and manufacturing.

Engineering management subjects provide a suitable perspective for evaluating alternative financial, organizational, and production systems as well as a firm's manufacturing policy.

Beyond the required core, the curriculum allows for choice from a broad set of relevant electives to provide additional training in engineering management and engineering design hardware. Here a student may tailor the program to meet individual interests and needs.

Students in the MSE program must have faculty approval and a minimum GPA of 3.0 in the 45 units presented in fulfillment of the degree requirements.

DUAL M.S.E. AND M.B.A. PROGRAM

Students interested in a career focused on manufacturing management and product development may apply for the dual Manufacturing Systems Engineering and Master of Business Administration Program. Minimum requirements can be met through seven quarters of study if the candidate matriculates to both programs simultaneously. For additional information, contact the MSE Design Division Office.

BIOMECHANICAL ENGINEERING

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

1. *M.S. in Mechanical Engineering:* students who apply and are admitted to the M.S.:ME program can elect to take biomechanical engineering courses as part of their M.S.:ME requirements. These courses are usually applied towards the student's engineering breadth or technical electives.
2. *M.S. in Engineering: Biomechanical Engineering* (M.S.E.:BME): this degree 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.

A Ph.D. in Biomechanical Engineering is not given. Students from either master's degree path (Mechanical Engineering or Biomechanical Engineering) receive their Ph.D. degrees in Mechanical Engineering. The Ph.D. qualifying examinations are flexible enough to accommodate students with either master's degree preparation.

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 this program on 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 can have been previously completed. The program must include at least 9 units of graduate-level work in the department other than ME 200-206 and 288, 290-297, 301, 311. 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.

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. It is most efficient to carry out this preliminary research effort during the M.S. degree year.

ENGINEER

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

This degree represents 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 frequently involves a paid research assistantship awarded by individual faculty members (usually from the funds of sponsored research projects under their direction) and *not* by the department. Thus, personal arrangement is necessary. Students studying for the M.S. degree at Stanford and desiring to continue to the Engineer degree ordinarily make such arrangements during the M.S. degree year. 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 an acceptable thesis; up to 18 units of credit are allowed for thesis work. 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).

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) taken beyond those required for the master's degree.

DOCTOR OF PHILOSOPHY

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

A student studying for the Ph.D. degree ordinarily will not take an Engineer degree, although this is not precluded. However, the student must have a master's degree, and must fulfill in essence 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 oral 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 oral examination. The academic level and subject matter of the examination correspond approximately to the M.S. program described above. The form and timing of the examination differs for the five divisions of the department. Information may be obtained from the division or Student Services office.

Normally, the qualifying examination is taken during the first post-master's year. A student must have the written approval of a tentative dissertation supervisor (sponsor) in order to take the examination. (Sponsorship carries no implication of financial support.) To apply for the examination, a student must have a Stanford graduate grade point average (GPA) equivalent of at least 3.25. Courses used in the GPA evaluation are the same as those that would be used to meet the M.S. GPA requirement. Students entering Stanford with an M.S. from another school must have a 3.25 GPA in that school's M.S. program to take the examination in their first quarter at Stanford. After the first quarter at Stanford, such a student must meet the GPA of 3.25 for courses taken at Stanford.

Ph.D. candidates must complete a minimum of 36 units 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 reading committee may approve a limited number of upper-division 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 36-unit requirement, all Ph.D. candidates must participate each quarter in one of the following (or equivalent) seminars:

ME 290, 294, 288, 289, 295, 296, 297, 298, 311; Aeronautics and Astronautics 296 or 297.

The Ph.D. thesis normally represents at least one full year of research work and must be a substantial contribution to knowledge. Students *may* register for course credit for thesis work (ME 301) to help fulfill University residence requirements, but there is no minimum limit on registered dissertation units. Candidates should note that University residence requirements (see the "Graduate Degrees" section of this bulletin) are expressed in terms of equivalent full-time registration and not in terms of units per se; questions on this should be addressed to the manager of Student Services.

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 course work that is approved by the dissertation reading committee.

The final University oral examination 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 and two faculty members chosen to read and sign the candidate's dissertation. 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.

A student wishing to complete the Ph.D. requirements in four years should ordinarily complete the M.S. by the Spring Quarter of the first year, pass the qualifying examination by the Autumn Quarter of the second year and complete the course work, demonstrate feasibility of research methods, and obtain approval of the dissertation proposal by the end of the third year.

COMBINED Ph.D./M.D. DEGREE PROGRAM

Students interested in a career oriented towards biomechanical research and clinical medicine can pursue the combined Ph.D./M.D. degree program.

The Ph.D. degree is administered by the Department of Mechanical Engineering of the School of Engineering. To be formally admitted as a Ph.D. degree candidate in this combined degree program, the student must apply through normal department channels and must have earned an M.S. in Mechanical Engineering, an M.S.E in Biomechanical Engineering, or a comparable master's degree. Students must pass the Department of Mechanical Engineering Ph.D. qualifying examination and pursue a doctoral thesis in a biomechanical engineering area.

The M.D. degree is administered by the School of Medicine. Students must apply separately through regular channels for admission to the M.D. program and satisfactorily complete 204 units in courses and clerkships approved for credit toward the M.D. degree. Of these, 72 quarter units must be in clerkships. For further information on the M.D. program, consult the *School of Medicine Catalog*.

For students fulfilling the full M.D. requirements who earned their master's level engineering degree at Stanford, the Department of Mechanical Engineering may waive its normal department requirement that the 36 units applied towards the Ph.D. degree (beyond the master's degree level) be formal course work. Consistent with the University Ph.D. requirements, the department may instead accept 36 units consisting of courses, research, or seminars that are approved by the student's Ph.D. thesis reading committee and the department chair. For further information, consult the manager of Student Services.

Ph.D. MINOR

Students who wish a Ph.D. minor in ME should consult the ME Student Services office. A minor in ME may be obtained by completing 20 units of approved graduate-level ME courses or by completing 9 units of graduate-level courses and passing the departmental qualifying oral examination in two appropriate areas identified by the minor adviser.

Courses approved for the minor must form a coherent program and must be selected from those satisfying requirement '2' for the M.S. in Mechanical Engineering.

COURSES

(WIM) indicates that the course meets the Writing in the Major requirements.

(AU) indicates that the course is subject to the University Activity Unit limitations (8 units maximum).

PRIMARILY FOR UNDERGRADUATES

Note 1—The following are especially suitable for freshmen.

101. Visual Thinking
103. Manufacturing and Design

Note 2—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.

10. Introduction to Engineering Analysis—(Enroll in Engineering 10.)

30. Engineering Thermodynamics—(Enroll in Engineering 30.)

33. 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. Euler n and s equations. Dimensional analysis and similarity. Flow in ducts. Boundary layer flows. Lift and drag. Lab demonstration experiments are related to course material. Limited enrollment Spring Quarter. When possible, register for Winter Quarter. Prerequisites: 10, Engineering 14 and 30.

4 units, Win (Cappelli)
Spr (Santiago)

38. The Design of Life—The design of a variety of living organisms is considered from a mechanical perspective.

3 units, Win (Carter)

70N. Stanford Introductory Seminar: The Aerodynamics of Sports Balls—Preference to freshmen. The aerodynamics of the ball play a major role in many sports, e.g., the curve and knuckle ball in baseball, the spiral of a correctly thrown football, the effect of top spin in tennis, and the effect of dimples on a golf ball. The complex aerodynamics can be understood by application of basic concepts and experimental techniques. Simple, intuitive application of the basic principles precede lab and/or field experiments to verify their intuition. Lab experiments involve flow visualization in a wind tunnel; field experiments may involve tests in throwing, hitting, or kicking various balls and interaction with local teams. Teams of two to three prepare a written report discussing the importance of aerodynamics in a particular sport.

