Aeronautics and Astronautics

Courses offered by the Department of Aeronautics and Astronautics are listed under the subject code AA on the (https://explorecourses.stanford.edu/search?filter-term-Autumn=on&filter-catalognumber-AA=on&filter-term-Summer=on&page=0&q=AA&filter-coursestatus-Active=on&view=catalog&filter-term-Spring=on&collapse=&filter-term-Winter=on&catalog=71)*Stanford Bulletin's* ExploreCourses web site.

The Department of Aeronautics and Astronautics 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, and related fields in engineering and the sciences.

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

- Aeroelasticity and Flow Simulation
- Aircraft Design, Performance, and Control
- Applied Aerodynamics
- Autonomy
- Computational Aero-Acoustics
- Computational Fluid Dynamics
- Computational Mechanics and Dynamical Systems
- Control of Robots, including Space and Deep-Underwater Robots
- Conventional and Composite Materials and Structures
- Decision Making under Uncertainty
- Direct and Large-Eddy Simulation of Turbulence
- High-Lift Aerodynamics
- Hybrid Propulsion
- Hypersonic and Supersonic Flow
- Micro and Nano Systems and Materials
- Multidisciplinary Design Optimization
- Navigation Systems (especially GPS)
- Optimal Control, Estimation, System Identification
- Sensors for Harsh Environments
- Space Debris Characterization
- Space Environment Effects on Spacecraft
- Space Plasmas
- Spacecraft Design and Satellite Engineering
- Turbulent Flow and Combustion

Mission of the Undergraduate Program in Aeronautics and Astronautics

The mission of the undergraduate program in Aeronautics and Astronautics Engineering is to provide students with the fundamental principles and techniques necessary for success and leadership in the conception, design, implementation, and operation of aerospace and related engineering systems. Courses in the major introduce students to engineering principles. Students learn to apply this fundamental knowledge to conduct laboratory experiments and aerospace system design problems. Courses in the major include engineering fundamentals, mathematics, and the sciences, as well as in-depth courses in aeronautics and astronautics, dynamics, mechanics of materials, fluids engineering, and heat transfer. The major prepares students for careers in aircraft and spacecraft engineering, space exploration, air and space-based telecommunication industries, teaching, research, military service, and many related technology-intensive fields.

Learning Outcomes (Graduate)

The purpose of the master's program is to provide students with the knowledge and skills necessary for a professional career or doctoral studies. This is done through course work which provides a solid grounding in the basic disciplines, including fluid mechanics, dynamics and control, propulsion, structural mechanics, and applied or computational mathematics, and course work or supervised research which provides depth and breadth in the student's area of specialization.

The Ph.D. is conferred upon candidates who have demonstrated substantial scholarship and the ability to conduct independent research. Through course work and guided research, the program prepares students to make original contributions in Aeronautics and Astronautics and related fields.

Graduate Programs in Aeronautics and Astronautics

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"). Applications for admission with financial aid (fellowships or assistantships) or without financial aid must be received and completed by December 1 for the next Autumn Quarter.

Information about admission to the Honors Cooperative Program is included in the "School of Engineering" section of this bulletin. The department may consider HCP applications for Winter or Spring quarters as well as for Autumn Quarter; prospective applicants should contact the department's student services office.

Further information and application forms for all graduate degree programs may be obtained from Graduate Admissions, the Registrar's Office, http://gradadmissions.stanford.edu.

Waivers and Transfer Credits

Waivers of the Basic Courses required for the M.S. degree in Aeronautics and Astronautics can only be granted by the instructor of that course. Students who believe that they have had a substantially equivalent course at another institution should consult with the course instructor to determine if they are eligible for a waiver, and with their adviser to judge the effect on their overall program plans. To request a waiver, students should fill out a Petition for Waiver form (reverse side of the department's program proposal) and have it approved by the instructor and their adviser. One additional technical elective must be added for each Basic Course that is waived.

A similar procedure should be followed for transfer credits. The number of transfer credits allowed for each degree (Engineer and Ph.D.) is delineated in the "Graduate Degrees" section of this bulletin; transfer credit is not accepted for the M.S. degree. 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, reduce the total number of Stanford units required for a degree.

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 at Stanford are eligible for course assistantships in the department; those who have demonstrated research capability are eligible for research assistantships from individual faculty members. Students may also hold assistantships in other departments if the work is related to their academic progress; the criteria for selecting course or research assistants are determined by each hiring department. A standard, 20 hours/week course or research assistantship provides a semi-monthly salary and an 8-10 unit tuition grant per quarter. Research assistants may be given the opportunity of additional summer employment. They may use their work as the basis for a dissertation or Engineer's thesis.

Aeronautics and Astronautics 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. The Durand Building also houses faculty and staff offices and several conference rooms.

Through the department's close relations with 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 supercomputers.

General Information

Further information about the facilities and programs of the department is available at http://aa.stanford.edu, or from the department's student services office.

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

Bachelor of Science in Engineering (Aeronautics and Astronautics)

Although primarily a graduate-level department, the program offers an undergraduate major in Aeronautics and Astronautics (AA) leading to the B.S. degree in Engineering. For further information, see the *Handbook for Undergraduate Engineering Programs* at http://ughb.stanford.edu.

Undergraduates interested in aerospace are encouraged to combine either a minor or a coterminal M.S. in Aeronautics and Astronautics with a major in a related discipline (such as Mechanical or Electrical Engineering). Students considering these options are encouraged to contact the department's student services office.

Aeronautics and Astronautics (AA)

Mission of the Undergraduate Program in Aeronautics and Astronautics

The mission of the undergraduate program in Aeronautics and Astronautics Engineering is to provide students with the fundamental principles and techniques necessary for success and leadership in the conception, design, implementation, and operation of aerospace and related engineering systems. Courses in the major introduce students to engineering principles. Students learn to apply this fundamental knowledge to conduct laboratory experiments and aerospace system design problems. Courses in the major include engineering fundamentals, mathematics, and the sciences, as well as in-depth courses in aeronautics and astronautics, dynamics, mechanics of materials, fluids engineering, and heat transfer. The major prepares students for careers in aircraft and spacecraft engineering, space exploration, air and space-based telecommunication industries, teaching, research, military service, and many related technology-intensive fields.

Completion of the undergraduate program in Aeronautics and Astronautics leads to the conferral of the Bachelor of Science in Engineering. The subplan "Aeronautics and Astronautics" appears on the transcript and on the diploma.

