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 undergraduate and 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 Bachelor of Science, 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

Learning Outcomes (Undergraduate)

The department expects undergraduate majors in the program to be able to demonstrate the following learning outcomes. These learning outcomes are used in evaluating students and the department's undergraduate program. Students are expected to demonstrate:

1. an ability to apply the knowledge of mathematics, science, and engineering to understand and solve complex interdisciplinary problems.
2. an ability to design and conduct relevant experiments, as well as to analyze and interpret the resulting outcomes to make appropriate design choices.
3. the broad education necessary to understand the impact of engineering solutions in a global and societal context.
4. an ability to work professionally in aircraft and spacecraft engineering, space exploration, air- and space-based telecommunication industries, autonomous systems, robotics, commercial space transportation, teaching, research, military service, and many related technology-intensive fields.
5. an ability to understand multidisciplinary challenges of modern aircraft and spacecraft design at the system level.
6. an ability to communicate effectively and to work in diverse and inter-disciplinary teams to accomplish objectives.
7. an understanding of professional and ethical responsibility.
8. an understanding of the impact that engineering solutions can have through entrepreneurial processes.
9. a recognition of the need for and an ability to engage in life-long learning, and to make original contributions in Aeronautics and Astronautics and related 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 considered for admission 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 4 for the next Autumn Quarter.

Information about admission to the Honors Cooperative Program is included in the "School of Engineering (http://exploredegrees.stanford.edu/schoolofengineering/#honorscooptext)" section of this bulletin. The department considers HCP applications for the Autumn, Winter and Spring Quarters; prospective applicants may contact the department's student services office with questions.

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

Transfer Credits

The number of transfer credits allowed for each degree (Engineer and Ph.D.) is delineated in the "Graduate Degrees (http://exploredegrees.stanford.edu/transferwork)" section of this bulletin; transfer credit is not accepted for the master'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 up to five quarters to cover tuition and living expenses. Stanford Graduate Fellowships, sponsored by the University, provide grants for up to 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 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.

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, autonomous systems, computational engineering, embedded programming, fluids engineering, and heat transfer. The major prepares students for careers in aircraft and spacecraft engineering, autonomy, robotics, unmanned aerial vehicles, drones, space exploration, air and space-based telecommunication industries, computational engineering, teaching, research, military service, and other related technology-intensive fields.

Completion of the undergraduate program in Aeronautics and Astronautics leads to the conferral of the Bachelor of Science in Aeronautics and Astronautics.

Requirements

		Units
Mathematics		
24 units minimum		
MATH 19	Calculus (required) [2]	3
MATH 20	Calculus (required) [2]	3
MATH 21	Calculus (required) [2]	4
CME 100/ENGR 154	Vector Calculus for Engineers (required) [3]	5
or MATH 51	Linear Algebra, Multivariable Calculus, and Modern Applications	
CME 102/ENGR 155A	Ordinary Differential Equations for Engineers (required) [3]	5
or MATH 53	Ordinary Differential Equations with Linear Algebra	
CME 106/ENGR 155C	Introduction to Probability and Statistics for Engineers (required)	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	
CME 104	Linear Algebra and Partial Differential Equations for Engineers (recommended) [3]	5
or MATH 52	Integral Calculus of Several Variables	
CME 108	Introduction to Scientific Computing (recommended)	3
Science		
20 units minimum		
PHYSICS 41	Mechanics (required) [4]	4
or PHYSICS 41E	Mechanics, Concepts, Calculations, and Context	
PHYSICS 43	Electricity and Magnetism (required) [4]	4
PHYSICS 45	Light and Heat (required)	4
CHEM 31X	Chemical Principles Accelerated (or CHEM 31A and CHEM 31B, or AP Chemistry) (required)	5
ENGR 80	Introduction to Bioengineering (Engineering Living Matter) (recommended)	4
School of Engineering approved Science Electives: See Undergraduate Handbook, Figure 4-2		3-5
Technology in Society (one course required)		
School of Engineering approved Technology in Society courses: See Undergraduate Handbook, Figure 4-3. The course must be on the School of Engineering approved list the year you take it.		3-5
ENGR 131	Ethical Issues in Engineering (recommended)	4
AA 252	Techniques of Failure Analysis (recommended)	3