3 units, Spr (Mungal)

71Q. Stanford Introductory Seminar: The Burning of Fossil Fuels, Global Warming, and the Environment—Preference to sophomores. Combustion has been humankind's primary energy source. The role that combustion plays as a future energy source and the environmental and economic consequences of this. Issues: projections of energy utilization and energy sources into the future (and the associated uncertainties), the environmental effects of combustion (including air quality and global warming), strategies to reduce the environmental effects of combustion, and the role of regulations in driving combustion technology and the use of fossil fuels. Structured presentations, open discussion, directed readings. Outside speakers; visit to the campus combustion laboratory. Project with oral/written reports.

3 units (Bowman) not given 2000-01

72N. Stanford Introductory Seminar: The Jet Engine—Preference to freshmen. The basics of how a jet engine works and the technologies and analytical techniques required to understand them. Brief coverage of dynamics, thermodynamics, turbomachinery, combustion and pollution formation, advanced materials, cooling technologies, and control systems. Field trips. Prerequisites: high school physics and an interest in how mechanical things work.

3 units, Aut (Eaton)

73N. Stanford Introductory Seminar: Designing the Human Experience—An Exploration into the Theory and Practice of Design Thinking—Preference to freshmen. Readings, discussion, and projects explore the proposition that design education is for everyone.

3 units, Win (Leifer)

74N. Stanford Introductory Seminar: Stuff—Preference to freshmen. The advancement of human society largely depends on the "stuff" available for housing, transportation systems, industrial products, defense systems, etc. Frequently, "human made stuff" gets exposed to unfriendly environments such as high temperatures, corrosive liquids, and gases. The most extreme conditions occurs in aircraft engines. A trip to an airline maintenance facility provides insight to what environmental conditions advanced turbine blades are required to suffer, and how engineers prevent the premature "death" of turbine blades to avoid major catastrophes.

3 units (Prinz) not given 2000-01

75N. Stanford Introductory Seminar: Mechanical Design Issues for Sports Equipment—Preference to freshmen. Any sporting goods department reveals interesting examples of mechanical design, accompanied by "literature" which highlights the novel design "features." Design features can be understood and are sensible, e.g., "perimeter weighting" in golf clubs, or are less obvious, and perhaps of no real utility, e.g., "bubble shaft" in golf clubs or "fat head" in baseball bats. Analyses of some designs, and conclusions about their relative merits.

3 units, Aut (Kenny)

76N. Stanford Introductory Seminar: Burn Baby Burn—The Science of Flames—Preference to freshmen. The roles that chemistry and fluid dynamics play in governing the behaviors of flames. Emphasis is on factors that affect flame microstructure, external appearance, and on the fundamental physical and chemical processes that cause flames and fires to propagate. Topics: history, thermodynamics, and pollutant formation in flames. Trips to labs where flames are studied. Prerequisites: high school physics and an interest in thermochemical phenomena.

3 units, Spr (Mitchell)

99. Mechanical Dissection—Series of mechanical dissection labs to resolve common questions of everyday products and provide confidence in "hands-on" skills. Students choose a current product, track its history, obtain samples (current and "antique"), disassemble, and explore functions. Formal and informal presentations. Lab. Enrollment limited to 20. Prerequisite: keen sense of curiosity.

3 units (Sheppard) not given 2000-01

100A,B. Mathematical and Computational Methods for Engineers—(Enroll Engineering 155A,B.)

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. Quickly executed diagrammatic, orthographic, perspective, and three-dimensional sketching with emphasis on fluent and flexible idea production. The relationship between visual thinking and the creative process. Enrollment limited to 60.

3 units, Aut, Win, Spr (Staff)

102. Integration, Prototyping, Design, and Evaluation—The integration of human values, technology, and manufacturing towards engineering solutions to design problems. Emphasis is on the development and timely evaluation of potential candidates through the use of methodology, computers, and rapid prototyping techniques. Lecture and lab. Enrollment limited to 30.

3 units (Milroy) not given 2000-01

103. Manufacturing and Design—(Graduate students register for 303.) Emphasis is on prototype development techniques as an intrinsic part of the design process. The fundamentals of machining, welding, and casting, introduced in lecture and supported by lab experience. Manufacturing processes through lecture, films, and field trips. Design aspects are developed in an individual term project chosen, designed, and fabricated by students. Limited enrollment with consent of instructor. Corequisite, unless student has prior drafting experience: 103D. Corequisite for Mechanical Engineering and Product Design undergraduate majors for WIM: Engineering 102M. (WIM)

4 units, Aut, Win (Beach)

103D. Engineering Drawing and Design—The fundamentals of engineering drawing including orthographic projection, dimensioning, sectioning, exploded and auxiliary views, and assembly drawings. Designed to accompany 103. Homework drawings are of parts fabricated by the student in the shop. Major assignments in 103 are supported by material in 103D and assignment dates are sequenced on the assumption that the student is enrolled in both courses simultaneously.

1 unit, Aut, Win (Milroy)

104. Dynamic Behavior—(Enroll in Engineering 104.)

105. Feedback Control Design—(Enroll in Engineering 105.)

106. Vehicle Dynamics and Control—(Graduate students register for 227.) The application of the principles of dynamics, kinematics, and control theory to the design and analysis of ground vehicle behavior. Simplified models of ride, handling, and braking, their role in developing intuition, and their limitations in engineering design. Suspension design fundamentals. Multibody dynamics approaches to vehicle modeling. Performance and safety enhancement through automatic control systems such as anti-lock braking, active suspensions, and stability control. Prerequisite: 161 or Engineering 104.

3 units, Spr (Gerdes)

106D. Vehicle Dynamics and Control Laboratory—(Graduate students register for 227D.) Demonstration of handling fundamentals, suspension set-up, and controller design using scale cars.

1 unit, Spr (Gerdes)

109. Computer Aided Design of Model Yachts—(Graduate students register for 209.) Hands-on introduction to the art and science of engineering and manufacturing. Students design and construct free sailing model yachts to a high standard of craftsmanship using Computer Aided Design and Manufacturing (CAD/CAM). Includes: sailing theory (aerodynamics and hydrodynamics of sail boats); model yacht design (nomenclature, scaling issues, lofting, history of rating rules, yacht aesthetics, tradeoffs between speed and control); the use of design and manufacturing systems (MaxSurf, Vellum, and laser-cuter); necessary construction techniques (hull fixture, planking, fiberglassing, casting ballast, sail making, finishing, and rigging); and sailing technique (tuning for performance). Field trips. Enrollment limited to 33.

