DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS

In the MIT Department of Aeronautics and Astronautics (AeroAstro), we look ahead by looking up.

At its core, aerospace empowers connection — interpersonal, international, interdisciplinary, and interplanetary. We seek to foster an inclusive community that values technical excellence, and we research and engineer innovative aerospace systems and technologies that have world-changing impact. We educate the next generation of leaders, creative engineers, and entrepreneurs who will push the boundaries of the possible to shape the future of aerospace. We do these things while holding ourselves to the highest standards of integrity and ethical practice. Working together with our partners in public and private sectors, we aim to expand the benefits of aerospace to create a more sustainable environment, strengthen global security, contribute to a prosperous economy, and explore other worlds for the betterment of humankind.

Our vision: to create an aerospace field that is a diverse and inclusive community, pushing the boundaries of the possible to ensure lasting positive impact on our society, economy, and environment.

MIT AeroAstro is a vibrant community of uniquely talented and passionate faculty, students, researchers, administrators, staff, and alumni. As the oldest program of its kind in the United States, we have a rich tradition of technical excellence, academic rigor, and research scholarship that has led to significant contributions to the field of aerospace for more than a century. Today, we continue to push the boundaries of what is possible to shape the future of air and space transportation, exploration, communications, autonomous systems, education, and national security.

Our department's core research capabilities include the following:

- autonomous systems and decision-making: autonomy, guidance, navigation, estimation, control, communications, and networks
- computational science and engineering: computational mathematics and numerical analysis, high-performance computing, model reduction and multifidelity modeling, uncertainty quantification, and optimization approaches to engineering design
- earth and space sciences: environmental impact of aviation, environmental monitoring, sciences of space and atmosphere, space exploration, earth observation, energy, plasma physics, aircraft/atmospheric interaction, and astrodynamics
- human-system collaboration: human-machine systems; interactive robotics for aerospace, medical, and manufacturing; human factors; supervisory control and automation; biomechanics; life support; and astronaut performance
- systems design and engineering: system architecture, safety, optimization, lifecycle costing, in-space manufacturing, and logistics
- transportation and exploration: aviation, space flight, aircraft operations, instrumentation, flight information systems, infrastructure, air traffic control, industry analysis, and space missions
- vehicle design and engineering: fluids, materials, structures, propulsion, energy, durability, turbomachinery, aerodynamics, astrodynamics, thermodynamics, composites, and avionics

In the latest version of the department's strategic plan, we identified seven additional areas of focus, or strategic thrusts, to pursue in tandem with our core capabilities. Strategic thrusts are forward-thinking, high-level initiatives that take into account both the current and future states of the aerospace field.

Our three research thrusts include: integrate autonomy and humans in real-world systems; develop new theory and applications for satellite constellations and swarms; and aerospace environmental mitigation and monitoring. These areas focus on long-term trends rather than specific systems and build upon our strengths while anticipating future changes as the aerospace field continues to evolve. Our two educational goals include: lead development of the College of Computing education programs in autonomy and computational science and engineering; and develop education for digital natives and digital immigrants. Both goals leverage the evolving MIT campus landscape as well as the increasing role of computing across society.

Our culture and leadership goals include: become the leading department at MIT in mentoring, advising, diversity, and inclusion; and make innovation a key component in MIT AeroAstro leadership. These areas respond to the priorities of our students and alumni while addressing pervasive challenges in the aerospace field.

The AeroAstro undergraduate engineering education model motivates students to master a deep working knowledge of the technical fundamentals while providing the skills, knowledge, and attitude necessary to lead in the creation and operation of products, processes, and systems.

The AeroAstro graduate program offers opportunities for deep and fulfilling research and collaboration in our three department teaching sectors (full descriptions below) and across MIT. Our students work side-by-side with some of the brightest and most motivated colleagues in academia and industry.

Our world-renowned faculty roster includes a former space shuttle astronaut, secretary of the Air Force, NASA deputy administrator, Air Force chief scientist, and NASA chief technologist, and numerous National Academy of Engineering members and American Institute of Aeronautics and Astronautics fellows.

Upon leaving MIT, our students go on to become engineering leaders in the corporate world, in government service, and in education. Our alums are entrepreneurs who start their own businesses; they are policy-makers shaping the direction of research and development for years to come; they are educators who bring their passion for learning to new generations; they are researchers doing transformative work at the intersection of engineering, technology and science.