Requirements

		Units
Mathematics		
24 units minimum [1]		
MATH 41	Calculus (or AP Calculus)	5
MATH 42	Calculus (or AP Calculus)	5
CME 100/ENGR 154	Vector Calculus for Engineers	5
or MATH 51	Linear Algebra and Differential Calculus of Several Variables	
CME 102/ENGR 155A	Ordinary Differential Equations for Engineers	5
or MATH 53	Ordinary Differential Equations with Linear Algebra	
CME 106/ENGR 155C	Introduction to Probability and Statistics for Engineers (or STATS 110, STATS 116, CS 109)	4-5
or STATS 110	Statistical Methods in Engineering and the Physical Sciences	
or STATS 116	Theory of Probability	
or CS 109	Introduction to Probability for Computer Scientists	
Science		
19 units minimum		
PHYSICS 41	Mechanics (or AP Physics)	4
PHYSICS 43	Electricity and Magnetism (or AP Physics)	4
PHYSICS 45	Light and Heat	4
CHEM 31X	Chemical Principles Accelerated (or CHEM 31A +B, AP Chemistry)	5
Science elective [2]		3-5
Technology in Society (one course required)		

3 units minimum [3]		3-5
Engineering Fundamentals (three courses required)		
11 units minimum		
ENGR 30	Engineering Thermodynamics	3
ENGR 70A	Programming Methodology	5
Fundamentals Elective [4]		3-5
Engineering Depth		
28 units minimum		
AA 100	Introduction to Aeronautics and Astronautics	3
AA 190	Directed Research and Writing in Aero/Astro	3-5
ME 70	Introductory Fluids Engineering	4
ENGR 14	Intro to Solid Mechanics	4
ME 131A	Heat Transfer	3
ENGR 15	Dynamics	4
ME 161	Dynamic Systems, Vibrations and Control	3-4
or PHYSICS 110	Advanced Mechanics	
CEE 101A	Mechanics of Materials	4
or ME 80	Mechanics of Materials	
Aero/Astro Depth		
18 units minimum		
Engineering Electives (two courses required) [5]		6-10
See Course List AA-1 below for a list of options		
Depth Area I (two courses required) [6]		6-10
See Course List AA-2 below for a list of options		
Depth Area II (two courses required) [6]		6-10
See Course List AA-2 below for a list of options		
Total Units		**104-126**

For additional information and sample programs see the Handbook for Undergraduate Engineering Programs (http://ughb.stanford.edu).

1. It is recommended that the CME series (100, 102, 104) be taken rather than the MATH series (51, 52, 53). If students take the MATH series, it is recommended to take MATH 51M Introduction to MATLAB for Multivariable Mathematics, offered Autumn Quarter.
2. Courses that satisfy the Science elective are listed in Figure 3-2 in the Handbook for Undergraduate Engineering Programs at http://ughb.stanford.edu.
3. Courses that satisfy the Technology in Society Requirement are listed in Figure 3-3 in the Handbook for Undergraduate Engineering Programs at http://ughb.stanford.edu.
4. Courses that satisfy the Engineering Fundamentals elective are listed in Figure 3-4 in the Handbook for Undergraduate Engineering Programs at http://ughb.stanford.edu. ENGR 70B or X (same as CS 106B or X) is not allowed to fulfill the third fundamentals requirement.
5. Courses that satisfy the Engineering Electives are listed in Figure AA-1 in the Handbook for Undergraduate Engineering Programs at http://ughb.stanford.edu, as well as Course List AA-1 below.
6. Courses that satisfy the Depth Area choices are listed in Figure AA-2 in the Handbook for Undergraduate Engineering Programs at http://ughb.stanford.edu, as well as Course List AA-2 below.

		Units
AA-1. Engineering Electives: Two Courses Required		
AA 250	Nanomaterials for Aerospace	3
ENGR 240	Introduction to Micro and Nano Electromechanical Systems	3
ME 210	Introduction to Mechatronics	4
ME 220	Introduction to Sensors	3-4
ME 227	Vehicle Dynamics and Control	3
ME 250	Internal Combustion Engines	3-5
ME 257	Turbine and Internal Combustion Engines	3
ME 260	Fuel Cell Science and Technology	3
ME 324	Precision Engineering	4
ME 331A	Advanced Dynamics & Computation	3
ME 331B	Advanced Dynamics, Simulation & Control	3
ME 345	Fatigue Design and Analysis	3
ME 348	Experimental Stress Analysis	3
ME 351A	Fluid Mechanics	3
ME 351B	Fluid Mechanics	3
CHEMENG 140	Micro and Nanoscale Fabrication Engineering	3
CS 107	Computer Organization and Systems	3-5
CS 110	Principles of Computer Systems	3-5
CS 140	Operating Systems and Systems Programming	3-4
CS 161	Design and Analysis of Algorithms	3-5
EE 102A	Signal Processing and Linear Systems I	4
EE 102B	Signal Processing and Linear Systems II	4
EE 101A	Circuits I	4
EE 101B	Circuits II	4
ENERGY 121	Fundamentals of Multiphase Flow	3
ENERGY 191	Optimization of Energy Systems	3-4
ENERGY 226	Thermal Recovery Methods	3
MATSCI 155	Nanomaterials Synthesis	4
MATSCI 156	Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution	3-4
MATSCI 197	Rate Processes in Materials	3-4
MATSCI 198	Mechanical Properties of Materials	3-4
PHYSICS 100	Introduction to Observational Astrophysics	4
* It is recommended that students review prerequisites for all courses.		

		Units
AA-2. Depth Area: Four Courses Required, Two From Each of Two Areas		
Dynamics and Controls		
ENGR 105	Feedback Control Design	3
ENGR 205	Introduction to Control Design Techniques	3
AA 203	Introduction to Optimal Control Theory	3
AA 222	Introduction to Multidisciplinary Design Optimization	3-4
AA 242A	Classical Dynamics	3
AA 271A	Dynamics and Control of Spacecraft and Aircraft	3
Systems Design		
AA 236A	Spacecraft Design	3-5
AA 236B	Spacecraft Design Laboratory	3-5
AA 241A	Introduction to Aircraft Design, Synthesis, and Analysis	3
AA 241B	Introduction to Aircraft Design, Synthesis, and Analysis	3
AA 284B	Propulsion System Design Laboratory	3
Fluids and CFD		
AA 200	Applied Aerodynamics	3
AA 201A	Fundamentals of Acoustics	3
AA 210A	Fundamentals of Compressible Flow	3
AA 214A/CME 207	Numerical Methods in Engineering and Applied Sciences	3
AA 283	Aircraft and Rocket Propulsion	3

ME 131B	Fluid Mechanics: Compressible Flow and Turbomachinery	4
ME 140	Advanced Thermal Systems	5
Structures		
AA 240A	Analysis of Structures	3
AA 240B	Analysis of Structures	3
AA 256	Mechanics of Composites	3
AA 280	Smart Structures	3
ME 335A	Finite Element Analysis	3

* It is recommended that students review prerequisites for all courses.