4 units (Faste) alternate years, given 2001-02

110A. Design Sketching—Freehand sketching, rendering, and design development. Work is guided by instructors. Concurrent assignments in 115 and 116B,C provide subject matter, but the class is open to anyone wishing to improve freehand drawing skills. (AU)

1 unit, Win, Spr (Staff)

110B. Advanced Design Sketching—Freehand sketching, rendering, design development, and some computer use. Work is guided by instruc-

tors. Concurrent assignments in 116A provide subject matter. Prerequisite: 110A or consent of instructor based on drawing skill. (AU)
1 unit, Aut (Staff)

111. Stress, Strain, and Strength—Review of the basic mechanics of materials and engineering properties of structural materials. Stress concentrations and their avoidance through design. Static failure theories for ductile and brittle materials. Introduction to fracture mechanics. Review of surface failure mechanisms including corrosion, fretting, and wear. Structural failure by global and local buckling of columns and plates. Introduction to failure by fatigue; fatigue failure criteria and life prediction methods. Case studies in failure of structural components emphasizing applications to mechanical design.
3 units, Aut (Pinsky)

112. Mechanical Systems Design—Objectives: provide students familiarity with the function of basic machine elements (e.g., gears, bearings), the trade-offs between various classes of machine elements, performance characteristics of various machine elements, and systems level design; and to provide experience in working in teams, selecting machine classes in synthesis-type problems, iterative design including prototyping, communicating ideas in graphical, textual, and oral forms, and design critiquing. Lecturers, labs. Prerequisites: 101, 111. Recommended: 103, Engineering 15.
4 units, Win (Gerdes)

113. Mechanical Engineering Design—Objective: create designs and models of new mechanical devices. Design is studied as an activity and experienced by students as they work on a team design project obtained from industry and other sponsoring organizations. Prerequisites: 101, 103, 111, 112.
3 units, Spr (Staff)

114. Elements of Form—An exploration of proportion, rhythm, metaphor, scale, modularity, and other key concepts that enhance the designer's ability to generate appropriate form.Demonstrations, discussions, drawing, product examples, and modeling exercises develop the student's form vocabulary. Enrollment limited to 12. Prerequisites: 103, 115, and consent of instructor.
2 units, Spr (Faste)

115. Human Values in Design—Active encounters with human values in design. Lectures survey the central philosophy of the product design program, emphasizing the relation between technical and human values, the innovation process, and design methodology. Lab exercises include development of simple product concepts visualized in rapidly executed three-dimensional mockups. Prerequisite: 101.
3 units, Win (Kelley)

116A. Advanced Product Design: Formgiving—(Graduate students register for 316A.) Small- and medium-scale design projects are carried to a high degree of aesthetic refinement. Emphasis is on generating the appropriate forms to the task and setting. Prerequisites: 115, Art and Art History 160.
4 units, Aut (Staff)

116B. Advanced Product Design: Needfinding—(Graduate students register for 316B.) Exploration of human needs that leads to 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. Prerequisite: 115, 116A, or consent of instructor.
4 units, Win (Faste)

116C. Advanced Product Design: Implementation—(Graduate students register for 316C.) Summary project utilizing the knowledge, methodology, and skills obtained in 115A,B, and 116A,B. Students implement design concept and present it to a professional jury. Prerequisite: 116.
4 units, Spr (Staff)

117. Introduction to Sensors—(Graduate students register for 220.) 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 (Kenny)

118. Introduction to Mechatronics—(Graduate students register for 318.) Open to undergraduate and graduate students. Introduces the technologies involved in mechatronics (Intelligent Electro-Mechanical Systems) and the techniques necessary to apply this technology to mechatronic system design. Topics: 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. Lab component of structural assignments. Large and open-ended team project. Limited enrollment. Prerequisites: Engineering 40, Computer Science 106, or equivalent.
4 units, Win (Kenny, Ohline)

120. History and Philosophy of Design—Major schools of 19th- and 20th-century design (Arts-and-Crafts Movement, Bauhaus, Industrial Design, and post-modernism) 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.
3-4 units, Spr (Katz)

128. Design for Appropriate Technology—(Graduate students register for 328.) Lecture/lab. Design products for developing countries and markets with emphasis on culturally sensitive need determination; local material, process, and maintenance limitation; and information transfer. Weekly labs reinforce lecture topics. Team design projects explore solutions to real-world needs.
3 units, Spr (Staff)

128X. Design for Appropriate Technology Seminar—(Graduate students register for 328X.) Lecture. Design products for developing countries and markets with emphasis on culturally sensitive need determination; local material, process, and maintenance limitation; and information transfer.
1 unit, Spr (Staff)

130. 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: Engineering 30, 33, 131A (or concurrent enrollment in 131A), or equivalent.
3 units, Aut (Edwards)

131A. Heat Transfer—(Graduate students register for 250.) The principles of heat transfer by conduction, convection, and radiation are introduced with specific examples from the engineering of practical devices and systems. Topics: transient and steady conduction, conduction by extended surfaces, boundary layer theory for forced and natural convection, boiling, heat exchangers, and graybody radiative exchange.

Prerequisites: 33, Engineering 30. Recommended: intermediate calculus, ordinary differential equations.
4 units, Aut (Goodson)

131B. Fluid Mechanics: Compressible Flow and Turbomachinery—Introduction to engineering applications involving compressible flow: aircraft propulsion, 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. Introduction to 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. Prerequisite: 131A.
3 units, Win (Squires)

134. Modern Experimentation—Practical introduction to modern techniques for data acquisition, experimental control, and statistical and time-domain analysis of sampled data. Introduction to and use of a range of measurement devices including traditional sensors and optically-based systems. Lab includes individual work in computerized data acquisition and experimental control including A/D and D/A conversion, digital interfacing, and software development using powerful graphical programming. Statistical concepts and sensor systems are introduced with simple experiments on small devices. Teams develop a fully integrated experiment to test and improve an interesting engineering system. Prerequisites: 33, 131A.
3 units, Win (Eaton)

140. Integrated Thermal Systems—Capstone course in thermal science, providing experience in thermal analysis and engineering, with emphasis on integrating heat transfer, fluid mechanics, and thermodynamics into a unified approach to treating complex systems. Lecture introduces mixtures, humidity, chemical and phase equilibrium, and availability. Labs apply principles through hands-on experience with a turbojet engine, a PEM fuel cell, and a hybrid solid/oxygen rocket motor. Analysis of systems is facilitated using MATLAB as a computational tool. Prerequisites: 131A, 131B, Engineering 30.
4 units, Spr (Edwards)

161. Dynamic Systems—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. Demonstrations and laboratory examples. Prerequisites: background in dynamics and calculus, e.g., Engineering 15 and Mathematics 43; and familiarity with differential equations, linear algebra, and basic electronics.
4 units, Aut (Mitiguy)

180. Skeletal Development and Evolution—(Graduate students register for 280.) The development, adaptation, repair, and aging of the vertebrate skeleton is considered from an evolutionary perspective. Emphasis is on the interacting influences of mechanobiology and molecular genetics.
3 units, Spr (Carter)

181. Biomechanics of Movement—(Graduate students register for 381.) Review of experimental techniques used 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, orthopaedics, neurology, and rehabilitation.
3 units, Aut (Delp)

182. Biomineralization—The process of formation and adaptation of mineralized structures formed by organisms, principally animal skeletons. Emphasis is on the interacting influences of phylogenic history, material constraints, mechanical factors, and other ecological and physiological considerations. Skeletal formation processes and the skeletal microstructure and ultrastructure of every animal phylum. The evolutionary aspects of body plan design among the major animal phyla with skeletons.
2 units, Spr (Constantz)

184A. Cardiovascular Biomechanics—(Graduate students register for 284A.) Biomechanical principles are developed and applied to the cardiovascular system. The relevance of mechanics in the study of cardiovascular function is examined from a historical perspective. Cardiovascular system anatomy, tissue mechanics, and blood rheology. Lumped parameter models, pulse wave propagation models. Womersley theory, finite element methods of blood flow, pulsatile flow in deformable vessels, and cardiac fluid dynamics. Problems in modeling blood flow within the context of disease research, device design, and surgical planning.
3 units, Win (Taylor)

184B. Cardiovascular Biomechanics—Continuation of 184A.
3 units, Spr (Taylor)

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 the adviser.
1-5 units, any quarter (Staff)

194. Medical Device Design—(Graduate students register for 384.) Offered in collaboration with the School of Medicine. Introduction to medical device design for undergraduate and graduate engineering students. Significant design and prototyping. Labs expose students to medical device environments, including hands on device testing and field trips to operating rooms and local device companies. Limited enrollment. Prerequisite: 103/303.
3 units, Aut (Milroy)

195. Design and Construction in Wood—(Graduate students register for 395.) The design and construction of objects using wood. Taught in the Product Realization Lab. Enrollment limited.
1-3 units, Spr (Milroy)

UNDERGRADUATE AND GRADUATE

The following are especially suitable for advanced undergraduates and graduates and may be used to satisfy the M.S. requirement, item '3' above, approved electives.

