AERONAUTICS AND ASTRONAUTICS

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The Department of Aeronautics and Astronautics (AA) prepares students for professional positions in industry, government, and academia by offering a comprehensive program of graduate teaching and research. In this broad program, students have the opportunity to learn and integrate multiple engineering disciplines. The program emphasizes structural, aerodynamic, guidance and control, and propulsion problems of aircraft and spacecraft. Courses in the teaching program lead to the degrees of Master of Science, Engineer, and Doctor of Philosophy. Undergraduates and doctoral students in other departments may also elect a minor in Aeronautics and Astronautics.

Requirements for all degrees include courses on basic topics in aeronautics and astronautics, as well as in mathematics, physics, and applied mechanics.

The current research and teaching activities cover a number of advanced fields, with special emphasis on:

Active Noise Control
Aerodynamic Noise
Aeroelasticity
Aircraft Design, Performance, and Control
Applied Aerodynamics
Biomedical Mechanics
Computational Aero-Acoustics
Computational Fluid Dynamics
Control of Robots, including Space and Deep-Underwater Robots
Conventional and Composite Materials and Structures
Direct and Large-Eddy Simulation of Turbulence
High-Lift Aerodynamics
Hypersonic and Supersonic Flow
Inertial Instruments
Multidisciplinary Design Optimization
Navigation Systems (especially GPS)
Optical Diagnostics in Fluid Dynamics
Optimal Control, Estimation, System Identification
Physical Gas Dynamics
Robust Control of Flexible Spacecraft
Shock Tube Studies of Vortex Interactions
Spacecraft Design and Satellite Engineering
Turbulent Flow and Combustion

INSTRUCTION AND RESEARCH

FACILITIES

The work of the department is centered in the William F. Durand Building for Space Engineering and Science. This 120,000 square foot building houses advanced research and teaching facilities and concentrates in one complex the Department of Aeronautics and Astronautics as well as the activities of other engineering organizations allied in space exploration and aerospace technology.

The Global Positioning System (GPS) Laboratory is engaged in research on precise aircraft, spacecraft, and ground vehicle navigation. The laboratory has extensive equipment including approximately 30 carrier phase receivers and has built approximately 20 pseudolites for centimeter level positioning research both inside and outside buildings. A nationwide network of reference stations has been installed for evaluation of the Wide Area Differential GPS concept. The laboratory has performed extensive flight testing in a twin engine aircraft at local airports.

The Aerospace Robotics Laboratory (ARL) is developing advanced robot systems and control techniques applicable to industrial automation and space and underwater robotics. Experimental research facilities include very-flexible-beam manipulators, SCARA-configured manipulators with flexible drive trains, quick mini-manipulators, and pairs of cooperating manipulators. A collection of model free-flying space robots that experience the dynamics of space through the use of air-cushion support systems makes possible leading-edge research in space-manipulator system dynamics. Object-based control puts the human operator at the task command level. ARL works closely with the Computer Science Robotics Laboratory on task-planning/task-execution systems and with the GPS Laboratory on the navigation and control of autonomous systems.

The ARL computing facilities include a dozen Sun workstations for control system design, analysis, and simulation; for real-time software development; for mechanical and electrical CAD; and for documentation. The workstations are complemented by a collection of real-time control computers networked by the labwide LAN. These microprocessor-based, single-board computers are used in multiprocessor configurations for implementing and testing control algorithms on experimental hardware.

The Guidance and Control Laboratories include a wide spectrum of specialized facilities for making and testing novel instruments of extremely high precision. In addition, students work in laboratories associated with interdepartmental science experiments such as Gravity Probe-B (a gyro test of general relativity), a Space Test of the Equivalence Principle, and an advanced Laser Interferometer Gravity-wave Observatory. Clean facilities, ultra-precision machining, and advanced electronics design and fabrication support the guidance, control, and instrumentation experiments and research in precision machining; for example, quiet hydraulics for actuation and metrology on machines expected to operate with 30 nm precision. Cryogenic gyro test facilities are available in the nearby Varian Physics Building, and Electrical Engineering's Integrated Circuit Fabrication Facility is adjacent.

The spacecraft design program is a total life-cycle space mission program. The Satellite Systems Development Laboratory (SSDL) provides the opportunity for building, testing, and operating low earth-orbiting microsatellites. Students at the master's degree level participate in mission planning, project management, spacecraft design, fabrication, testing, launch integration, and mission operations. Students in the engineer and doctoral programs are involved with multiyear satellite programs for more complex missions. These programs involve direct interaction with payload customers and industry in both design and operations.

The Aircraft Aerodynamics and Design Group is involved with research in applied aerodynamics and aircraft design. Their work ranges from the development of computational and experimental methods for aerodynamic analysis to studies of unconventional aircraft concepts and new architectures for multidisciplinary design optimization.

The Flow Physics and Computation Division (FPC) is a joint laboratory between the departments of Aeronautics and Astronautics, and Mechanical Engineering. The FPC offers courses in acoustics, aerodynamics, applied mathematics, compressible flow, computational fluid mechanics, numerical analysis, and propulsion.

The goal of the FPC is to carry out basic research leading to the development of improved computational tools and physical models for accurate engineering design, analysis, and control of complex flows.