Aeronautics and Astronautics (AA) Minor

The Aero/Astro minor introduces undergraduates to the key elements of modern aerospace systems. Within the minor, students may focus on aircraft, spacecraft, or disciplines relevant to both. The course requirements for the minor are described in detail below. Courses cannot be double-counted within a major and a minor, or within multiple minors; if necessary, the Aero/Astro adviser can help select substitute courses to fulfill the AA minor core.

The following core courses fulfill the minor requirements:

		Units
AA 100	Introduction to Aeronautics and Astronautics	3
ENGR 14	Intro to Solid Mechanics *	4
ENGR 15	Dynamics *	4
ENGR 30	Engineering Thermodynamics *	3
ME 70	Introductory Fluids Engineering	4
ME 131A	Heat Transfer	3
Two courses from one of the upper-division elective areas below (min. 6 units)		
Plus one course from a second area below (min. 3 units)		9-14
Aerospace Systems Synthesis/Design		
AA 236A	Spacecraft Design	
AA 236B	Spacecraft Design Laboratory	
AA 241A	Introduction to Aircraft Design, Synthesis, and Analysis	
AA 241B	Introduction to Aircraft Design, Synthesis, and Analysis	
AA 284B	Propulsion System Design Laboratory	
Dynamics and Controls		
ENGR 105	Feedback Control Design	
ENGR 205	Introduction to Control Design Techniques	
AA 203	Introduction to Optimal Control Theory	
AA 222	Introduction to Multidisciplinary Design Optimization	
AA 242A	Classical Dynamics	
AA 271A	Dynamics and Control of Spacecraft and Aircraft	
Fluids		
AA 200	Applied Aerodynamics	
AA 201A	Fundamentals of Acoustics	
AA 210A	Fundamentals of Compressible Flow	
AA 214A	Numerical Methods in Engineering and Applied Sciences	
AA 283	Aircraft and Rocket Propulsion	
ME 131B	Fluid Mechanics: Compressible Flow and Turbomachinery	
ME 140	Advanced Thermal Systems	
Structures		
AA 240A	Analysis of Structures	
AA 240B	Analysis of Structures	
AA 256	Mechanics of Composites	
AA 280	Smart Structures	
ME 335A	Finite Element Analysis	
Total Units		**30-35**

* ENGR 14 Intro to Solid Mechanics, ENGR 15 Dynamics, or ENGR 30 Engineering Thermodynamics are waived as minor requirements if already taken as part of the major.

Coterminal Master's Program in Aeronautics and Astronautics

This 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.

University Coterminal Requirements

Coterminal master’s degree candidates are expected to complete all master’s degree requirements as described in this bulletin. University requirements for the coterminal master’s degree are described in the “Coterminal Master’s Program (http://exploredegrees.stanford.edu/cotermdegrees)” section. University requirements for the master’s degree are described in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/#masterstext)" section of this bulletin.

After accepting admission to this coterminal master’s degree program, students may request transfer of courses from the undergraduate to the graduate career to satisfy requirements for the master’s degree. Transfer of courses to the graduate career requires review and approval of both the undergraduate and graduate programs on a case by case basis.

In this master’s program, courses taken three quarters prior to the first graduate quarter, or later, are eligible for consideration for transfer to the graduate career. No courses taken prior to the first quarter of the sophomore year may be used to meet master’s degree requirements.

Course transfers are not possible after the bachelor’s degree has been conferred.

The University requires that the graduate adviser be assigned in the student’s first graduate quarter even though the undergraduate career may still be open. The University also requires that the Master’s Degree Program Proposal be completed by the student and approved by the department by the end of the student’s first graduate quarter.

Master of Science in Aeronautics and Astronautics

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.

Grade Point Averages

A minimum grade point average (GPA) of 2.75 is required to fulfill the department's M.S. degree requirements; a minimum GPA of 3.5 is 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, ENGR 298 Seminar in Fluid Mechanics). 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.

Course Requirements

The Master of Science (M.S.) program is a terminal degree program. It is based on the completion of lecture courses focused on a theme within the discipline of Aeronautics and Astronautics engineering. No thesis is required. No research is required.

The Master's degree program requires 45 quarter units of course work, which must be taken at Stanford. The course work is divided into four categories

- Basic Courses
- Mathematics Courses
- Technical Electives
- Other Electives

Basic Courses

M.S. candidates must select eight courses as follows:

		Units
(I) Five courses in the basic areas of Aeronautics and Astronautics (one in each area):		
Fluids		
AA 200	Applied Aerodynamics	3
AA 210A	Fundamentals of Compressible Flow	3
Structures		
AA 240A	Analysis of Structures	3
Guidance and Control		
ENGR 105	Feedback Control Design	3
ENGR 205	Introduction to Control Design Techniques	3
Propulsion		
AA 283	Aircraft and Rocket Propulsion	3
Experimentation/Design Requirements (see courses under Related Courses tab above)		
(II) Three courses (one each from three of the four areas below)		
Fluids		
AA 200	Applied Aerodynamics	3
AA 210A	Fundamentals of Compressible Flow	3
AA 244A	Introduction to Plasma Physics and Engineering	3
Structures		
AA 240B	Analysis of Structures	3
AA 242B	Mechanical Vibrations	3
AA 256	Mechanics of Composites	3
AA 280	Smart Structures	3
Guidance and Control		
AA 242A	Classical Dynamics	3
AA 242B	Mechanical Vibrations	3
AA 251	Introduction to the Space Environment	3
AA 271A	Dynamics and Control of Spacecraft and Aircraft	3
AA 272C	Global Positioning Systems	3
AA 279A	Space Mechanics	3
One course selected from AA courses numbered 200 and above, excluding seminars and independent research		

Candidates who believe they have satisfied a basic course requirement in previous study may request a waiver of one or more courses (see "Waivers and Transfer Credits" in the "Graduate Programs in Aeronautics and Astronautics" section of this bulletin).