103. Manufacturing and Design
105. Feedback Control Design—(Enroll in Engineering 105)
113. Engineering Design
161. Dynamic Systems
250. Heat Transfer

PRIMARILY FOR GRADUATES

ENGINEERING MATHEMATICS AND COMPUTATION

200A,B,C are intended for students in the master's program with some proficiency in undergraduate engineering mathematics and computing. Students enrolling in this sequence should have had some exposure to elementary linear algebra (for example, elementary operations with matrices), ordinary differential equations (for example, Mathematics 130), and computer programming. Students who do not meet these guidelines should be prepared to devote additional remedial time to these courses or consider satisfying their requirements through Mathematics 113 and 131, and Computer Science 137.

200A. Mathematical and Computational Methods in Engineering—The theory of linear algebra; basis, linear independence, column space, null space, rank. Emphasis is on computer solutions of the linear system of algebraic and differential equations. Roundoff errors, pivoting, and ill-conditioned matrices. Quadratic forms, norm and condition numbers, projection and least-squares, operation counts, eigenvalues, eigenvectors, and their computation. The canonical diagonal form, functions of a matrix. Unitary, Hermitian, and normal matrices. Principal stresses and axes. Recommended: familiarity with computer programming; Mathematics 103, 130, or equivalent.

3 units, Aut (Staff)

200B. Mathematical and Computational Methods in Engineering—Geometric interpretation of partial differential equations (PDEs), characteristics, solution of first-order equations, characteristics and classification of second-order PDEs, separation of variables, special functions, eigenfunction expansions, Fourier integrals and transforms, Laplace transforms, method of characteristics, analytic and numerical techniques, self-similarity. Prerequisite: 200A.

3 units, Win (Ferziger)

200C. Mathematical and Computational Methods in Engineering—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, non-linear equations. Prerequisites: 200A,B.

3 units, Spr (Moin)

205A,B,C. Partial Differential Equations of Applied Mathematics—(Enroll in Mathematics 220A,B,C.)

206. Introduction to Symmetry Analysis—(Enroll in Aeronautics and Astronautics 218.)

DESIGN AND CONTROLS

207A,B. Integrated Design for Marketability and Manufacturing (IDMM)—Integrated market research, product design, prototype manufacture, pricing, and product management. New product launching, with emphasis on compressed development cycle time and cross functional staffing. Teams of MBAs and engineers compete for simulated sales and profitability. Innovative use of market research as a design tool, immersion in hands-on manufacturing process, product definition communication, and sales. Instructors specify the product market in which all teams compete. IDMM aims to graduate leaders in product development. Limited enrollment. Enroll both quarters.

4 units, Aut, Win (Beach, Srinivasan)

209. Computer Aided Design of Model Yachts—See 109.

211A,B,C. Product Design Master's Thesis—For Product Design or Design (Art) majors only. Students create and present two masters' 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 take for 4 units, Art students take for 2 units. Corequisite: Art and Art History 360.

211A. *2-4 units, Aut (Faste, Kelley)*

211B. *2-4 units, Win (Faste, Kelley)*

211C. *2-4 units, Spr (Faste, Kelley)*

212. Calibrating the Instrument—Open to Product Design or Design (Art) majors. Calibrating the designer's mind/body "instrument" in regards to aesthetic, kinesthetic, sensory, behavioral and experiential self-knowledge. Improvisation, educational kinesiology, Brain Gym, Zazen, and other methods are used to center and inform the designer. Shared stories and goal setting begin building community.

2 units, Aut (L. Faste, R. Faste)

213. Computer-Aided Prototyping—Design course concentrating on an integrated suite of modern computer tools: rapid prototyping, solid modeling, computer-aided machining, computer numerical control manufacturing. Students choose, design, and manufacture individual products, emphasizing product definition, user benefits, and computer design tools. Manufacturing focuses on CNC machining. Stanford's Product Realization Lab's relationship to the outside world. Structured lab experiences build a basic CAD/CAM/CNC proficiency. Evaluation balances process and results. Enrollment limited.

3 units, Spr (Milroy)

214. Good Products and Bad Products—An analysis of characteristics of industrial products that can cause them to be successes or failures: the straight-forward (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. Readings, lectures, projects, papers, guest speakers, and field trips. Enrollment limited.

3 units, Win (Adams, Beach)

215. The Designer in Society—Open to all graduate students. Participants' career objectives and psychological orientation are 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. Attendance mandatory. Enrollment limited to 24.

3 units, Win (Roth)

216. Introduction to Aircraft Design, Synthesis, and Analysis—(Enroll in Aeronautics and Astronautics 241A.)

217A. Design for Manufacturability: Product Definition—Systematic methodologies to define, develop, and produce competitive products. Methods cover the characterization of user values, design for manufacturability, and environmental compatibility. 217A addresses the key issues for product competitiveness. Student teams identify opportunities for improvement and develop a comprehensive product definition. Topics: design for value, functional analysis, quality function deployment, value engineering, design for assembly, product line structuring, process and material selection, design for productability, failure modes and effects analysis (FMEA), design for serviceability, environmental product design, and organization issues for simultaneous engineering. Enrollment limited to 40. No maximum enrollment for Stanford Instructional Television Network (SITN) students. Minimum enrollment of two per viewing site; single student site by prior consent of instructor.

4 units, Win (Ishii)

217B. Design for Manufacturability: Quality by Design—Building on the product definition process covered in 217A, focuses 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 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 SITN students. Minimum enrollment of two per SITN viewing site; single student site by prior consent of instructor. Prerequisite: 217A.

4 units, Spr (Ishii)

217C. Manufacturing Systems Design—(Enroll in Management Science and Engineering 264.)

218A. Smart Product Design Fundamentals—Introduction. Lecture, lab, and design project based series on programmable electromechanical systems design. Topics: transistors as switches, basic digital and analog circuits, boolean algebra, combinatorial and sequential logic, operational amplifiers, comparators, software design, programming in FORTH and "C." Team project. Enrollment in 218B,C is contingent on completing 218A or passing a Smart Product Design Fundamentals proficiency examination given at the start of Autumn Quarter. Lab fee. Limited enrollment.
5 units, Aut (Carryer)

218B. Smart Product Design Applications—Intermediate level in the series of programmable electromechanical systems design, introduced in the context of lab assignments and integrated into a team project. Topics: user I/O, timer systems, interrupts, signal conditioning, software design for embedded systems, sensors, actuators, noise, and power supplies. Team project. Lab fee. Limited enrollment. Prerequisite: completion of 218A or passing of the Smart Product Design Fundamentals proficiency examination.
5 units, Win (Carryer)

218C. Smart Product Design Practice—Advanced level in the series on programmable electromechanical systems design. Topics: interprocessor communication, system design with multiple microprocessors, architecture and assembly language programming for the PIC microcontroller, design with programmable logic, understanding and controlling the embedded software tool chain, A/D and D/A techniques, electronic manufacturing technology. Lab fee. Limited enrollment. Team project. Prerequisite: completion of 218B.
5 units, Spr (Carryer)