Problems of interest include aerodynamics, electronics cooling, material processing, planetary entry, power systems, propulsion, and semiconductor manufacturing. Research is conducted in a variety of disciplines including acoustics, chemical reactions, combustion, data display, environmental fluid mechanics, flow control, flow interactions with electromagnetic waves, numerical analysis, plasmas and processing, and scientific computing.

The computational facilities of the FPC include powerful workstations, color displays and reproduction facilities, and direct access to the major national computing facilities of the nearby NASA-Ames Research Center which includes CRAY-C90s and massively parallel super computers. The Center for Turbulence Research (CTR), a research consortium between Stanford and NASA, is affiliated with this group. The intellectual atmosphere of the Flow Physics and Computation Division is greatly enhanced from interactions with CTR's large staff of postdoctoral researchers and distinguished visiting scientists.

Experimental fluid mechanics research is carried out using the facilities of the Aero-Fluid Mechanics Laboratories (AFML). Facilities include several laser sources and flow measuring systems; a high pressure shock tube; a flow visualization water channel; and a temperature stabilized subsonic wind tunnel equipped with a unique free-to-roll, free-to-yaw high angle-of-attack model support system. Collaborative projects with NASA Ames provide Stanford faculty and graduate students access to a variety of large-scale experimental flow facilities. Research is directed at using experimentation to enhance a basic understanding of fluid flow phenomena with application to aeronautical systems including the aerodynamics of high lift systems, new propulsion concepts, and advanced aerodynamic measurement techniques.

The Structures and Composites Laboratories include facilities for studying and testing the behavior of small-scale structures of metal and fiber reinforced composites. Equipment is also available to fabricate structural elements made of composite material using an autoclave, resin transfer molding, and hot press.

The department has over 100 computers in the Durand Building for use in the academic and research programs. Two clusters of Macintoshes and PCs are available for student use, and each research group is equipped with advanced workstations, Macintoshes, and/or PCs. In addition, computer clusters throughout the campus provide access to electronic mail, the WorldWide Web, and time-shared computation via the campus academic computer network. They are available to all students at no cost for their course work or unsponsored research.

The Durand Building also houses faculty and staff offices and several conference rooms. Attached to the building is a modern classroom building equipped for televising lectures; it contains a lecture auditorium.

Through the consortium arrangement between Stanford and the nearby NASA-Ames Research Center, students and faculty have access to one of the best and most extensive collections of experimental aeronautical research facilities in the world, as well as the latest generation of super-computers.

INSTITUTES AND RESEARCH PROGRAMS

The Joint Institute for Aeronautics and Acoustics (JIAA) is co-sponsored by Stanford University and NASA-Ames Research Center. The overall purpose of the JIAA is to prepare students for leadership in the nation's aeronautics enterprise. The institute provides the environment necessary for long-term cooperative research and graduate education in specialized areas of aeronautics and acoustics. Stanford faculty, staff, and students collaborate with center staff on research topics motivated by problems facing the aeronautics industry. Current topics include active flow control, jet noise, aerodynamics and acoustics of high lift systems and application of luminescent paint to aerodynamic measurement.

The Center for Turbulence Research (CTR) is a research consortium for fundamental study of turbulent flows, jointly operated by Stanford and NASA-Ames Research Center. Its principal objective is to stimulate significant advances in the physical understanding of turbulence, leading to improved capabilities for control of turbulence and turbulence modeling for engineering analysis. Emphasis is placed on probing turbulent flow fields, developed by direct numerical simulations and/or laboratory experiments using new diagnostic techniques and mathematical methods, and on concepts for turbulence control and modeling. Although the role of the CTR is to advance the understanding of turbulent flows for aerospace applications, it is an interdisciplinary program; researchers with interest in turbulence are sought from aeronautics, mathematics, meteorology, oceanography, physics, and other areas.

GENERAL INFORMATION

Further information about the facilities and programs of the Department of Aeronautics and Astronautics is available on the World Wide Web (at http://aa.stanford.edu/) or by request from the department's Student Services office.

The department has a very active student branch of the American Institute of Aeronautics and Astronautics, which sponsors films covering aerospace topics and monthly socials. It also conducts visits to nearby research, government, and industrial facilities, and sponsors a Young Astronauts Program in the local schools.

UNDERGRADUATE PROGRAMS

BACHELOR OF SCIENCE

Although primarily a graduate-level department, Aeronautics and Astronautics offers an interdisciplinary program in Aeronautics and Astronautics (AA) leading to the B.S. degree in Engineering. For further information, see the "School of Engineering" section of this bulletin and the *Undergraduate Handbook*, available from the Office of the Dean of Engineering.

Undergraduates interested in aerospace may also elect a minor in Aeronautics and Astronautics. For information about an AA undergraduate minor, see the "School of Engineering" section of this bulletin.

COTERMINAL PROGRAM

This special program allows Stanford undergraduates an opportunity to work simultaneously toward a B.S. in another field and an M.S. in Aeronautics and Astronautics. General requirements for this program and admissions procedures are described in the "School of Engineering" section of this bulletin. Admission is granted or denied through the departmental faculty Admissions and Awards Committee. A coterminal student must meet the course and scholarship requirements detailed for the M.S. below.

GRADUATE PROGRAMS

Admission—To be eligible to apply for admission to the department, a student must have a bachelor's degree in engineering, physical science, mathematics, or an acceptable equivalent. Students who have not yet received a master's degree in a closely allied discipline will be admitted to the master's program; eligibility for the Ph.D. program is considered after the master's year (see "Doctor of Philosophy" below). Applications for all degree programs are accepted throughout the year, although applications for fellowship aid must be received and completed by January 15 for the next Autumn Quarter.