Mathematics Courses

M.S. candidates are expected to exhibit competence in applied mathematics. Students meet this requirement by taking a minimum of 6 units of either advanced mathematics offered by the Mathematics Department or technical electives that strongly emphasize applied mathematics. Common choices include:

AA 214A Numerical Methods in Engineering and Applied Sciences

AA 214B Numerical Methods for Compressible Flows

AA 214C Numerical Computation of Viscous Flow

AA 215A Advanced Computational Fluid Dynamics

AA 215B Advanced Computational Fluid Dynamics

AA 218 Introduction to Symmetry Analysis

AA 222 Introduction to Multidisciplinary Design Optimization

See the list of mathematics courses under Related Courses tab above for additional suggestions. All courses in the Mathematics Department numbered 200 or above are also included as suggestions.

Technical Electives

Students, in consultation with their advisers, select at least four courses (totaling at least 12 units) from among the graduate-level courses offered by departments of the School of Engineering and related science departments. Normally, one course (3 units) may be directed research.

Other Electives

It is recommended that all candidates enroll in a humanities or social sciences course to complete the 45-unit requirement. Practicing courses in, for example, art, music, and physical education do not qualify in this category. Language courses may qualify.

Master of Science in Engineering (AA)

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 units). This program is described in the "Graduate Programs in the School of Engineering" 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 in Aeronautics and Astronautics

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 full-time 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. 24 units of approved technical electives, of which 9 are in mathematics or applied mathematics. See the list of mathematics courses under Related Courses tab above. All courses in the Mathematics Department numbered 200 or above are included. The remaining 15 units are 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. 6 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 letter grade.

Doctor of Philosophy in Aeronautics and Astronautics

The University's basic requirements for the Ph.D. degree are outlined in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees)" section of this bulletin. Department requirements are stated below.

Before beginning dissertation research for the Ph.D. degree, a student must pass the departmental Qualifying Examination. A student must meet the following conditions by the appropriate deadline to be able to take the Qualifying Examination:

1. 30 units of Master's coursework completed in our department. A student who has completed fewer than 30 units may petition to take Quals.
2. Stanford graduate GPA of 3.5 or higher.
3. Investigation of a research problem, under the direction of a faculty member who will evaluate this work as evidence of the potential for doctoral research. The minimum requirement for taking Quals is to complete 3 units of AA 290 before the Quals quarter.

Additional information about the deadlines, nature, and scope of the Ph.D. qualifying examination can be obtained from the department. After passing the exam, the student must submit an approved program of Ph.D. course work on an Application for Candidacy for Doctoral Degree to the department's student services office.

Course Requirements

Each individual Ph.D. program in Aeronautics and Astronautics, designed by the student in consultation with the adviser, should represent a strong and cohesive program reflecting the student's major field of interest. A total of 90 units of work is required beyond the master's degree, 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. The remainder of the 90 units may be in the form of either Ph.D. dissertation units or free electives. For students who elect a minor in another department, a maximum of 12 units from the minor program may be included in the 36 units of formal course work; the remaining minor units may be considered free electives and are included in the 90 unit total required for the AA Ph.D. degree.

Ph.D. students in Aeronautics and Astronautics must take 12 units of mathematics courses, with at least 6 of these units from courses with numbers over 200. The AA department and other engineering departments offer many courses that have sufficient mathematical content that they may be used to satisfy the mathematics requirement. See the list of mathematics courses under Related Courses tab above for suggestions. Others may be acceptable if approved by the adviser and the AA Student Services Office. University requirements for continuous registration apply to doctoral students for the duration of the degree.

Grade Point Average

A minimum grade point average (GPA) of 3.0 is required to fulfill the department's Ph.D. It is incumbent upon Ph.D. students to request letter grades in all courses listed on the Application for Candidacy form.

Candidacy

Ph.D. students must complete the candidacy process and be admitted to candidacy by their second year of doctoral study. There are two requirements for admission to Ph.D candidacy in Aeronautics and Astronautics: students must first pass the departmental qualifying exam and must then submit an application for candidacy. The candidacy form lists the courses the student will take to fulfill the requirements for the degree. The form must include the 90 non-MS units required for the Ph.D.; it should be signed by the adviser and submitted to the AA Student Services Office for the candidacy chairman's signature. AA has a department-specific candidacy form, which may be obtained in the AA student services office. Candidacy is valid for five years; this term is not affected by leaves of absence.

Dissertation Reading Committee

Each Ph.D. candidate is required to establish a reading committee for the doctoral dissertation within six months after passing the department's Ph.D. qualifying exam. Thereafter, the student should consult frequently with all members of the committee about the direction and progress of the dissertation research.

A dissertation reading committee consists of the principal dissertation adviser and at least two other readers. If the principal adviser is emeritus, there should be a non-emeritus co-adviser. Reading committees in Aeronautics and Astronautics often include faculty from another department. It is expected that at least two members of the AA faculty be on each reading committee. If the principal research adviser is not within the AA department, then the student's AA academic adviser should be one of those members. The initial committee, and any subsequent changes, must be approved by the department Chair.

Although all readers are usually members of the Stanford Academic Council, the department Chair may approve one non-Academic Council reader if the person brings unusual and necessary expertise to the dissertation research. Generally, this non-Academic Council reader will be a fourth reader, in addition to three Academic Council members.

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 faculty examiners, plus a chairman). The examiners usually include the three members on the student's Ph.D. reading committee. The chairman must not be in the same department as the student or the adviser. Once the oral has been passed, the student finalizes the dissertation for reading committee review and final approval. Forms for the University oral scheduling and a one-page dissertation abstract should be submitted to the AA Student Services Office at least three weeks prior to the date of the oral for departmental review and approval. Students must be enrolled during the quarter when they take their University oral. If the oral takes place during the vacation time between quarters, the student must be enrolled in the prior quarter.

Ph.D. Minor in Aeronautics and Astronautics

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.

Emeriti: (Professors) Arthur E. Bryson, Robert H. Cannon, Richard Christensen*, Daniel B. DeBra, Robert W. MacCormack, Bradford W. Parkinson*, J. David Powell, George S. Springer, Charles R. Steele, Stephen W. Tsai*, Walter G. Vincenti

Chair: Charbel Farhat

Professors: Juan Alonso, Brian J. Cantwell, Fu-Kuo Chang, Per Enge, Charbel Farhat , Ilan Kroo, Sanjay Lall, Sanjiva Lele, Stephen Rock

Research Professors: Antony Jameson

Assistant Professors: Sigrid Close, Simone D'Amico, Mykel Kochenderfer, Marco Pavone, Debbie Senesky, Mac Schwager

Courtesy Professors: J. Christian Gerdes, Ronald K. Hanson, Lambertus Hesselink

Consulting Professors: G. Scott Hubbard, Heinz Erzberger

Consulting Assistant Professors: Andrew Barrows, Andrew Kalman, Frank Van Diggelen

* Recalled to active duty.