218D. Smart Product Design Projects—Industrially sponsored project course is the culmination of the Smart Product Design sequence. Student teams take on an industrial project that requires the application and extension of the knowledge gained in the prior three quarters, including prototyping of a final solution with hardware, software, and professional documentation and presentation. Lectures extend the students' knowledge of electronic and software design, and electronic manufacturing techniques. Topics: chip level design of microprocessor systems, real time operating systems, alternate microprocessor architectures, PCB layout and fabrication.
4 units, Aut (Carryer)

219. Introduction to Robotics—(Enroll in Computer Science 223A.)

220. Introduction to Sensors—See 117.

221. Materials Selection in Design—(Enroll in Materials Science and Engineering 270.)

222. Kinematic Synthesis of Mechanisms—The rational design of linkages. Techniques are presented to determine linkage proportions to fulfill various design requirementsusing analytical, graphical, and computer based methods.
3 units, Win (Roth)

224. 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 is gained through the design and manufacture of a precision engineering project, emphasizing the principles of precision engineering. Lectures, structured labs, and field trips. Undergraduate prerequisite: consent of instructors.
4 units, Spr (Beach, DeBra)

225A. Control System Design and Simulation—(Enroll in Engineering 206.)

225B. Analysis and Control of Nonlinear Systems—(Enroll in Engineering 209A.)

226A. Modern Control Design I—(Enroll in Engineering 207A.)

226B. Modern Control Design II—(Enroll in Engineering 207B.)

227. Vehicle Dynamics and Control—See 106.

227D. Vehicle Dynamics and Control Laboratory—See 106D.

228. Introduction to Control Design Techniques—(Enroll in Engineering 205.)

MECHANICS OF SOLIDS

229. Physical Solid Mechanics—Statistical mechanics of solids. Microscopic foundation of solid mechanics including metals, ceramics, amorphous and alloy materials. Thermodynamics and statistical mechanics of materials. Atomic structure of solids. Dynamics of crystals. Point defects, dislocations, grain boundaries in solids. Micromechanics of interfaces and thin films. Mechanics of nanostructures.
3 units, Spr (Cho)

230. 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)

231A. Dynamics—Formulation of the equations of motion for rigid multibody systems. Summary of vector calculus. Matrix algebra. Reference frames. Coordinate systems and vector differentiation. Angular velocity and acceleration of rigid bodies. Generalized coordinates. Holonomic and non-holonomic constraints. Generalized velocities. Geometry of masses. Center of mass. Inertia tensor. Inertia properties. Principal axes of inertia. Elements of reduction. Generalized active forces. Generalized inertia forces.
3 units, Aut (Heegaard)

231B. Dynamics—Methods for obtaining equations of motion for rigid multibody systems. Newton's equations. D'Alembert's principle. Energy functions. Lagrange's equations. Hamilton's formalism. Kane's method. Gibbs-Appel method. Constraint forces. Contact and impact problems. Numerical integration of equations of motion. Computer simulations of multibody systems.
3 units, Win (Heegaard)

232A. Introduction to Computational Mechanics I—Overview of modern computational methods for solving problems arising in the mechanics of solids and structures. Basic concepts of the finite element method (FEM) and boundary element method (BEM). Equations of linear solid mechanics including variational formulations. Elastic bars (elasticity in one-dimension), steady heat conduction (diffusion), and plane elasticity (plane stress and strain, axisymmetric elasticity). Students develop a finite element code in Matlab using the PDE Toolbox pre- and post-processor, solve problems, and visualize results at every stage. Introduction to simulation-based design methodologies.
3 units, Win (Pinsky)

232B. Introduction to Computational Mechanics II—Introduction to convergence analysis of the finite and boundary element method. Advanced element formulations: mixed finite element models for incompressible and constrained media. Variational treatment of constraints based on Lagrange multiplier and penalty methods; contact mechanics. Extension of the finite element and boundary element methods to time-dependent problems, including transient heat conduction and dynamic analysis. Extension of Matlab finite element code for the time-dependent problems.

3 units, Spr (Pinsky)

234A. Finite Element Methods in Fluid Mechanics—Finite element methods for basic classes of problems in fluid mechanics. Convective-diffusive equations. Mixed and penalty methods for incompressible viscous flows. Shock capturing schemes for compressible Euler and Navier-Stokes equations. Comparisons with finite difference methods.

3 units (Hughes) alternate years, not given 2001-02

234B. Finite Element Methods in Fluid Mechanics—Continuation of 234A.

3 units (Hughes) alternate years, not given 2001-02

234C. Finite Element Methods in Fluid Mechanics—Continuation of 234B.

3 units (Hughes) alternate years, not given 2001-02

235A. Finite Element Analysis—Emphasis is on 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 (Hughes) alternate years, given 2001-02

235B. 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 (Hughes) alternate years, given 2001-02

235C. Finite Element Analysis—Nonlinear continuum mechanics. Galerkin formulation of nonlinear elliptic, parabolic, and hyperbolic problems. Explicit, implicit, and "implicit-explicit" algorithm in nonlinear transient analysis. Stability of ordinary differential equation solvers for nonlinear problem classes; "energy-conserving algorithms." Automatic time-step selection strategies. Methods of solving nonlinear algebraic systems. Newton-type methods and quasi-Newton updates. Iterative procedures. Arc-length methods. Architecture of computer codes for nonlinear finite element analysis. Applications from structural and solid mechanics, e.g., nonlinear elasticity.

3 units (Hughes) alternate years, given 2001-02

237. Free and Forced Motion of Structures—(Enroll in Aeronautics and Astronautics 244A.)

238A. Continuum Mechanics: An Introduction—Introduction to tensor algebra and calculus. Basic kinematics of continuum deformation. Stress, strain, and strain rate. Conservation of mass and balance of linear and angular momentum. Conservation of energy and thermodynamics. Governing equations for deformation of an arbitrary continuum body. Closing the equations through constitutive modeling.

3 units, Aut (Cho)

238B. Continuum Mechanics: Applications—Application of continuum mechanics to solids. General theory of mechanical constitutive equations. Multiscale constitutive models of continuum solids from microscopic structures. Linear and nonlinear elasticity, viscoelasticity, thermoelasticity, and plasticity models. Applications to biosolids, polymers, metals, structural mechanics, geomechanics, micro-electronic devices, and MEMS modeling.

3 units, Win (Cho)

240A. Theory and Applications of Elasticity—Concepts of deformation, strain, stress, and strain energy. Kinematic relations, balance of momentum and energy, generalized Hooke's law, and symmetry properties of elastic constants. Compatibility and uniqueness of solutions. Formulation of boundary value problems and solution methods using stress functions and complex variable potentials. Elastic waves in deformable solids. Stress concentration at holes, inclusions, notches, dislocations, and cracks.

3 units, Win (Gao)

240B. Introduction to Fracture Mechanics—Linear and nonlinear analysis of crack tip fields. Stress intensity factors and fracture modes. Energy release rate and fracture criterion. J-integral concept and other conservation integrals. Generalized Eshelby forces on defects. Mechanisms of crack nucleation and growth. Paris law of fatigue crack growth. Dynamic crack propagation. Prerequisite: 240A.

3 units, Spr (Gao)

240C. Micromechanics of Fracture in Solids—Micromechanics of fracture processes near a crack tip. Crack interaction with dislocations. Ductile brittle transition of solids. Plastic void growth in ductile fracture. Hyperelastic deformation at a crack tip. Local crack tip instabilities during dynamic fracture. Formation of crack-like flaws by surface diffusion in nanoscale thin film structures. Mixed continuum and atomistic views of brittle fracture.