Engineering Fundamentals (three courses required)		
11 units minimum		
ENGR 21	Engineering of Systems (required)	3
ENGR 70A/CS 106A	Programming Methodology (required)	5
ENGR 10	Introduction to Engineering Analysis (recommended)	4
ENGR 40M	An Intro to Making: What is EE (recommended)	3-5
Fundamentals Elective; see list of Approved Courses in Undergraduate Engineering Handbook website at ughb.stanford.edu, Figure 4-4		3-5
Aero/Astro Depth Requirements		
27 units minimum		
ENGR 14	Intro to Solid Mechanics (required)	3
ENGR 15	Dynamics (required)	3
ENGR 105	Feedback Control Design (required)	3
ME 30	Engineering Thermodynamics (required)	3
AA 100	Introduction to Aeronautics and Astronautics (required)	3
AA 101 Introduction to Aero Fluid Mechanics, required [1]		
AA 102	Introduction to Applied Aerodynamics	3
AA 103	Air and Space Propulsion	3
AA 131	Space Flight (required)	3
AA 141	Atmospheric Flight (required)	3
AA 171 Autonomous Systems, required [1]		
AA 190	Directed Research and Writing in Aero/Astro	3-5
Aero/Astro Focus Electives		
15 units minimum		
AA 111 Introduction to Aerospace Computational Engineering [1]		
AA 135 Introduction to Space Policy [1]		
AA 151	Lightweight Structures	3
AA 156	Mechanics of Composite Materials	3
AA 173 Flight Mechanics and Controls [1]		
AA 175 Embedded Programming [1]		
AA 272C	Global Positioning Systems	3
AA 279A	Space Mechanics	3
AA 199	Independent Study in Aero/Astro	1-5
MS&E 178	The Spirit of Entrepreneurship	2
Aero/Astro Suggested Courses (not required)		
AA 149	Operation of Aerospace Systems	1
Aero/Astro Capstone Requirement		
7 units minimum		
AA 123A Air Capstone I, satisfies the Writing in the Major requirement, (WIM) [1]		
AA 123B Air Capstone II [1]		
AA 124A Space Capstone I, satisfies the Writing in Major requirement, (WIM) [1]		
AA 124B Space Capstone II [1]		

For additional information and sample programs see the Handbook for Undergraduate Engineering (http://ughb.stanford.edu) and the Aeronautics and Astronautics Undergraduate Program Sheet (https://ughb.stanford.edu/program-sheets).

All courses taken for the major must be taken for a letter grade if that option is offered by the instructor.

Minimum Combined GPA for all courses in Engineering Topics (Engineering Fundamentals and Depth courses) is 2.0.

Transfer and AP credits in Math, Science, Fundamentals, and the Technology in Society course must be approved by the School of Engineering Dean's office.

1 This course will be offered in the near future. See the department's web site for more information about our future course offerings (https://aa.stanford.edu/academics/undergraduate-program). For courses yet not offered please contact the Aero/Astro Student Services Office (https://aa.stanford.edu/academics/student-services-office) for a list of approved replacement courses.

2 A score of 4 on the Calculus BC test or 5 on the AB test only gives students 8 units, not 10 units, so is equal to MATH 19 + MATH 20, but not MATH 21. The Math Placement Exam determines what math course the student starts with.

3 It is recommended that the CME series (100, 102, 104) be taken rather than the MATH series (51, 52, 53). It is recommended that students taking the MATH series also take CME 192 Introduction to MATLAB.

4 A score of 5 on the AP Physics C Mechanics test places the student out of PHYSICS 41. Similarly, a score of 5 on the AP Physics Electricity and Magnetism test places the student out of PHYSICS 43.

Honors Program

The Department of Aeronautics and Astronautics honors program has been designed to allow undergraduates with strong records and enthusiasm for independent research to engage in a significant project leading to a degree with departmental honors.