Experimentation/Design Requirements Courses

The following courses satisfy the master's Experimentation/Design Requirements.

		Units
AA 236A	Spacecraft Design	3-5
AA 241X	Design, Construction, and Testing of Autonomous Aircraft	3
AA 284B	Propulsion System Design Laboratory	3
CS 225A	Experimental Robotics	3
CS 402L	Beyond Bits and Atoms - Lab	1-3
EE 133	Analog Communications Design Laboratory	3-4
EE 233	Analog Communications Design Laboratory	3-4
EE 234	Photonics Laboratory	3
EE 265	Digital Signal Processing Laboratory	3-4
EE 410	Integrated Circuit Fabrication Laboratory	3-4
EE 412	Advanced Nanofabrication Laboratory	3
ENGR 206	Control System Design	3-4
ENGR 207A	Linear Control Systems I	3
ENGR 341	Micro/Nano Systems Design and Fabrication	3-5
MATSCI 160	Nanomaterials Laboratory	4
MATSCI 161	Nanocharacterization Laboratory	3-4
MATSCI 162	X-Ray Diffraction Laboratory	3-4
MATSCI 163	Mechanical Behavior Laboratory	3-4
MATSCI 164	Electronic and Photonic Materials and Devices Laboratory	3-4
MATSCI 171	Nanocharacterization Laboratory	3-4
MATSCI 172	X-Ray Diffraction Laboratory	3-4
MATSCI 173	Mechanical Behavior Laboratory	3-4
MATSCI 322	Transmission Electron Microscopy Laboratory	3
ME 210	Introduction to Mechatronics	4
ME 218A	Smart Product Design Fundamentals	4-5
ME 218B	Smart Product Design Applications	4-5
ME 218C	Smart Product Design Practice	4-5
ME 218D	Smart Product Design: Projects	3-4
ME 220	Introduction to Sensors	3-4
ME 310A	Product-Based Engineering Design, Innovation, and Development	4
ME 310B	Product-Based Engineering Design, Innovation, and Development	4
ME 310C	Project-Based Engineering Design, Innovation, and Development	4
ME 324	Precision Engineering	4
ME 348	Experimental Stress Analysis	3
ME 354	Experimental Methods in Fluid Mechanics	4
ME 367	Optical Diagnostics and Spectroscopy Laboratory	4
ME 385	Tissue Engineering Lab	1-2

Mathematics Courses

Each Aero/Astro degree has a mathematics requirement, for which courses on the following list are pre-approved. (Other advanced courses may also be acceptable.) Students should consult with their advisers in selecting the most appropriate classes for their field. M.S. candidates select 2 courses; they may also use the mathematics courses listed as common choices in the master's degree course requirements . Engineers select 3 courses; Ph.D. candidates select 4 courses, with at least 6 units from courses numbered above 200.

		Units
AA 214B	Numerical Methods for Compressible Flows	3
AA 214C	Numerical Computation of Viscous Flow	3
AA 215A	Advanced Computational Fluid Dynamics	3

AA 215B	Advanced Computational Fluid Dynamics	3
AA 218	Introduction to Symmetry Analysis	3
AA 222	Introduction to Multidisciplinary Design Optimization	3-4
CEE 281	Mechanics and Finite Elements	3
CME 306	Numerical Solution of Partial Differential Equations	3
CME 326	Numerical Methods for Initial Boundary Value Problems	3
EE 261	The Fourier Transform and Its Applications	3
EE 263	Introduction to Linear Dynamical Systems	3
EE 264	Digital Signal Processing	3-4
EE 364A	Convex Optimization I	3
EE 364B	Convex Optimization II	3
ENGR 207B	Linear Control Systems II	3
ENGR 209A	Analysis and Control of Nonlinear Systems	3
MATH 113	Linear Algebra and Matrix Theory	3
MATH 115	Functions of a Real Variable	3
MATH 120	Groups and Rings	3
MATH 132	Partial Differential Equations II	3
ME 300A	Linear Algebra with Application to Engineering Computations	3
ME 300B	Partial Differential Equations in Engineering	3
ME 300C	Introduction to Numerical Methods for Engineering	3
ME 335A	Finite Element Analysis	3
ME 335B	Finite Element Analysis	3
ME 335C	Finite Element Analysis	3
ME 408	Spectral Methods in Computational Physics	3
ME 469	Computational Methods in Fluid Mechanics	3
ME 469B	Computational Methods in Fluid Mechanics	3
MSE 201	Dynamic Systems	3-4
MSE 211	Linear and Nonlinear Optimization	3-4
MSE 311	Optimization	3
MSE 312	Advanced Methods in Numerical Optimization	3
PHYSICS 211	Continuum Mechanics	3
STATS 110	Statistical Methods in Engineering and the Physical Sciences	4-5
STATS 116	Theory of Probability	3-5
STATS 217	Introduction to Stochastic Processes	2-3

Courses

AA 47SI. Why Go To Space?. 1 Unit.
Why do we spend billions of dollars exploring space? What can modern policymakers, entrepreneurs, and industrialists do to help us achieve our goals beyond planet Earth? Whether it is the object of exploration, science, civilization, or conquest, few domains have captured the imagination of a species like space. This course is an introduction to space policy issues, with an emphasis on the modern United States. We will present a historical overview of space programs from all around the world, and then spend the last five weeks discussing present policy issues, through lectures and guest speakers from NASA, the Department of Defense, new and legacy space industry companies, and more. Students will present on one issue that piques their interest, selecting from various domains including commercial concerns, military questions, and geopolitical considerations.

AA 100. Introduction to Aeronautics and Astronautics. 3 Units.
The principles of fluid flow, flight, and propulsion; the creation of lift and drag, aerodynamic performance including takeoff, climb, range, and landing performance, structural concepts, propulsion systems, trajectories, and orbits. The history of aeronautics and astronautics. Prerequisites: MATH 20, 21 or MATH 41, 42; elementary physics.

AA 115N. The Global Positioning System: Where on Earth are We, and What Time is It?. 3 Units.
Preference to freshmen. Why people want to know where they are: answers include cross-Pacific trips of Polynesians, missile guidance, and distraught callers. How people determine where they are: navigation technology from dead-reckoning, sextants, and satellite navigation (GPS). Hands-on experience. How GPS works; when it does not work; possibilities for improving performance.