3 units (Gao)

241A. Theory of Plates—Analysis of stress, deformation in plates bent by transverse loads. Applications to circular, rectangular, other shapes. Vibrations, buckling. Prerequisite: 111 or Civil and Environmental Engineering 114.

3 units (Steele)

241B. Theory of Shells—Axisymmetric deformation of shells of revolution. Asymptotic expansions, direct and bending stress. Application to design of domes, pressure vessels, expansion joints and pressure sensing devices. Use of asymptotic solutions for "very large finite element computation." Prerequisite: 111 or Civil and Environmental Engineering 114.

3 units (Steele)

241D. Vibration and Stability of Plates and Shells: Biomechanical Applications—Basic concepts of vibration, wave propagation, and stability for the beam, ring, and shell revolution. Nonlinear shallow-shell equations. Applications to biology: fluid-elastic interaction in arterial flow, waves in the inner ear, and morphogenesis of plants.

3 units, Spr (Steele)

243. Micromechanics—(Enroll in Materials Science and Engineering 350.)

244. Atomistic Simulations of Materials—Fundamental concepts and practical techniques of atomistic simulations. Fundamental concepts of molecular dynamics (MD) and Monte Carlo (MC) simulations are introduced based on the finite difference method. Practical computational techniques of MD and MC simulations. The strength and weakness of atomistic simulations under the light of the accuracy of interatomic potentials. Standard methods of simulation analysis in connection with numerical data analysis and statistical mechanics. Advanced simulation techniques (generalized MD, smart MC simulations, accelerated dynamics, and multiscale analysis).

3 units (Cho) not given 2000-01

245. 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, multiaxial 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: strength of materials.
3 units, Win (Nelson)

246. Techniques of Failure Analysis—Enroll in Aeronautics and Astronautics 252.)

247A. Microstructure and Mechanical Properties—(Enroll in Materials Science and Engineering 251.)

248. Experimental Stress Analysis—Theory and applications of photoelasticity, strain gages, and holographic interferometry. Comparison of test results with theoretical predictions of stress and strain. Discussion of other methods of stress and strain determination (optical fiber sensors, acoustoelasticity, thermoelasticity, brittle coating, Moiré). Student project on use of strain gages. Lab fee.
3 units, Spr (Nelson)

249A. Quantum Simulations of Molecules and Materials—(Enroll in Chemical Engineering 444A.)

249B. Quantum Simulations: Materials Micro Mechanics—Quantum atomistic simulations of materials to predict structure, strength, defect energetics and motion, and surfaces and interfaces. Tight-binding and density functional methods for covalent, ionic, and metallic solids. Pseudopotential and plane wave basis for ab initio solid electronic structure calculations. Applications to real materials systems including micromechanics of electronic devices, MEMS, nanotechnology, and biomaterials.
3 units (Cho) not given 2000-01

HEAT TRANSFER, FLUID MECHANICS, AND HIGH TEMPERATURE GAS DYNAMICS

250. Heat Transfer—For graduate students; see 131A.
3 units, Aut

251A. Fluid Mechanics—Exact and approximate analysis of fluid flow covering kinematics, global and differential equations of mass, momentum, and energy conversation. 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 (Lele)

251B. Fluid Mechanics—Laminar viscous fluid flow. Brief review of 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. Prerequisite: 251A.
3 units, Win (Lele)

252A. 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 252B,C for depth in heat transfer. Prerequisites: graduate standing and undergraduate course in heat transfer. Recommended: computer skills.
3 units, Aut (Mitchell)

252B. 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)

252C. 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. Prerequisites: 250, 251B, or equivalents.
3 units, Spr (Eaton)

254. Computers and Instrumentation in the Fluid Mechanics Laboratory—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.
3 or 4 units, Win (Santiago)

255. Compressible Flow—Recommended for students with little experience in compressible flow. Introduction to compressible flow. Sound waves and normal shock-waves. Quasi-one-dimensional steady flows in variable area ducts with friction, heating, and cooling; unsteady one-dimensional flow, two-dimensional supersonic flow; oblique shock waves, Prandtl-Meyer expansions, detonation waves, method of characteristics.
3 units, Win (Bowman)

256. Turbomachinery, Fluid Dynamics, and Design—Theory, performance, and design of turbomachines (turbines, pumps, compressors, wind turbines, etc.). Turbomachines function as the result of the dynamic interaction of a moving fluid with a bladed rotor. Problems sets, and a final design problem such as the specification of blading for a compressor or a turbine stage to meet prescribed performance criteria. Prerequisities: 251A or equivalent, plus one-dimensional flow of a perfect gas as presented in 131B or equivalent.
3 units (Staff) not given 2000-01

257. Fluid Flow in Microdevices—Introduction to the effects of physico-chemical forces on the fluid flow of micron-scale flow devices. Basic descriptions of creeping flow, charge double-layers, and electrochemical transport (e.g., Nernst-Planck equations) lead to a study of the hydrodynamics of solutions of charged and uncharged particles. Device applications of interest include microsystems that perform capillary electrophoresis, drug dispension, and hybridization assays. Emphasis is on bioanalytical applications where electrophoresis, electro-osmosis, and Brownian motion effects are important. Prerequisite: consent of instructor.
3 units, Aut (Santiago)

258. 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, e.g., chemical-vapor-deposited (CVD) diamond. Final project can be based on student research interests. Prerequisite: consent of instructor.
3 units, Spr (Goodson)

259A. Numerical Methods in Fluid Mechanics—(Enroll in Aeronautics and Astronautics 214A.)

259B. Numerical Computation of Compressible Flow—(Enroll in Aeronautics and Astronautics 214B.)

259C. Numerical Computation of Viscous Flow—(Enroll in Aeronautics and Astronautics 214C.)

261A. Statistical Theory and Modeling for Turbulent Flow—Averaging and correlations, vorticity and vortex stretching, and the energy cascade. Reynolds stresses; introduction to transport equations. Length scales and spectra; "universal" scaling of small eddies. Law of the wall, local equilibrium, and eddy viscosity. Properties of boundary layers and other "thin" shear layers; complex flows. Introduction to prediction methods; local equilibrium, stress-transport, and eddy-viscosity transport models. Prerequisite: 251B.
3 units, Win (Staff)

261B. Advanced Topics in Turbulence—Topics vary each year and may include: spectral representation, rapid distortion theory, Cayley-Hamilton theorem and consitutive modeling of turbulence, turbulent dispersion, stochastic differential equations, Reynolds average and modeling for reacting flows, vortical structures (topology), intermittancy, proper orthogonal characteristic eddy decomposition, chaos, Lyapunoff exponents, fractals, large eddy simulations, subgrid closure, and geophysical turbulence.
3 units, Spr (Staff)

262A. 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, e.g., combustion and materials processing.
3 units, Aut (Cappelli)

262B. Nonequilibrium Processes in High-Temperature Gases—Introduction to chemical kinetics and energy transfer in high-temperature gases. Collision theory, transition state theory, and unimolecular reaction theory. Prerequisite: 262A.
3 units, Win (Golden)

263. 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: 262A or consent of instructor.
3 units, Spr (Cappelli)

264. Optical Diagnostics and Spectroscopy—Introduction to 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: 262A or equivalent.
3 units (Hanson) not given 2000-01

267. Optical Diagnostics and Spectroscopy Laboratory—Introduction to the 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. Prerequisites: 262A and/or 264.
4 units, Spr (Hanson)