Information about admission to the Honors Cooperative Program is included in the "School of Engineering" section of this bulletin.

Further information and application forms may be obtained from Graduate Admissions, the Registrar's Office (http://www.stanford.edu/dept/registrar/admissions/).

Waivers and Transfer Credits—Students may receive departmental waivers of required courses for the M.S. degree in Aeronautics and Astronautics by virtue of substantially equivalent and satisfactorily performed course work at other institutions. A waiver petition (signed by the course instructor and adviser) should be submitted to the Student Services office indicating (1) the Stanford University course number and title, and (2) the institution, number(s), and title(s) of the course(s) wherein substantially equivalent material was treated. If a waiver is granted, the student may take an additional technical elective in place of the required course. The total 45-unit requirement for the master's degree is not reduced by course waivers.

A similar procedure should be followed for transfer credits. However, transfer credit is allowed only for courses taken as a graduate student, after receiving a bachelor's degree, in which equivalence to Stanford courses is established and for which a grade of 'B' or better has been awarded. Transfer credits, if approved, will reduce the total number of Stanford units required for a degree. The number of transfer credits accepted for each degree (M.S., Engineer, and Ph.D.) is delineated in the "Graduate Degrees" section of this bulletin.

Fellowships and Assistantships—Fellowships and course or research assistantships are available to qualified graduate students. Fellowships sponsored by Gift Funds, Stanford University, and Industrial Affiliates of Stanford University in Aeronautics and Astronautics provide grants to several first-year students for the nine-month academic year to cover tuition and living expenses. Stanford Graduate Fellowships, sponsored by the University, provide grants for three full years of study and research; each year, the department is invited to nominate several outstanding doctoral or predoctoral students for these prestigious awards. Students who have excelled in their master's-level course work are eligible for course assistantships in the department; those who have demonstrated research capability are eligible for research assistantships from individual faculty members. A half-time course or research assistantship provides a semi-monthly salary and a 9-unit tuition grant per quarter. Research assistants may be given the opportunity of full-time summer employment at twice the half-time rate. They may use their work as the basis for a dissertation or Engineer's thesis.

MASTER OF SCIENCE

The University's basic requirements for the master's degree are outlined in the "Graduate Degrees" section of this bulletin. Students with an aeronautical engineering background should be able to qualify for the master's degree in three quarters of work at Stanford. Students with a bachelor's degree in physical science, mathematics, or other areas of engineering may find it necessary to take certain prerequisite courses, which would lengthen the time required to obtain the master's degree. The following are departmental requirements.

SCHOLARSHIP REQUIREMENTS

A minimum grade point average (GPA) of 2.75 is required to fulfill the department's M.S. degree requirements and a 3.0 is the minimum required for eligibility to attempt the Ph.D. qualifying examination. It is incumbent upon both M.S. and potential Ph.D. candidates to request letter grades in all courses except those that do not offer a letter grade option and those that fall into the categories of colloquia and seminars (for example, AA 293, 297, and 298). Insufficient grade points on which to base the GPA may delay expected degree conferral or result in refusal of permission to take the qualifying examinations. Candidates with GPAs of 3.0 through 3.2 must request the permission of the Candidacy Committee to attempt the qualifying examinations.

AERONAUTICS AND ASTRONAUTICS

The master's program (45 quarter units) in Aeronautics and Astronautics (AA) is designed to provide a solid grounding in the basic disciplines and a foundation for systems engineering. All candidates for this degree are expected to meet the basic course requirements in experimentation in aeronautics and astronautics, fluid mechanics, guidance and control, propulsion, and structural mechanics (Category A below), in addition to work in applied mathematics (Category B) and technical electives (Category C).

A. *Basic Courses*—Candidates select eight courses as follows:

1. Five courses in the basic areas of Aeronautics and Astronautics (one each):
   a) Experimentation: 236A or 290; or Engr. 205, 206, or 207A
   b) Fluids: one of 200A, 200B, 210A
   c) Guidance and Control: Engr. 105
   d) Propulsion: 280 or 283
   e) Structures: 240A
2. Three courses, one each from three of the areas below:
   a) Fluids: 200A or 200B (if 210A was taken or waived in item 1); or 210A (if 200A or 200B was taken or waived in item 1)
   b) Structures: 240B or 256
   c) Guidance and Control: 271A or 279
   d) Aero Astro elective: AA course numbered 200 and above, excluding seminars and independent research.

Candidates who believe they have satisfied a Basic Courses requirement in previous study may request a waiver of one or more courses (see "Waivers and Transfer Credits" above). If a requirement in fluids, guidance and control, or structures in item 1 is waived, it is expected that a course in the same category from item 2 will be substituted.

B. *Mathematics Courses*—During graduate study, each candidate is expected to develop a competence in the applied mathematics pertinent to his or her major field. This requirement can be met by matriculating in a minimum of 6 units in either (1) applied mathematics (for example, complex variables, linear algebra, partial differential equations, probability), or (2) technical electives that strongly emphasize applied mathematics. A list of courses approved for the mathematics requirement is available in the departmental Student Services office. (Calculus, ordinary differential equations, and vector analysis are fundamental mathematics prerequisites, and will not satisfy the master's mathematics requirement.) Students planning to continue to the Ph.D. should note that 25 percent of the major-field Ph.D. qualifying examination is devoted to pertinent mathematics.