AA 116Q. Electric Automobiles and Aircraft. 3 Units.
Transportation accounts for nearly one-third of American energy use and greenhouse gas emissions and three-quarters of American oil consumption. It has crucial impacts on climate change, air pollution, resource depletion, and national security. Students wishing to address these issues reconsider how we move, finding sustainable transportation solutions. An introduction to the issue, covering the past and present of transportation and its impacts; examining alternative fuel proposals; and digging deeper into the most promising option: battery electric vehicles. Energy requirements of air, ground, and maritime transportation; design of electric motors, power control systems, drive trains, and batteries; and technologies for generating renewable energy. Two opportunities for hands-on experiences with electric cars. Prerequisites: Introduction to calculus and Physics AP or elementary mechanics.

AA 190. Directed Research and Writing in Aero/Astro. 3-5 Units.
For undergraduates. Experimental or theoretical work 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. May be repeated for credit. Prerequisite: consent of student services manager and instructor.

AA 199. Independent Study in Aero/Astro. 1-5 Unit.
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. May be repeated for credit. Prerequisite: consent of instructor.

AA 200. Applied Aerodynamics. 3 Units.
Analytical and numerical techniques for the aerodynamic analysis of aircraft, focusing on airfoil theory, finite wing theory, far-field and Trefftz-plane analysis, two-dimensional laminar and turbulent boundary layers in airfoil analysis, laminar-to-turbulent transition, compressibility effects, and similarity rules. Biweekly assignments require MATLAB or a suitable programming language. Prerequisite: undergraduate courses in basic fluid mechanics and applied aerodynamics, AA 210A.

AA 201A. Fundamentals of Acoustics. 3 Units.
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.

AA 201B. Topics in Aeroacoustics. 3 Units.
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, Ffowcs Williams, and Hawkings; application of acoustic theories to the noise from propulsive jets, and airframe and rotor noise; computational methods for acoustics. Prerequisite: 201A or consent of instructor.

AA 202. Hypersonic Flow. 3 Units.
The fundamental principals and equations governing hypersonic flight and high temperature gas dynamics, including chemical and thermal equilibrium and non-equilibrium; statistical thermodynamics; kinetic theory; transport phenomena; radiation; surface heating; and scramjet engines. Prerequisite: understanding of aerodynamics. Recommended: AA 200A.

AA 203. Introduction to Optimal Control Theory. 3 Units.
Basic solution techniques for optimal control problems. Dynamic programming, calculus of variations, and numerical techniques for trajectory optimization. Special cases (chiefly LQR and robotic motion planning); modern solution approaches (such as MPC and MILP); and introduction to stochastic optimal control. Examples in MATLAB. Prerequisites: Linear algebra (EE 263 or equivalent).

AA 206. Bio-Aerodynamics. 3 Units.
Topics: flapping flight, low Reynolds number aerodynamics, wing design, flocks, swarms, and dynamic soaring. Readings from current and historical literature dealing with theoretical and observational studies. Applications in aircraft design, and simulation-based problem sets. Prerequisite: course in aerodynamics such as 100, 200A, or 241A.

AA 208. Aerodynamics of Aircraft Dynamic Response and Stability. 3 Units.
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).

AA 210A. Fundamentals of Compressible Flow. 3 Units.
Topics: development of the three-dimensional, non-steady, 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.

AA 210B. Fundamentals of Compressible Flow. 3 Units.
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.

AA 212. Advanced Feedback Control Design. 3 Units.
Analysis and design techniques for multivariable feedback systems. Loop shaping and limitations of performance. Structural properties of multi-input, multi-output linear time-invariant systems. Study of the stability and robustness of feedback loops. Approaches for optimal and robust feedback control design, chiefly H2, H-infinity, and mu synthesis. Use of computer-aided design with MATLAB. Prerequisite: ENGR 205. Recommended: Linear algebra (EE 263 or equivalent).

AA 214A. Numerical Methods in Engineering and Applied Sciences. 3 Units.
Scientific computing and numerical analysis for physical sciences and engineering. Advanced version of CME206 that, apart from CME206 material, includes nonlinear PDEs, multidimensional interpolation and integration and an extended discussion of stability for initial boundary value problems. Recommended for students who have some prior numerical analysis experience. Topics include: 1D and multi-D interpolation, numerical integration in 1D and multi-D including adaptive quadrature, numerical solutions of ordinary differential equations (ODEs) including stability, numerical solutions of 1D and multi-D linear and nonlinear partial differential equations (PDEs) including concepts of stability and accuracy. Prerequisites: linear algebra, introductory numerical analysis (CME 108 or equivalent).
Same as: CME 207, GEOPHYS 217

AA 214B. Numerical Methods for Compressible Flows. 3 Units.
For M.S.-level graduate students. Covers the hierarchy of mathematical models for compressible flows. Introduction to finite difference, finite volume, and finite element methods for their computation. Ideal potential flow; transonic potential flow; Euler equations; Navier-Stokes equations; representative model problems; shocks, expansions, and contact discontinuities; treatment of boundary conditions; time and pseudo-time integration schemes. Prerequisites: basic knowledge of linear algebra and ODEs (CME 206 or equivalent).

AA 214C. Numerical Computation of Viscous Flow. 3 Units.
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.

AA 215A. Advanced Computational Fluid Dynamics. 3 Units.
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.
Same as: CME 215A

AA 215B. Advanced Computational Fluid Dynamics. 3 Units.
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.
Same as: CME 215B

AA 218. Introduction to Symmetry Analysis. 3 Units.
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. Mathematica-based software developed by the instructor is used for finding invariant groups of ODEs and PDEs.

AA 222. Introduction to Multidisciplinary Design Optimization. 3-4 Units.
Design of aerospace systems within a formal optimization environment. Mathematical formulation of the multidisciplinary design problem (parameterization of design space, choice of objective functions, constraint definition); survey of algorithms for unconstrained and constrained optimization and optimality conditions; description of sensitivity analysis techniques. Hierarchical techniques for decomposition of the multidisciplinary design problem; use of approximation theory. Applications to design problems in aircraft and launch vehicle design. Prerequisites: multivariable calculus; familiarity with a high-level programming language: FORTRAN, C, C++, MATLAB, Python, or Julia.