269A. Computational Methods in Fluid Mechanics—Advanced methods for solving systems of linear equations: multigrid and conjugate gradient methods; methods for potential flow; integral methods for boundary layers and their coupling to potential flow solutions; methods for the boundary layer equations; methods for solving the incompressible flow equations on structured grids: projection, fractional step and artificial compressibility methods. Students use and modify provided codes. Prerequisites: 200C, 251B or equivalents.
3 units, Aut (Ferziger)

269B. Computational Methods in Fluid Mechanics—Review of turbulence modeling; solution of the incompressible flow equations with turbulence models; methods for convective heat and mass transfer; methods for reacting flows, finite volume methods for structured and unstructured grids; direct numerical; simulation; large eddy simulation including subgrid scale models and numerical methods; methods for two phase flows; applications to compressible flow. Project involving solution of a problem of the student's choosing. Prerequisite: 269A.
3 units, Win (Staff)

THERMODYNAMICS AND ENERGY CONVERSION

270. Engineering Thermodynamics—Thermodynamic analysis of engineering systems, emphasizing systematic methodology for application of basic principles. Introduction to availability analysis. Thermodynamics of gas mixtures and reacting systems. Modern computational equations of state. Thermodynamics of condensed phases, including solutions. Prerequisites: undergraduate background in engineering thermodynamics and computer skills.
3 units, Aut (Bowman)

271. 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: 262A or 270, or consent of instructor.
3 units, Win (Mitchell)

272. 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: 271.
3 units, Spr (Bowman)

BIOMECHANICAL ENGINEERING

280. Skeletal Development and Evolution—See 180.

281. Orthopaedic/Cardovascular Bioengineering and Medicine—Engineering approaches are applied to the musculoskeletal and cardiovascular system within the context of surgical and medical care. Introduction to fundamental anatomy and physiology. The material and structural characteristics of hard and soft connective tissues and organ systems, and the role of mechanics in normal development and pathogen-

esis. Engineering methods are used in the evaluation and planning of medical procedures, surgery, and devices.
3 units, Aut (Carter)

282A. **Biomedical Device Design and Evaluation I**—Introduction to the 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. Attendance at grand rounds in clinical departments.
4 units, Win (Delp, Andriacchi)

282B. Biomedical Device Design and Evaluation II—Continued industry sponsored projects from 282A. With the assistance of faculty and expert consultants, students finalize product designs or complete detailed design evaluations of new medical products. Attendance at grand rounds in clinical departments. Strategies for funding new medical ventures.
4 units, Spr (Andriacchi)

283. Computational Locomotion Biomechanics—Review of the computational methods used to model and simulate the mechanics of human locomotion. Multibody dynamics, inverse dynamics, simple models of locomotion, torque actuation and energy flow. Joint kinematics and biomechanics, models of articular contact. Optimal control of musculotendon units, simulation of locomotion tasks including human gait and athletic performance. Prerequisite: 231, 381, or equivalent.
3 units (Heegaard, Delp) alternate years, given 2001-02

284A. Cardiovascular Biomechanics—See 184A.

284B. Cardiovascular Biomechanics—See 184B.

285. Tissue Engineering—Tissue engineering is an expanding discipline that applies biological and engineering principles to create substitutes or replacements for defective tissues or organs. The principles of cell biology provide a foundation for using engineering approaches to generate tissue structure and function. Emphasis is on how scaffolds, smart polymers, and mechanical forces can be used to reproduce the physical environment that acts, at the whole organ system level, to maintain specialized cellular function through molecular and genetic mechanisms.
2 units, Win (Smith)

286. Neuromuscular Biomechanics—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, Spr (Delp)

287. Biomechanics and Ecological Physiology of Intertidal Communities—(Enroll in Biological Sciences 277H.)

DIRECTED STUDY AND SEMINARS

288. Biomechanical Engineering Seminar—Invited speakers present research topics at the interfaces of biology, medicine, physics, and engineering. (AU)
1 unit, Win (Arnold)
Spr (Alexander)

289. Medical Device Forum—Invited speakers discuss engineering, medical, legal, and business issues associated with the development of medical devices. (AU)
1 unit, Aut (Taylor)

290. Thermosciences Research Project Seminar—Review of work in a particular research program and presentations of other related work. (AU)
1 unit, Aut, Win, Spr (Staff)

291. 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 292. Students must find a faculty sponsor.
1-5 units, any quarter (Staff)

291X. Teaching Participation—Credit is given for assisting a professor in the teaching of a mechanical engineering course. Prerequisite: consent of supervising instructor.
1-3 units, Aut, Win, Spr (Staff)

292. Experimental Investigation of Engineering Problems—Graduate engineering students undertake experimental investigation under guidance of staff member. Previous work under 291 may be required to provide background for experimental program. Faculty sponsor required.
1-5 units, any quarter (Staff)

293. Interdisciplinary Interaction Design—(Same as Computer Science 447.) Small teams develop innovative technology prototypes that combine product and interaction design. Focus is on software and hardware interfaces, interaction, design aesthetics, and some underpinnings of successful design: a reflective, interactive design process, group dynamics of effective interdisciplinary teamwork, and working with users. Prerequisite: 247A.
3-4 units, Spr (Kelley, Winograd)

293X. Human-Computer Interaction: Interaction Design Studio—(Enroll in Computer Science 247A.)

294. Design Forum—Invited speakers address issues of interest to designers. Brief presentation followed by open discussion. Spring Quarter emphasis on manufacturing and design. (AU)
1 unit, Aut (Gerdes)
Spr (Milroy)

295. Seminar in Solid Mechanics—Problems in all branches of solid mechanics. All Ph.D. candidates in solid mechanics are normally expected to attend. (AU)
1 unit, Aut, Win, Spr (Staff)

296. Manufacturing Systems Engineering Forum—Invited speakers address issues of interest to design and manufacturing engineers. Brief presentations are followed by open discussion. Sponsored by Stanford Engineering Club for Automation and Manufacturing. (SECAM) (AU)
1 unit, Aut, Win, Spr (Beach)

297. Design Theory and Methodology Forum—A mixture of research reports, literature reviews, and designer interviews promote rigorous examinations of the cognitive basis for designer behavior and design tool development. (AU)
1 unit, Aut, Win, Spr (Leifer, Mabogunje)

298. Seminar in Fluid Mechanics—(Enroll in Engineering 298.)

299. Practical Training—Educational opportunities in high-technology research and development labs in industry. Qualified graduate students engage in internship work and integrate that work into their academic program. Following internship, work students complete a research report outlining their work activity, problems investigated, key results, and any follow-on projects they expect to perform. Meets the requirements for Curricular Practical Training for Students on F-1 visas.