Students who meet the eligibility criteria and wish to be considered for the honors program should apply to the program by the end of the junior year. All applications are subject to the review and final approval by the Aero/Astro Undergraduate Curriculum Committee.

Application Requirements:

- One-page written statement describing the research topic and signed adviser form
- GPA of 3.5 or higher in the major
- Unofficial Stanford transcript (from Axess)
- Signature of thesis adviser

Honors criteria:

- Maintain the 3.5 GPA required for admissions to the honors program.
- Arrangement with an Aero/Astro faculty member who agrees to serve as the thesis adviser. The adviser must be a member of the Academic Council.
- Under the direction of the thesis adviser, complete at least two quarters of research with a minimum of 9 units of independent research; 3 of these units may be used towards a student's Aero/Astro Focus Elective requirement.
- Submit an honors thesis (20-30 pages). Thesis is due by April 30th of senior year in order to be eligible for University prizes.
- Attend Research Experience for Undergraduates Poster Session or present in another suitable forum approved by the faculty adviser.

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. If any core classes (aside from ENGR 21; see footnote) are part of student's major or other degree program, the Aero/Astro adviser can help select substitute courses to fulfill the Aero/Astro minor requirements; no double counting allowed. All courses taken for the minor must be taken for a letter grade if that option is offered by the instructor. Minimum GPA for all minor courses combined is 2.0.

The following core courses fulfill the minor requirements:

		Units
AA Core		
12 Core Units, 24 Total Program Units		
ENGR 21	Engineering of Systems [2]	3
AA 100	Introduction to Aeronautics and Astronautics	3
AA 131	Space Flight	3
AA 141	Atmospheric Flight	3
AA Electives		
Choose 4 courses		
AA 101 Introduction to Aero Fluid Mechanics [1]		
AA 102	Introduction to Applied Aerodynamics	3
AA 103	Air and Space Propulsion	3
AA 111 Introduction to Aerospace Computational Engineering [1]		
AA 135 Introduction to Space Policy [1]		
AA 151	Lightweight Structures	3
AA 156	Mechanics of Composite Materials	3
AA 171 Autonomous Systems [1]		
AA 173 Flight Mechanics and Controls [1]		
AA 175 Embedded Programming [1]		
AA 272C	Global Positioning Systems	3
AA 279A	Space Mechanics	3
ENGR 105	Feedback Control Design	3

1 This course will be offered in the future. Please see our website for future course offerings (https://aa.stanford.edu/academics/undergraduate-program). For courses yet not offered please contact the Aero/Astro Student Services Office (https://aa.stanford.edu/academics/student-services-office) for a list of approved replacement courses.

2 ENGR 21 is waived as minor requirement if already taken as part of the major program.

Master of Science in Aeronautics and Astronautics

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

Students with an aeronautical engineering background should be able to complete the master's degree in five quarters; note that many courses are not taught during the summer. 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 may lengthen the time required to obtain the master's degree.

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 offered. Research is optional (required to take the qualifying examination).

Grade Point Averages

A minimum grade point average (GPA) of 2.75 is required to fulfill the department's master's degree requirements. A minimum GPA of 3.5 is required for eligibility to attempt the Ph.D. qualifying examination. Students must also meet the University's quarterly academic requirements for graduate students as described in the "Degree Progress (http://exploredegrees.stanford.edu/graduatedegrees/#degreeprogresstext)" section of this bulletin and in the "Satisfactory Progress" section of the Guide to Graduate Studies in Aeronautics and Astronautics. All courses (excluding seminars) used to satisfy the requirements for basic courses, mathematics and technical electives must be taken for a letter grade. 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'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

Master's degree 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 240	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 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 274	Principles of Robotic Autonomy	3

AA 277	Multi-robot Control, Communication, and Sensing	3
AA 279A	Space Mechanics	3
One course selected from AA courses numbered 200 and above, excluding seminars and independent research		

Course Waivers

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.