C. *Technical Electives*—Candidates, in consultation with their advisers, select at least four courses in their major field from among the graduate-level courses offered by the departments of the School of Engineering and related science departments. This requirement increases by one course, taken in either the major or peripheral fields, for each basic course that is waived. Normally, one course (3 units) in this category may be directed research. Courses taken in satisfaction of the other master's requirements (categories A, B, and D) may not also be counted as technical electives.

D. *Other Electives*—It is recommended that all candidates enroll in at least one humanities or social science course. Language classes qualify in this category, but practicing courses in, for example, art, music, and physical education do not qualify.

When planning their programs, candidates should check course descriptions carefully to ensure that all prerequisites have been satisfied. A course that is taken to satisfy a prerequisite for courses in Category A (Basic Courses) or B (Mathematics) cannot be counted as a technical elective, but can count toward the M.S. degree in Category D (Other Electives).

ENGINEERING

Students whose career objectives require a more interdepartmental or narrowly focused program than is possible in the M.S. program in Aeronautics and Astronautics (AA) may pursue a program for an M.S. degree in Engineering (45 quarter units). This program is described in the School of Engineering "Graduate Programs of Study" section of this bulletin.

Sponsorship by the Department of Aeronautics and Astronautics in this more general program requires that the student file a proposal before completing 18 units of the proposed graduate program. The proposal must be accompanied by a statement explaining the objectives of the program and how the program is coherent, contains depth, and fulfills a well-defined career objective. The proposed program must include at least 12 units of graduate-level work in the department and meet rigorous standards of technical breadth and depth comparable to the regular AA Master of Science program. The grade and unit requirements are the same as for the M.S. degree in Aeronautics and Astronautics.

ENGINEER

The degree of Engineer represents an additional year (or more) 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. It is expected that fulltime students will be able to complete the degree within two years of study after the master's degree.

The University's basic requirements for the degree of Engineer are outlined in the "Graduate Degrees" section of this bulletin. The following are department requirements. The candidate's prior study program should have fulfilled the department's requirements for the master's degree or a substantial equivalent. Beyond the master's degree, a total of 45 units of work is required, including a thesis and a minimum of 30 units of courses chosen as follows:

1. Twenty-four units of approved electives, of which 9 shall be in mathematics or applied mathematics. The remaining 15 units shall be chosen in consultation with the adviser, and represent a coherent field of study related to the thesis topic. Suggested fields include: (a) acoustics, (b) aerospace structures, (c) aerospace systems synthesis and design, (d) analytical and experimental methods in solid and fluid mechanics, (e) computational fluid dynamics, and (f) guidance and control.
2. Six units of free electives.
3. The remaining 15 units may be thesis, research, technical courses, or free electives.

Candidates for the degree of Engineer are expected to have a minimum grade point average (GPA) of 3.0 for work in courses beyond those required for the master's degree. All courses except seminars and directed research should be taken for a grade.

DOCTOR OF PHILOSOPHY

The University's basic requirements for the Ph.D. degree are outlined in the "Graduate Degrees" section of this bulletin. Department requirements are stated below.

Qualifications for candidacy for the doctoral degree are contingent on:

1. Fulfilling department requirements for the master's degree or its substantial equivalent.
2. Maintaining a high scholastic record for graduate course work at Stanford.
3. Completing 3 units of a directed research problem (AA 290 or an approved alternative).
4. In the first year of doctoral study, passing an oral Ph.D. qualifying examination given by the department during Autumn and Spring quarters.

Detailed information about the nature and scope of the Ph.D. qualifying examination can be obtained from the department. Research on the doctoral dissertation may not be formally started before passing this examination.

Beyond the master's degree, a total of 90 additional units of work is required, including a minimum of 36 units of approved formal course work (excluding research, directed study, and seminars). The courses should consist primarily of graduate courses in engineering and related sciences, and should form a strong and coherent doctoral program. At least 12 units must be from graduate-level courses in mathematics or applied mathematics (a list of approved courses is available from the department Student Services office). University requirements for continuous registration do apply to doctoral students for the duration of the degree, including registration for each quarter in which the student requires department consultation to complete dissertation work.

University Oral and Dissertation—The Ph.D. candidate is required to take the University oral examination after the dissertation is substantially completed (with the dissertation draft in writing), but before final approval. The examination consists of a public presentation of dissertation research, followed by substantive private questioning on the dissertation and related fields by the University oral committee (four selected faculty members, plus a chair from another department). The University oral normally occurs toward the end of the fourth doctoral year. Once the oral has been passed, the student finalizes the dissertation for reading committee review and final approval. The dissertation reading committee is selected, in consultation with the adviser and subject to the approval of the department chair, during the second year of doctoral study. Forms for the University oral scheduling and a one-page dissertation abstract should be submitted to the department Student Services office at least three weeks prior to the date of the oral for departmental review and approval.

Ph.D. MINOR

A student who wishes to obtain a Ph.D. minor in Aeronautics and Astronautics should consult the department office for designation of a minor adviser. A minor in Aeronautics and Astronautics may be obtained by completing 20 units of graduate-level courses in the Department of Aeronautics and Astronautics, following a program (and performance) approved by the department's candidacy chair.

The student's Ph.D. reading committee and University oral committee must each include at least one faculty member from Aeronautics and Astronautics.