AA 228. Decision Making under Uncertainty. 3-4 Units.
This course is designed to increase awareness and appreciation for why uncertainty matters, particularly for aerospace applications. Introduces decision making under uncertainty from a computational perspective and provides an overview of the necessary tools for building autonomous and decision-support systems. Following an introduction to probabilistic models and decision theory, the course will cover computational methods for solving decision problems with stochastic dynamics, model uncertainty, and imperfect state information. Topics include: Bayesian networks, influence diagrams, dynamic programming, reinforcement learning, and partially observable Markov decision processes. Applications cover: air traffic control, aviation surveillance systems, autonomous vehicles, and robotic planetary exploration. Prerequisites: basic probability and fluency in a high-level programming language.
Same as: CS 238

AA 229. Advanced Topics in Sequential Decision Making. 3-4 Units.
Survey of recent research advances in intelligent decision making for dynamic environments from a computational perspective. Efficient algorithms for single and multiagent planning in situations where a model of the environment may or may not be known. Partially observable Markov decision processes, approximate dynamic programming, and reinforcement learning. New approaches for overcoming challenges in generalization from experience, exploration of the environment, and model representation so that these methods can scale to real problems in a variety of domains including aerospace, air traffic control, and robotics. Students are expected to produce an original research paper on a relevant topic. Prerequisites: AA 228/CS 238 or CS 221.
Same as: CS 239

AA 236A. Spacecraft Design. 3-5 Units.
The design of unmanned spacecraft and spacecraft subsystems emphasizing 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.

AA 236B. Spacecraft Design Laboratory. 3-5 Units.
Continuation of 236A. Emphasis is on practical application of systems engineering to the life cycle program of spacecraft design, testing, launching, and operations. Prerequisite: 236A or consent of instructor.

AA 236C. Spacecraft Design Laboratory. 3-5 Units.
.

AA 240A. Analysis of Structures. 3 Units.
Elements of two-dimensional elasticity theory. Boundary value problems; energy methods; analyses of solid and thin walled section beams, trusses, frames, rings, monocoque and semimonocoque structures. Prerequisite: ENGR 14 or equivalent.

AA 240B. Analysis of Structures. 3 Units.
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.

AA 241A. Introduction to Aircraft Design, Synthesis, and Analysis. 3 Units.
New aircraft systems emphasizing commercial aircraft. Economic and technological factors that create new aircraft markets. Determining market demands and system mission performance requirements; optimizing configuration to comply with requirements; the interaction of disciplines including aerodynamics, structures, propulsion, guidance, payload, ground support, and parametric studies. Applied aerodynamic and design concepts for use in configuration analysis. Application to a student-selected aeronautical system; applied structural fundamentals emphasizing fatigue and fail-safe considerations; design load determination; weight estimation; propulsion system performance; engine types; environmental problems; performance estimation. Direct/indirect operating costs prediction and interpretation. Aircraft functional systems; avionics; aircraft reliability and maintainability. Prerequisite: 100 or equivalent.

AA 241B. Introduction to Aircraft Design, Synthesis, and Analysis. 3 Units.
New aircraft systems emphasizing commercial aircraft. Economic and technological factors that create new aircraft markets. Determining market demands and system mission performance requirements; optimizing configuration to comply with requirements; the interaction of disciplines including aerodynamics, structures, propulsion, guidance, payload, ground support, and parametric studies. Applied aerodynamic and design concepts for use in configuration analysis. Application to a student-selected aeronautical system; applied structural fundamentals emphasizing fatigue and fail-safe considerations; design load determination; weight estimation; propulsion system performance; engine types; environmental problems; performance estimation. Direct/indirect operating costs prediction and interpretation. Aircraft functional systems; avionics; aircraft reliability and maintainability. Prerequisite: 100 or equivalent.

AA 241X. Design, Construction, and Testing of Autonomous Aircraft. 3 Units.
Students grouped according to their expertise to carry out the multidisciplinary design of a solar-powered autonomous aircraft that must meet a clearly stated set of design requirements. Design and construction of the airframe, integration with existing guidance, navigation, and control systems, and development and operation of the resulting design. Design reviews and reports. Prerequisites: expertise in any of the following disciplines by having satisfied the specified courses or equivalent work elsewhere: conceptual design (241A,B); applied aerodynamics (200A,B); structures (240A); composite manufacturing experience; guidance and control (208/271, ENGR 205).

AA 242A. Classical Dynamics. 3 Units.
Accelerating and rotating reference frames. Kinematics of rigid body motion; Euler angles, direction cosines. D'Alembert's principle, equations of motion. Inertia properties of rigid bodies. Dynamics of coupled rigid bodies. Lagrange's equations and their use. Dynamic behavior, stability, and small departures from equilibrium. Prerequisite: ENGR 15 or equivalent.

AA 242B. Mechanical Vibrations. 3 Units.
For M.S.-level graduate students. Covers the vibrations of discrete systems and continuous structures. Introduction to the computational dynamics of linear engineering systems. Review of analytical dynamics of discrete systems; undamped and damped vibrations of N-degree-of-freedom systems; continuous systems; approximation of continuous systems by displacement methods; solution methods for the Eigenvalue problem; direct time-integration methods. Prerequisites: AA 242A or equivalent (recommended but not required); basic knowledge of linear algebra and ODEs; no prior knowledge of structural dynamics is assumed.
Same as: ME 242B

AA 244A. Introduction to Plasma Physics and Engineering. 3 Units.
Physics and engineering of plasmas, including space and laboratory plasmas. Debye length and distribution functions. Single-particle motion and drifts. Plasmas as fluids and fluid drifts. Waves in plasmas, including electrostatic and electromagnetic. Diffusion and resistivity. Magnetohydrodynamics.

AA 244B. Advanced Plasma Physics and Engineering. 3 Units.
Equilibrium and instability. Turbulent flow in plasmas. Kinetic theory and the Vlasov equation. Nonlinear effects and solutions. Radiation in a plasma. Plasma diagnostics in ground- and space-based experiments.

AA 250. Nanomaterials for Aerospace. 3 Units.
Properties of nanomaterials and current approaches for engineering spacecraft, aircraft, and subsystems with nanotechnology. Manufacturing of nanomaterials; nano-fiber reinforced composites; structural mechanics of nanomaterials; structure-property relationships; and application of nanotechnology for lightweight structures, thermal protection, nanopropellants, and nanoelectronics.

AA 251. Introduction to the Space Environment. 3 Units.
The environment through which space probes and vehicles travel and orbit. Survey of physical phenomena in the sun, solar wind, magnetospheres, ionospheres, and upper atmospheres of objects in the solar system. Introduction to the physical processes governing space plasmas, solar-terrestrial interactions, and ionized and neutral media surrounding the Earth and other solar system bodies. Prerequisite: Introduction to Plasma Physics.