Mathematics Courses

M.S. candidates are expected to exhibit competence in applied mathematics. Students meet this requirement by taking two courses, for 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 203 Optimal and Learning-based Control
- AA 212 Advanced Feedback Control Design
- AA 214A Numerical Methods in Engineering and Applied Sciences
- AA 214B Numerical Methods for Compressible Flows
- AA 218 Introduction to Symmetry Analysis
- AA 222 Engineering Design Optimization
- AA 228 Decision Making under Uncertainty
- AA 229 Advanced Topics in Sequential Decision Making
- AA 242B Mechanical Vibrations

See the list of mathematics courses under Related Courses (http://exploredegrees.stanford.edu/aeronauticsandastronautics/#relatedcoursestext) tab for additional suggestions, which includes all courses in the Mathematics Department numbered 200 or above.

A maximum of three independent study/research units (AA 290 or independent study in another department) may count toward your M.S. program. If you fulfill your experimentation/design requirement with a course other than AA 290 (or equivalent from another department), it is possible to count AA 290 as a technical or free elective.

Technical Electives

Students, in consultation with their adviser, select at least four courses* from among the graduate-level courses, totaling at least 12 units, from departments in the School of Engineering and related science departments. These courses should be taken for a letter grade; the student should not elect the credit/no-credit option for any course except free elective.

*Up to three seminar units may count toward an M.S. program, and are counted as one technical elective. At least three additional graduate courses offered in Engineering or related math/science departments should be taken to meet the technical elective section requirement.

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.

Coterminal Master's Program in Aeronautics and Astronautics

This program allows Stanford undergraduates an opportunity to work simultaneously toward a B.S. degree and an M.S. in Aeronautics and Astronautics. Stanford undergraduates who wish to continue their studies for the master of science degree in the coterminal program must have earned a minimum of 120 units towards graduation. This includes allowable Advanced Placement (AP) and transfer credit.

The department-specific Aero/Astro coterminal program application, which includes information and deadlines, can be obtained from the Aero/Astro Student Services Office (https://aa.stanford.edu/academics/student-services-office). A completed application (including letters of recommendation, transcripts and GRE scores) must be received no later than the quarter prior to the expected completion of the undergraduate degree. Admission is granted or denied through the departmental faculty admissions committee. Stanford undergraduates interested in learning more about receiving an Aero/Astro master's degree as a coterm student should review the information on the University Registrar's web site (https://registrar.stanford.edu/students/coterminal-degree-programs) and visit the Aero/Astro Student Services Office (https://aa.stanford.edu/academics/student-services-office).

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.

The Honors Cooperative Program

The Honors Cooperative Program (HCP) makes it possible for academically qualified engineers and scientists in nearby companies to be part-time master's students in Aeronautics and Astronautics while continuing nearly full-time professional employment. Prospective HCP students follow the same admission process and must meet the same admission requirements as full-time master's students. For more information regarding the Honors Cooperative Program, see the "School of Engineering (http://exploredegrees.stanford.edu/schoolofengineering/#honorscooptext)" section of this bulletin.

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 (Aero/Astro) 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 (http://exploredegrees.stanford.edu/schoolofengineering/#masters)" 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 Aero/Astro 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 (http://exploredegrees.stanford.edu/graduatedegrees)" 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 21 units of courses chosen as follows:

1. 21 units of approved technical electives, of which 6 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. The remaining 24 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.

Engineer's thesis

For specific information on the format and deadlines for submission of theses, please check with the Graduate Degree Progress Office. The department recommends that students follow the format defined in the handbook Directions for Preparing Doctoral Dissertations (https://studentaffairs.stanford.edu/registrar/students/dissertation-thesis), available in the Graduate Degree Progress Office. Note: the adviser must sign the thesis before the filing deadline, which is generally the last day of classes during the graduation quarter.

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. Applicants who have received their M.S. from other institutions may apply directly to the Ph.D. program. Students who are currently pursuing the M.S. in our department and wish to continue for the Ph.D. should submit a graduate program authorization petition form online through Axess before their last quarter in the master's program.

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 course work completed. A student who has completed fewer than 30 units may petition to take the qualifying examination.
2. Stanford graduate GPA of 3.5 or higher.
3. Investigation of a research problem, under the direction of a faculty member who evaluates this work as evidence of the potential for doctoral research. The minimum requirement for taking the qualifying examination is to complete 3 units of AA 290 before the qualifying examination quarter.