COURSES

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

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

100. Introduction to Aeronautics and Astronautics—The principles of fluid flow, flight, and propulsion; the creation of lift and drag, aerodynamic performance including take-off, climb, range, and landing performance, structural concepts, propulsion systems, trajectories, and orbits. Remarks on the history of aeronautics and astronautics. Prerequisites: Mathematics 41, 42; elementary physics.

3 units, Aut (Alonso)

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

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

190. Directed Research and Writing in Aeronautics and Astronautics—Experimental or theoretical work for undergraduate students, under faculty direction, and emphasizing development of research and communication skills. Written report(s) and letter grade required; if this is not appropriate, enroll in 199. Consult faculty in area of interest for appropriate topics, involving one of the graduate research groups or other special projects. Prerequisite: consent of Student Services Manager and instructor. (WIM)

3-5 units, any quarter (Staff)

199. Independent Study in Aeronautics and Astronautics—Directed reading, lab, or theoretical work for undergraduate students. Consult faculty in area of interest for appropriate topics involving one of the graduate research groups or other special projects. Prerequisite: consent of instructor.

1-5 units, any quarter (Staff)

200A. Applied Aerodynamics—Review of the fundamental equations of fluid dynamics and the physical assumptions on which they are based; overview of appropriate methods for solving these equations including nonlinear CFD, conformal mapping, linear panel and vortex methods; estimation of pressure distributions and resultant airloads on 2-D airfoils, finite wings, slender bodies, and lifting systems; compressibility effects; boundary layer analysis and prediction of drag, separation, and displacement effects. Application to airfoil and wing design. Prerequisite: undergraduate aeronautics course. Recommended: 210A.

3 units, Win (MacCormack)

200B. Applied Aerodynamics II—Analytical and numerical techniques for the aerodynamic analysis of aircraft, focusing on finite wing theory, far-field and Trefftz-plane analysis, two-dimensional laminar and turbulent boundary layers in airfoil analysis, similarity rules, aerodynamic stability derivatives. Bi-weekly assignments require MATLAB or a suitable programming language. Prerequisite: 200A or equivalent. Recommended: 210A.

3 units, Spr (Alonso)

201A. Fundamentals of Acoustics—Acoustic equations for a stationary homogeneous fluid; wave equation; plane, spherical, and cylindrical waves; harmonic (monochromatic) waves; simple sound radiators; reflection and transmission of sound at interfaces between different media; multipole analysis of sound radiation; Kirchoff integral representation; scattering and diffraction of sound; propagation through ducts (dispersion, attenuation, group velocity); sound in enclosed regions (reverberation, absorption, and dispersion); radiation from moving sources; propagation in the atmosphere and underwater. Prerequisite: first-year graduate standing in engineering, mathematics, sciences; or consent of instructor.

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

201B. Topics in Aeroacoustics—Acoustic equations for moving medium, simple sources, Kirchhoff formula, and multipole representation; radiation from moving sources; acoustic analogy approach to sound generation in compact flows; theories of Lighthill, Powell, and Mohring; acoustic radiation from moving surfaces; theories of Curl, FfowcsWilliams, and Hawkings; application of acoustic theories to the noise from propulsive jets, airframe noise and rotor noise; computational methods for acoustics. Prerequisite: 201A or consent of instructor.

3 units (Lele) not given 2000-01

208. Aerodynamics of Aircraft Dynamic Response and Stability—Companion to 200A for those interested in control and guidance. Typical vehicles and the technical tradeoffs affecting their design. Equations of motion, stressing applications to dynamic performance, stability, and forced response. Forms and sources for the required aerodynamic data. Response to small disturbances and stability derivatives. Static stability and trim. Review of aerodynamic fundamentals, leading to airload predictions for wings, bodies, and complete aircraft. Paneling and other methods for derivative estimation. Natural motions of the aircraft, and the influence on them of various configuration parameters. Vehicle behavior in maneuvers of small and large amplitudes. Prerequisites: 200A, 210A or equivalents (may be taken concurrently).

3 units (Kroo) not given 2001-02

210A. Fundamentals of Compressible Flow—Introduction to compressible flow. Topics: development of the three-dimensional, nonsteady, field equations for describing the motion of a viscous, compressible fluid; differential and integral forms of the equations; constitutive equations for a compressible fluid; the entropy equation; compressible boundary layers; area-averaged equations for one-dimensional steady flow; shock waves; channel flow with heat addition and friction; flow in nozzles and inlets; oblique shock waves; Prandtl-Meyer expansion; unsteady one-dimensional flow; the shock tube; small disturbance theory; acoustics in one-dimension; steady flow in two-dimensions; potential flow; linearized potential flow; lift and drag of thin airfoils. Prerequisites: undergraduate background in fluid mechanics and thermodynamics.

3 units, Aut (Cantwell)

210B. Fundamentals of Compressible Flow—Continuation of 210A with emphasis on more general flow geometry. Use of exact solutions to explore the hypersonic limit. Identification of similarity parameters. Solution methods for the linearized potential equation with applications to wings and bodies in steady flow; their relation to physical acoustics and wave motion in nonsteady flow. Nonlinear solutions for nonsteady constant area flow and introduction to Riemann invariants. Elements of the theory of characteristics; nozzle design; extension to nonisentropic flow. Real gas effects in compressible flow. Flows in various gas dynamic testing facilities. Prerequisite: 210A.