Student is responsible for arranging own employment. Register under adviser's section number.
1 unit (Staff)

300. Thesis—Investigation of some engineering problems. Required of candidates for the degree of Engineer.
2-15 units, any quarter (Staff)

301. Thesis—Dissertation for the degree of Ph.D.
2-15 units, any quarter (Staff)

303. Manufacturing and Design—(Same as 103.)

ADVANCED MATHEMATICS AND COMPUTATION ANALYSIS

305. Asymptotic Methods and Applications—Asymptotic vs. 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: 200B, graduate-level fluid mechanics.
3 units (Durbin) not given 2000-01

308. Spectral Methods in Computational Physics—Data analysis, spectra and correlations, sampling theorem, non-periodic 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 eigen function expansions. Discontinuities and Gibbs phenomenon. Aliasing errors and control. Efficient implementation of spectral methods. Spectral methods for complicated domains. Time differencing and numerical stability. Data management methods for the Navier-Stokes equations. Prerequisites: 200A,B,C.
3 units (Moin) not given 2000-01

DESIGN

309. Finite Element Analysis in Mechanical Design—Part I: basic concepts of finite elements, with applications to problems confronted by mechanical designers. Linear static, modal, and thermal formulations are emphasized; nonlinear and dynamic formulations are introduced. Students implement simple element formulations to obtain a deeper understanding of the essential features of this numerical technique. Part II: application of a commercial finite element code in analyzing design problems. Issues: solution methods, modeling techniques features of various commerical codes, basic problem definition. Individual projects focus on the interplay of analysis and testing in product design/development. Prerequisite: ability to program, Mathematics 103, or equivalent. Recommended: 111, or equivalent in structural and/or solid mechanics; some exposure to principles of heat transfer.
3 units (Sheppard) not given 2000-01

310A. Tools for Team-Based Design—(Same as Engineering 310A.) For graduate students; open to limited SITN/global enrollment. Project-based, exposing students to the tools and methodologies useful for forming and managing an effective engineering design team in a business environment, including product development teams that may be spread around the world. Topics: personality profiles for creating teams with balanced diversity; computational tools for project coordination and management; real time electronic documentation as a critical design process variable; and methods for refining project requirements to ensure that the team addresses the right problem with the right solution. Computer-aided tools are employed for supporting geographically distributed teams. The final project analyzes a set of industry-sponsored design projects for consideration in 310B,C. The investigation includes benchmarking and meetings with industrial clients. The deliverable is a detailed document with specifications for the project and the optimal design team that should work on the project in subsequent quarters. Limited enrollment, consent of instructor for off-campus (global) registrants.
4 units, Aut (Cutkosky)

310B,C. Design Project Experience with Corporate Partners—(Same as Engineering 310B,C.) Two-quarter project for graduate students who already have some design experience and want in-depth involvement in an entrepreneurial design team with real world industrial partners. The products developed are part of the student's portfolio. For some projects, 217 and 218 may be prerequisites or co-requisities (see http://me310.stanford.edu for admission guidelines). Each team functions like a small start-up company, working closely with a technical advisory board, consisting of the instructional staff and a coach. Teams use computer-aided tools for project management, communication, and documentation, and are provided a budget for direct expenses including hiring technical assistants and conducting tests. Teams interact with corporate liaisons weekly via site visits, video conferencing, email, fax, and phone. Hardware demonstrations, peer reviews, scheduled documentation releases, and an intense team environment provide the mechanisms and culture for design information sharing. Enrollment by consent of instructor and depends on the results of a pre-enrollment survey in December and the recommendations made by project definition teams in 310A.
4-5 units, Win, Spr (Cutkosky)

311. Engineering: Women's Perspective—Master's and Ph.D.-level seminar series driven by student interests. Possible topics: time management, career choices, health and family, diversity, professional development, and personal values. Graduate students share experiences and examine scientific research in these areas. Guests speakers from academia and industry, student presentations with an emphasis on group discussion. (AU)
1 unit, Win (Sheppard)

313. Ambidextrous Thinking—Visual and kinesthetic skills are developed and exercised in solving design problems. Quickly executed perspective, orthographic, diagrammatic, and three-dimensional sketches are emphasized in conjunction with fluent and flexible idea production. Exercises to appreciate and develop the entire body's role in creative thinking. Enrollment limited to 60.
3 units, Aut (Faste)

314. Solid State Physics for Mechanical Engineering—Introductory overview of the principles of statistical mechanics, quantum mechanics, and solid-state physics. Provides graduate mechanical engineering students with the understanding needed to work on devices or technologies which rely on solid-state physics.
3 units (Kenny) alternate years, given 2001-02

316A. Advanced Product Design: Formgiving—See 116A. Prerequisites: 313, 303; art.
4 units, Win (Burnett)

316B. Advanced Product Design: Needfinding—See 116B. Prerequisite: consent of instructor.
4 units, Win

316C. Advanced Product Design: Implementation—Prerequisite: 316B.
4 units, Spr

317. Total Product Integration Engineering—Targets students aspiring to be product development executives and leaders in dfM research and education. Students learn 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, etc. Small teams or individuals conduct a practical project that produces either an in-depth case study

using advanced tools or a significant enhancement to the dfM methods and tools. Enrollment limited to 16. Prerequisites: 217A,B.
4 units, Aut (Ishii)

318. Introduction to Mechatronics—See 118.

319. Robotics and Vision Lab—For graduate students with some familiarity in robotics who want project experience with robotic and vision systems. Current topics in robotics and machine vision with applications to flexible, automated manufacturing; emphasis is on integrated problems and techniques for fine motion control, calibration, acquisition of sensory data, and programming. Cell level topics: architectures and strategies for cell control. Research issues: dextrous manipulation and languages for high-level task specification. Typical projects: robotic deburring, assembly using force feedback and/or vision, part inspection, and cell control. Short assignments provide practice with various equipment. Enrollment limited to 30. Prerequisites: 219 or equivalent, some familiarity with programming.
3 units (Staff) not given 2000-01

327B. Introduction to Computer Vision—(Enroll in Computer Science 223B.)

328. Design for Appropriate Technology—See 128.

ADVANCED MECHANICS OF SOLIDS

349. Engineering Quantum Mechanics—Basic quantum mechanics topics necessary for engineering graduate students to understand the atomic, electronic, magnetic, and optical properties of diverse material systems and the fundamental underlying principles of microscopic measurement processes (e.g., STM, MFM, TEM, SNOM, etc.). Topics: electronic bound states, collision theory, symmetry in quantum mechanics, approximation methods, identical particles and spin, electromagnetic field, and relativistic wave equations.
3 units, Sum (Cho)

ADVANCED FLUID MECHANICS

351A. Advanced Fluid Mechanics—For advanced students specializing in 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-level courses in compressible and viscous flow.
3 units (Staff) not given 2000-01

351B. 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. Stability 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. Focus is on flow instabilities. Prerequisites: graduate-level courses in compressible and viscous flow.
3 units (Staff) not given 2000-01

351C. 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: 255, 261A, or equivalents.
3 units (Staff) not given 2000-01

353. Introduction to Dilute Multiphase Flow—Introduction to multiphase flow in dilute particle, droplet, and spray systems. Forces on particles, particle motion and dispersion, the Stokes number, and preferential transport. Atomization of liquids and spray formation. Spray description and measurements. Droplet hydrodynamics: deformation, breakup, and coalescence. Droplet and spray evaporation. The spray equation. Modeling approaches to dilute particle/spray flows.
3 units (Edwards) not given 2000-01

OTHER

381. Biomechanics of Movement—See 181.

382. Modeling and Simulation of Human Movement—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: 231, 381, or equivalent.
3 units, Spr (Delp, Heegaard) alternate years, not given 2001-02

384. Medical Device Design—See 194.

395. Design and Construction in Wood—See 195.

396. Product Realization Lab: Special Project—Material varies each year, emphasizing design and technique in either foundry work, machining projects, or wood construction.
1 unit, Spr (Milroy)

459. Frontiers in Interdisciplinary Biosciences—Introduction to cutting-edge research involving interdisciplinary approaches to bioscience and biotechnology; for specialists and non-specialists. Associated with Stanford's Clark Center for Interdisciplinary Bioscience, and held in conjunction with a seminar series meeting twice monthly during 2000-01. Leading investigators from Stanford and throughout the world speak on their research; students also meet separately to present and discuss the ever-changing subject matter, related literature, and future directions. Prerequisite: keen interest in all of science, with particular interest in life itself. Recommended: basic knowledge of biology, chemistry and physics.
2 units, Aut, Win, Spr (S. Block)