Additional information about the deadlines, nature, and scope of the Ph.D. qualifying examination can be obtained from the department. Recommended courses to prepare for the qualifying examination are listed on the Aero/Astro website (http://aa.stanford.edu/academics/graduate-programs/doctoral-program). 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 Aero/Astro 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 credit is required beyond the M.S. Of these 90 units, a minimum of 27 must be formal course work (excluding research, directed study and seminars), consisting primarily of graduate courses in engineering and the pertinent 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 9 units from the minor program may be included in the 27 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 Aero/Astro Ph.D. degree.

Ph.D. students in Aeronautics and Astronautics must take 9 units of mathematics courses, with at least 6 of these units from courses with numbers over 200. The Aero/Astro 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 (p. 8) tab for suggestions. Others may be acceptable if approved by the adviser and the Aero/Astro 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. degree requirements. 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-M.S. units required for the Ph.D.; it should be signed by the adviser and submitted to the Aero/Astro student services office for the candidacy chairman's signature. Aero/Astro has a department-specific candidacy form, which may be obtained in the Aero/Astro 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. It is expected that at least two members of the Aero/Astro faculty be on each reading committee. If the principal research adviser is not within the Aero/Astro department, then the student's Aero/Astro 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 Examination

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 examination has been passed, the student finalizes the dissertation for reading committee review and final approval. Forms for the University oral examination scheduling and a one-page dissertation abstract should be submitted to the Aero/Astro student services office at least three weeks prior to the date of the oral examination for departmental review and approval. Students must be enrolled during the quarter when they take their University oral examination. If the oral examination takes place during the vacation time between quarters, the student must be enrolled in the prior quarter.

Doctoral Dissertation

See the Directions for Preparing Doctoral Dissertation (https://registrar.stanford.edu/students/dissertation-and-thesis-submission/preparing-dissertations-electronic-submission/format), which outlines the University guidelines for preparing a Ph.D. dissertation.

When a student is ready for a final draft of the dissertation, the student should make an appointment to consult with the graduate degree progress officer in the Registrar's Office to review the completion of the Ph.D. program and the strict formatting requirements for the dissertation. Students must submit the final version of the dissertation to the Registrar's Office no later than the posted deadline. *Note:* All members of the reading committee must sign the dissertation before the filing deadline.

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

Ph.D. Minor in Aeronautics and Astronautics

A student who wishes to obtain a Ph.D. minor in Aeronautics and Astronautics should consult the Aero/Astro student services 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 Aero/Astro.

Graduate Advising Expectations

The Department of Aeronautics and Astronautics is committed to providing academic advising in support of graduate student education and professional development. The advising relationship should entail collaborative engagement by both the adviser and the advisee. As a best practice, advising expectations should be discussed and reviewed to ensure mutual understanding. Both the adviser and the advisee are expected to maintain professionalism and integrity.

Graduate students are active contributors to the advising relationship, proactively seeking academic and professional guidance and taking responsibility for informing themselves of policies and degree requirements for their graduate program.

In addition, the faculty Candidacy Chair is available for consultation during the academic year by email and during office hours. The Aero/Astro student services office is also an important part of the advising team. Staff in the office inform students and advisers about university and department requirements, procedures, and opportunities, and maintain the official records of advising assignments and approvals.

For a statement of University policy on graduate advising, see the "Graduate Advising (http://exploredegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext)" section of this bulletin.

Master of Science

At the start of graduate study, each student is assigned a master's program adviser: a member of our faculty who provides guidance in course selection, course planning, and in exploring short and long term academic opportunities and professional pathways. The program adviser serves as the first resource for consultation and advice about a student's academic program. The Guide to Graduate Studies in Aeronautics and Astronautics (https://aa.stanford.edu/sites/default/files/aa_guide_to_graduate_studies_2017-18_0.pdf) provides information and suggested timelines for advising meetings. Usually, the same faculty member serves as program adviser for the duration of master's study. In rare instances, a formal adviser change request may be considered. See the Aero/Astro student services office for additional information on this process.