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

211A. Physical Gas Dynamics—(Enroll in Mechanical Engineering 262A.)

214A. Numerical Methods in Fluid Mechanics—The basic principles underlying the Navier-Stokes equations. Relations between time-accurate and relaxation methods. Implicit and explicit methods combined with flux splitting and space factorization. Considerations of accuracy, stability of numerical methods, and programming complexity. Prerequisites: knowledge of linear algebra and Mechanical Engineering 200A, 200B, or equivalent approved by instructor.

3 units, Aut (Pulliam)

214B. Numerical Computation of Compressible Flow—Numerical methods for solving hyperbolic sets of partial differential equations. Explicit, implicit, flux-split, finite difference, and finite volume procedures for approximating the governing equations and boundary conditions. Numerical solution by direct approximate factorization and iterative Gauss-Seidel line relaxation. Application to the Euler equations in two and three dimensions. Computational problems are assigned. Prerequisite: 214A.

3 units, Win (MacCormack)

214C. Numerical Computation of Viscous Flow—Numerical methods for solving parabolic sets of partial differential equations. Numerical approximation of the equations describing compressible viscous flow with adiabatic, isothermal, slip, and no-slip wall boundary conditions. Applications to the Navier-Stokes equations in two and three dimensions at high Reynolds number. Computational problems are assigned. Prerequisite: 214B.

3 units, Spr (MacCormack)

215A,B. Advanced Computational Fluid Dynamics—High resolution schemes for capturing shock waves and contact discontinuities; upwinding and artificial diffusion; LED and TVD concepts; alternative flow splittings; numerical shock structure. Discretization of Euler and Navier Stokes equations on unstructured meshes; the relationship between finite volume and finite element methods. Time discretization; explicit and implicit schemes; acceleration of steady state calculations; residual averaging; math grid preconditioning. Automatic design; inverse problems and aerodynamic shape optimization via adjoint methods. Pre- or corequisite: 214B or equivalent.

3 units each, Win, Spr (Jameson)

217A,B,C. Mathematical and Computational Methods in Engineering—(Enroll in Mechanical Engineering 200A,B,C.)

218. Introduction to Symmetry Analysis—Introduction to the methods of symmetry analysis and their use in the reduction and simplification of physical problems. Topics: dimensional analysis, phase-space analysis of autonomous systems of ordinary differential equations, use of Lie groups to reduce the order of nonlinear ODEs and to generate integrating factors, use of Lie groups to reduce the dimension of partial differential equations and to generate similarity variables, exact solutions of nonlinear PDEs generated from groups. Symmetries and conservation laws, application to Hamiltonian systems, generalized symmetries, recursion operators, Backlund transformations, use of non-local groups to generate soliton solutions of nonlinear wave equations, symmetries derived from a potential equation. Invariant groups of the classical equations of mathematical physics. The two-body problem in classical mechanics, problems in nonlinear heat conduction, nonlinear waves, compressible flow, boundary layers, viscous jets and vortex rings, similarity rules for turbulent shear flows. Mathematica-based software developed by the instructor for finding invariant groups of ODEs and PDEs. Prerequisite: Mechanical Engineering 200A or equivalent.

3 units, Spr (Cantwell)

219A,B. Computational Methods in Fluid Mechanics—(Enroll in Mechanical Engineering 269A,B.)

220. Parallel Methods in Numerical Analysis—(Enroll in Computer Science 238.)

225. Stochastic Processes in Aeronautics—Applications of probability theory to problems in aeronautics, emphasizing random behavior in fluid, thermodynamic, chemical, structural, and control systems of aerospace interest. The random-walk model introduces basic concepts and connects the topics. Time evolution of probability distributions, linking problems in chemical kinetics, rarefied gas flows, thermodynamic nonequilibrium, and finite difference methods in fluid mechanics. Statistical variables: power spectra, correlation functions, transform techniques, the response of a linear system to a random forcing function, and the statistical theory of turbulence. Stochastic models on microcomputers.

3 units (Staff) not given 2000-01

230. Rotorcraft Aerodynamics—The fundamental aerodynamics of rotorcraft, including general momentum theory, blade-element theory, and physical concepts of blade motions in hover and forward flight. Topics: dynamics stall, blade-vortex interactions, and active blade controls. Prerequisite: undergraduate aerodynamics.

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

235A,B. Space Systems Engineering—(Enroll in Engineering 235A,B.)

236A. Spacecraft Design—The design of unmanned spacecraft and spacecraft subsystems concentrating on identification of design drivers and current design methods. Topics: spacecraft configuration design, mechanical design, structure and thermal subsystem design, attitude control, electric power, command and telemetry, and design integration and operations.

3 units, Win (Twiggs)

236B,C,D. Spacecraft Design—Continuation of 236A.

236B. *3 units, Spr (Twiggs)*
236C. *3 units, Sum (Twiggs)*
236D. *3 units, Aut (Twiggs)*

238. Human-Centered Design for Aerospace Engineers—The what, when, who, and how of human-centered design. Is it art? or magic? Is it science? or engineering? How to integrate human-centered processes into engineering design processes. Analysis of several recent human-centered aeronautical and space systems to evaluate their successes and limitations.