AA 252. Techniques of Failure Analysis. 3 Units.
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.

AA 256. Mechanics of Composites. 3 Units.
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: ENGR 14 or equivalent.

AA 260. Sustainable Aviation. 3 Units.
Quantitative assessment of the impact of aviation on the environment including noise, local, and global emissions, and models used to predict it. Current and future technologies that may allow the air transportation system to meet anticipated growth while reducing or minimizing environmental problems. Atmospheric effects of NOx, CO2, particulates, unburned hydrocarbons, and water vapor deposition at high altitudes and metrics for assessing global climate effects. Noise sources, measurement, and mitigation strategies. Fundamentals of aircraft and engine performance needed to assess current and future concepts. Major national and international policy implications of existing and future technology choices. Recommended: AA 241B.

AA 270. Distributed Space Systems. 3 Units.
Keplerian orbital mechanics and orbital perturbations; the general relative motion problem; linear formation flying dynamics and control; impulsive station-keeping and reconfiguration; high order relative motion equations; formulation of relative motion using orbital elements; perturbation-invariant formations; nonlinear formation control; low-thrust propulsion for formation flying; relative navigation using GNSS and optical navigation; applications: sparse-aperture imaging, remote sensing, on-orbit servicing, rendezvous, and docking. Prerequisite: AA 242A, ENGR 105, AA 279A, and familiarity with MatLab.

AA 271A. Dynamics and Control of Spacecraft and Aircraft. 3 Units.
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. For spacecraft in orbit: natural longitudinal and lateral dynamic behavior and the design of attitude control systems. Prerequisites: AA242A, ENGR 105.

AA 271B. Advanced Dynamics and Control of Spacecraft. 3 Units.
Attitude representation and parametrization; unperturbed and perturbed attitude dynamics and stability; attitude sensors and actuators; linear and nonlinear attitude control; optimal attitude maneuvers; dynamics of flexible spacecraft and space tethers; invited lectures from industry. Prerequisites: AA 242A, ENGR 105, AA 279A, and familiarity with MatLab.

AA 272C. Global Positioning Systems. 3 Units.
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 and MatLab (or another mathematical programming language).

AA 272D. Integrated Navigation Systems. 3 Units.
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; ENGR 15, 105. Recommended: ENGR 205.

AA 279A. Space Mechanics. 3 Units.
Orbits of near-earth satellites and interplanetary probes; relative motion in orbit; transfer and rendezvous; orbit determination; influence of earth's oblateness; sun and moon effects on earth satellites; decay of satellite orbits; invited lectures from industry. Prerequisite: ENGR 15 and familiarity with MatLab.

AA 279B. Advanced Space Mechanics. 3 Units.
Restricted 3-body problem. Relative motion, Hill's and Clohessy-Wiltshire equations. Lambert's problem. Satellite constellations and optimization. Communications and link budgets. Space debris. High fidelity simulation. Interplanetary mission planning, launch windows and gravity assists. Basic trajectory optimization. Several guest lectures from practitioners in the field. Individual final project chosen in consultation with instructor. Prerequisites: 279A or equivalent with permission of instructor. Fluency with MATLAB (or another mathematical programming language with 2D and 3D plotting capabilities).

AA 280. Smart Structures. 3 Units.
Mechanics of smart materials and current approaches for engineering smart structures to monitor health, self heal, and adapt to environment. Definition of smart structures; constitutive models for smart materials; piezoelectric ceramics; electro-active polymers; shape memory alloys; bio-inspired materials and structures; self-healing materials; sensors and sensor networks; structural health monitoring; and energy harvesting. Prerequisite: AA 240A or consent of instructor.

AA 283. Aircraft and Rocket Propulsion. 3 Units.
Introduction to the design and performance of airbreathing and rocket engines. Topics: the physical parameters used to characterize propulsion system performance; gas dynamics 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.

AA 284A. Advanced Rocket Propulsion. 3 Units.
The principles of rocket propulsion system design and analysis. Fundamental aspects of the physics and chemistry of rocket propulsion. Focus is on the design and analysis of chemical propulsion systems including liquids, solids, and hybrids. Nonchemical propulsion concepts such as electric and nuclear rockets. Launch vehicle design and optimization issues including trajectory calculations. Limited enrollment. Prerequisites: 283 or consent of instructor.

AA 284B. Propulsion System Design Laboratory. 3 Units.
Propulsion systems engineering through the design and operation of a sounding rocket. Students work in small teams through a full project cycle including requirements definition, performance analysis, system design, fabrication, ground and flight testing, and evaluation. Prerequisite: 284A and consent of instructor.

AA 284C. Propulsion System Design Laboratory. 3 Units.
Continuation of 284A,B. Prerequisite: 284B, and consent of instructor.

AA 290. Problems in Aero/Astro. 1-5 Unit.
(Undergraduates register for 190 or 199.) Experimental or theoretical investigation. Students may work in any field of special interest. Register for section belonging to your research supervisor. May be repeated for credit.

AA 291. Practical Training. 1-3 Unit.
Educational opportunities in high-technology research and development labs in aerospace and related industries. Internship integrated into a student's academic program. Research report outlining work activity, problems investigated, key results, and any follow-on projects. Meets the requirements for Curricular Practical Training for students on F-1 visas. Student is responsible for arranging own employment and should see department student services manager before enrolling. May be repeated for credit.

AA 294. Case Studies in Aircraft Design. 1 Unit.
Presentations by researchers and industry professionals. Registration for credit optional. May be repeated for credit.

AA 295. Aerospace Structures and Materials. 1 Unit.
Presentations by researchers and industry professionals in aerospace structures and materials. May be repeated for credit.

AA 297. Seminar in Guidance, Navigation, and Control. 1 Unit.
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. May be repeated for credit.

AA 300. Engineer Thesis. 1-15 Unit.
Thesis for degree of Engineer. Students register for section belonging to their thesis adviser.

AA 301. Ph.D. Dissertation. 1-15 Unit.
Prerequisite: completion of Ph.D qualifying exams. Students register for section belonging to their thesis adviser. (Staff).

AA 801. TGR Engineer Thesis. 0 Units.
Engineer's thesis or non-doctoral work for a TGR student.

AA 802. TGR Ph.D. Dissertation. 0 Units.
Doctoral dissertation for a TGR student in PhD program.