Ph.D. and Engineer

Faculty research advisers guide students in key areas such as selecting courses, designing and conducting research, developing of teaching pedagogy, navigating policies and degree requirements, and exploring academic opportunities and professional pathways. The Guide to Graduate Studies in Aeronautics and Astronautics (https://aa.stanford.edu/sites/default/files/aa_guide_to_graduate_studies_2017-18_0.pdf) provides information and suggested timelines for advising meetings in the different stages of the doctoral or engineering program. Each individual program, designed by the student in consultation with the research adviser, should represent a strong and cohesive program reflecting the student's major field of interest. When the research adviser is from outside the Aero/Astro department, the student must also identify a program adviser from departmental primary faculty to provide guidance on departmental requirements and opportunities.

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

Chair: Charbel Farhat

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

Associate Professor: Sigrid Close, Marco Pavone

Assistant Professors: Simone D'Amico, Mykel Kochenderfer, Zachary Manchester, Mac Schwager, Debbie Senesky

Adjunct Professors: Andrew Barrows, G. Scott Hubbard, James Spilker

Lecturers: Dan Berkenstock, John Fenwick, Ward Hanson, Abid Kemal, Sherman Lo, Tyler Reid

* 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 236B	Spacecraft Design Laboratory	3-5
AA 236C	Spacecraft Design Laboratory	3-5
AA 241X	Autonomous Aircraft: Design/Build/Fly	3
AA 284B	Propulsion System Design Laboratory	3
AA 284C	Propulsion System Design Laboratory	3
CS 225A	Experimental Robotics	3
CS 402L	Beyond Bits and Atoms - Lab	1-3
EE 233	Analog Communications Design Laboratory	3-4
EE 234	Photonics Laboratory	3
EE 251	High-Frequency Circuit Design Laboratory	3
EE 312	Integrated Circuit Fabrication Laboratory	3-4
ENGR 341	Micro/Nano Systems Design and Fabrication	3-5
MATSCI 160	Nanomaterials Laboratory	4
MATSCI 164	Electronic and Photonic Materials and Devices Laboratory	3-4
MATSCI 171	Energy Materials 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	Engineering Design Entrepreneurship and Innovation: exploring the problem space	4
ME 310B	Engineering Design Entrepreneurship and Innovation: exploring the solution space	4
ME 310C	Engineering Design Entrepreneurship and Innovation: make it REAL	4
ME 324	Precision Engineering	4
ME 348	Experimental Stress Analysis	3
ME 354	Experimental Methods in Fluid Mechanics	4-5
ME 367	Optical Diagnostics and Spectroscopy Laboratory	4

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 3 courses, with at least 6 units from courses numbered above 200.

		Units
AA 212	Advanced Feedback Control Design	3
AA 214B	Numerical Methods for Compressible Flows	3
AA 218	Introduction to Symmetry Analysis	3
AA 222	Engineering Design Optimization	3-4
AA 228	Decision Making under Uncertainty	3-4
AA 229	Advanced Topics in Sequential Decision Making	3-4
AA 242B	Mechanical Vibrations	3
CEE 281	Mechanics and Finite Elements	3
CME 108	Introduction to Scientific Computing	3
CME 302	Numerical Linear Algebra	3
CME 303	Partial Differential Equations of Applied Mathematics	3
CME 306	Numerical Solution of Partial Differential Equations	3
CME 307	Optimization	3
CME 308	Stochastic Methods in Engineering	3
CS 221	Artificial Intelligence: Principles and Techniques	3-4
CS 229	Machine Learning	3-4
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 278	Introduction to Statistical Signal Processing	3
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 171	Fundamental Concepts of Analysis	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
MS&E 201	Dynamic Systems	3-4
MS&E 221	Stochastic Modeling	3
MS&E 311	Optimization	3
MS&E 351	Dynamic Programming and Stochastic Control	3
PHYSICS 211	Continuum Mechanics	3
STATS 110	Statistical Methods in Engineering and the Physical Sciences	5
STATS 116	Theory of Probability	4
STATS 217	Introduction to Stochastic Processes I	3