3 units, Aut (Null)

240A. Analysis of Structures—Elements of two-dimensional elasticity theory. Boundary value problems; energy methods; analyses of solid and thin walled section beams, trusses, frames, rings, monocoque and semi-monocoque structures. Prerequisite: Engineering 14 or equivalent.

3 units, Aut (F. Chang)

240B. Analysis of Structures—Thin plate analysis. Structural stability. Material behavior: plasticity and fracture. Introduction of finite element analysis; truss, frame, and plate structures. Prerequisite: 240A or consent of instructor.

3 units, Win (F. Chang)

241A,B. Introduction to Aircraft Design, Synthesis, and Analysis—The total development of new aircraft systems, emphasizing commercial aircraft; the underlying economic and technological factors that create markets for new aircraft from rational and historical viewpoints; determining market demands and system mission performance requirements; optimizing configurations to comply with requirements, emphasizing the interaction of various disciplines (aerodynamics, structures, propulsion, guidance, payload, and ground support; parametric studies); applied aerodynamic and design concepts for use in configuration analysis (airplane layout, wing design, high lift systems, drag, stability and control requirements, and tail sizing). Application to an individually chosen aeronautical system; applied structural fundamentals emphasizing fatigue and fail-safe considerations; design load determination; weight estimation; propulsion system performance and installation; engine types; environmental problems (noise and smoke); performance estimation (takeoff, climb, cruise, and landing). Direct/indirect operating costs prediction and interpretation. Aircraft functional systems (hydraulic, electrical, environmental control); avionics; importance and achievement of aircraft reliability and maintainability. Prerequisite: 100 or equivalent.

241A. *3 units, Win (Alonso)*
241B. *3 units, Spr (Kroo)*

242A. Continuum Mechanics: An Introduction—(Enroll in Mechanical Engineering 238A.)

242B. Continuum Mechanics: Applications—(Enroll in Mechanical Engineering 238B.)

243A,B. Dynamics—(Enroll in Mechanical Engineering 231A,B.)

244A. Free and Forced Motion of Structures—Vibrations and forced response of linear systems with a finite number of degrees of freedom. Vibrations and forced response of continuous structures, developed in a framework of analytical dynamics; rods, beams, membranes, and other elastic systems. Approximate methods for analyzing nonuniform and built-up structures. Finite-element methods in a dynamic context. Introduction to random responses and to nonlinear systems, as time permits. Prerequisites: 240A, Engineering 15 or equivalent.

3 units, Win (Ashley)

245. Structural Dynamics and Aeroelasticity—Finite-element methods and vibration of continuous, two-dimensional structures. Introduction to aeroelasticity from a unified viewpoint applicable to flight vehicles, rotating machinery, and other elastic systems. Aeroelastic operators and unsteady aerodynamics in two dimensions. Forced response, static and dynamic eigenvalues of a simplified system. Aeroelastic analysis of representative one- and two-dimensional systems. Computational problems covering aeroelastic analysis of simple systems. Prerequisite: familiarity with MATLAB or a programming language.

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

246A. Theory of Plates—(Enroll in Mechanical Engineering 241A.)

246B. Theory of Shells—(Enroll in Mechanical Engineering 241B.)

246D. Vibration and Stability of Plates and Shells: Biomechanical Applications—(Enroll in Mechanical Engineering 241D.)

250. Collapse Analysis of Structures—Stability analysis of structures; prediction of buckling load of bars, frames, plates, and shells. Effect of imperfection on structural stability. Analysis of postbuckling behavior and nonlinear collapse of structures. Basic criteria and approaches for stability analysis; energy methods and finite element methods. Numerical techniques for solving governing nonlinear equations. Prerequisite: consent of instructor.

3 units, not given 2000-01

252. Techniques of Failure Analysis—Introduction to the field of failure analysis, including fire and explosion analysis, large scale catastrophe projects, traffic accident reconstruction, aircraft accident investigation, human factors, biomechanics and accidents, design defect cases, materials failures and metallurgical procedures, and structural failures. Product liability, failure modes and effects analysis, failure prevention, engineering ethics, and the engineer as expert witness.

2 units, Spr (Ross)

256. Mechanics of Composites—Fiber reinforced composites. Stress, strain, and strength of composite laminates and honeycomb structures. Failure modes and failure criteria. Environmental effects. Manufacturing processes. Design of composite structures. Individual design project

required of each student, resulting in a usable computer software. Prerequisite: Engineering 14 or equivalent.
3 units, Win (Springer)

257. Design of Composite Structures—Analyses and design of composite beams and columns. Analysis of composite plates; bending-shear coupling effect, interlaminar stresses, and structural stability. Application of finite element methods (FEM) to composite structures. Failure criteria and fracture mechanics of composite materials. Prediction of matrix and fiber failure, and edge and stability-induced delamination. Impact damage, compression after impact, bolted and bonded joints. Composite structures with embedded sensors and actuators for damage detection and vibration control. Prerequisite: 256 or consent of instructor.
3 units, Spr (F. Chang)

261A. Statistical Theory and Modeling for Turbulent Flow—(Enroll in Mechanical Engineering 261A.)

268. Digital Image Processing—(Enroll in Electrical Engineering 368A.)

269. Optical Methods in Engineering Science—(Enroll in Electrical Engineering 347.)

270. Introduction to Modern Optics—(Enroll in Electrical Engineering 268.)

271A. Dynamics and Control of Aircraft and Spacecraft—The dynamic behavior of aircraft and spacecraft, and the design of automatic control systems for them. For aircraft: non-linear and linearized longitudinal and lateral dynamics; linearized aerodynamics; natural modes of motion; autopilot design to enhance stability, control the flight path, and perform automatic landings. GPS based navigation and attitude determination. For spacecraft in orbit: natural longitudinal and lateral dynamic behavior and the design of attitude control systems. Prerequisites: 200A or 208; Engineering 15 or equivalent, Engineering 105, and experience with Matlab.
3 units, Spr (Staff)

272C. Global Positioning System—The principles of satellite navigation using GPS. Positioning techniques using code tracking, single and dual frequency, carrier aiding, and use of differential GPS for improved accuracy and integrity. Use of differential carrier techniques for attitude determination and precision position determination. Prerequisite: familiarity with matrix algebra.
3 units, Win (Enge)

272D. Integrated Navigation Systems—Review of navigation satellites (GPS, GLONASS), GPS receivers, principles of inertial navigation for ships, aircraft, and spacecraft. Kalman Filters to integrate GPS and inertial sensors. Radio navigation aids (VOR, DME, LORAN, ILS). Doppler navigation systems. Prerequisites: 272C; Engineering 15, 105. Recommended: Engineering 205.
3 units (Enge) alternate years, given 2001-02

273A. Modern Control Design I—(Enroll in Engineering 207A.)

273B. Modern Control Design II—(Enroll in Engineering 207B.)

274A. Robust Control Analysis and Synthesis—(Enroll in Engineering 210A.)

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

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

277A. Analysis and Control of Nonlinear Systems—(Enroll in Engineering 209A.)

277B. Advanced Nonlinear Control—(Enroll in Engineering 209B.)

278A. Optimal Control and Hybrid Systems—Models for continuous-time and discrete-event dynamic systems. Modeling techniques for hybrid systems. Optimization problems for continuous and discrete dynamic systems. Dynamic programming and the Hamilton-Jacobi equation. Differential games. Automatic verification and controller synthesis for hybrid systems. Hybrid systems simulation. Driving examples from flight management system logic, and automated air traffic systems. Prerequisites: Electrical Engineering 263, Engineering 209.
3 units (Tomlin) alternate years, given 2001-02

279. Space Mechanics—Orbits of near-earth satellites and interplanetary probes; transfer and rendezvous; decay of satellite orbits; influence of earth's oblateness; sun and moon effects on earth satellites. Prerequisite: Engineering 15 or equivalent.
3 units, Spr (Parkinson)

283. Aircraft and Rocket Propulsion—Introduction to the design and performance of airbreathing and rocket engines. Topics: the physical parameters used to characterize propulsion system performance; gasdynamics of nozzles and inlets; cycle analysis of ramjets, turbojets, turbofans, and turboprops; component matching and the compressor map; introduction to liquid and solid propellant rockets; multistage rockets; hybrid rockets; thermodynamics of reacting gases. Prerequisites: undergraduate background in fluid mechanics and thermodynamics.
3 units, Win (Cantwell)

290. Problems in Aeronautics and Astronautics—Undergraduates enroll in 190 or 199. Investigation, experimental or theoretical, of problems in aeronautics and astronautics. Students may work in any field of special interest.
1-5 units, any quarter (Staff)

291. Practical Training—Educational opportunities in high-technology research and development labs in aerospace and related industries. Qualified graduate students engage in internship work and integrate that work into their academic program. Students register in the quarter of their internship work, and at the end of the quarter submit a research report outlining their work activity, problems investigated, key results, and any follow-on projects they expect to perform as part of further graduate education. Meets the requirements for Curricular Practical Training for students on F-1 visas. Sign up for section number corresponding to your academic adviser. Student is responsible for arranging own employment and should see department student services manager before enrolling.
1-3 units, any quarter (Staff)

293. Seminar in Spacecraft Application—For undergraduates and graduates interested in small low-cost satellites, their applications in earth-orbiting and interplanetary exploration, and the commercial and scientific opportunities; others invited. Topics are related to the present small spacecraft mission planning, design, fabrication, and operation; presented by industry lecturers, faculty, and students. Registration for credit optional; letter grade given for students who make presentations. May be repeated for credit. (AU)
1 unit, Aut, Win, Spr (Twiggs)

297. Seminar in Guidance, Navigation, and Control—For graduate students with an interest in automatic control applications in flight mechanics, guidance, navigation, and mechanical design of control systems; others invited. Problems in all branches of vehicle control, guidance, and instrumentation presented by researchers on and off campus. Registration for credit optional; letter grade given for students who make presentations. May be repeated for credit. (AU)
1 unit, Aut, Win, Spr (Staff)

298. Seminar in Fluid Mechanics—(Enroll in Engineering 298.) May be repeated for credit. (AU)

300. Thesis—Thesis for degree of Engineer.
1-15 units, any quarter (Staff)

301. Ph.D. Thesis—Dissertation for degree of Doctor of Philosophy.
1-15 units, any quarter (Staff)

308. Spectral Methods in Computational Physics—(Enroll in Mechanical Engineering 308.)

311. System Identification—(Enroll in Engineering 211.)

351A,B,C. Advanced Fluid Mechanics—(Enroll in Mechanical Engineering 351A,B,C.)

366. Introduction to Fourier Optics—(Enroll in Electrical Engineering 366.)

370. Advanced Modern Optics—(Enroll in Electrical Engineering 349.)