Whether you are passionate about flying machines, pushing the boundaries of human civilization in space, or high-integrity, complex systems that operate in remote, unstructured, and dynamic environments, you belong here (*https://vimeo.com/396965214*).

Sectors of Instruction

The department's faculty are organized into three sectors of instruction. Typically, a faculty member teaches both undergraduate and graduate subjects in one or more of the sectors.

Air Sector

The Air Sector is concerned with advancing a world that is mobile, sustainable, and secure. Achieving these objectives is a multidisciplinary challenge spanning the engineering sciences and systems engineering, as well as fields such as economics and environmental sciences.

Air vehicles and associated systems provide for the safe mobility of people, goods, and services covering urban to global distances. While this mobility allows for greater economic opportunity and connects people and cultures, it is also the most energy-intensive and fastest growing form of transportation. For this reason, much of the research and teaching in the Air Sector is motivated by the need to reduce energy use, emissions, and noise. Examples of research topics include improving aircraft operations, lightweight aerostructures, efficient engines, advanced aerodynamics, and quiet urban air vehicles. Air vehicles and associated systems also provide for critical national security and environmental observation capabilities. As such research and teaching in the sector are also concerned with topics including designing air vehicles for specialized missions, high-speed aerodynamics, advanced materials, and environmental monitoring platforms.

Teaching in the Air Sector includes subjects on aerodynamics, materials and structures, thermodynamics, air-breathing propulsion, plasmas, energy and the environment, aircraft systems engineering, and air transportation systems.

Space Sector

The design, development, and operation of space systems require a depth of expertise in a number of disciplines and the ability to integrate and optimize across all of these stages. The Space Sector faculty represent, in both research and teaching, a broad range of disciplines united under the common goal to develop space technologies and systems for applications ranging from communications and earth observation, to human and robotic exploration. The research footprint of the sector spans the fundamental science and the rigorous engineering required to successfully create and deploy complex space systems. There is also substantive research engagement with industry and government, both in the sponsorship of projects and through collaboration.

The research expertise of the Space Sector faculty includes human and robotic space exploration, space propulsion, orbital communications, distributed satellite systems, enterprise architecture, systems engineering, the integrated design of space-based optical systems, reduced gravity research into human physiology, and software development methods for mission-critical systems. Numerous Space Sector faculty design, build, and fly spaceflight experiments ranging from small satellites to astronaut space missions. Beyond these topics, there is outreach and interest in leveraging our skills into applications that lie outside the traditional boundaries of aerospace.

Academically, the Space Sector organizes subjects relevant to address the learning objectives of students interested in the fundamental and applied aspects of space engineering theories, devices, and processes. This includes courses in astrodynamics, space propulsion, space systems engineering, plasma physics, and humans in space.

Computing Sector

Most aerospace systems critically depend upon, and continue to be transformed by, advances in computing. The missions of many aerospace systems are fundamentally centered on gathering, processing, and transmitting information. Aerospace systems rely on computing-intensive subsystems to provide essential on-board functions, including navigation, autonomous or semi-autonomous guidance and control, cooperative action (including formation flight), and health monitoring systems. Computing technologies are also central to communication satellites, surveillance and reconnaissance aircraft and satellites, planetary rovers, global positioning satellites, transportation systems, and integrated defense systems. Almost every aircraft or satellite is one system within a larger system, and information plays a central role in the interoperability of these subsystems. Equally important is the role that computing plays in the design of aerospace vehicles and systems.

Faculty members in the Computing Sector teach and conduct research on a broad range of areas, including guidance, navigation, control, autonomy and robotics, space and airborne communication networks, air and space traffic management, real-time mission-critical software and hardware, and the computational design, optimization, and simulation of fluid, material, and structural systems. In many instances, the functions provided by aerospace computing technologies are critical to life or mission success. Hence, uncertainty quantification, safety, fault-tolerance, verification, and validation of large-scale engineering systems are significant areas of inquiry.

The Computing Sector has linkages with the other sectors through a common interest in research on autonomous air and space operations, methodologies for large-scale design and simulation, and human-automation interactions in the aerospace context.

Moreover, the sector has strong links to the Department of Electrical Engineering and Computer Science and the Schwarzman College of Computing through joint teaching and collaborative research programs.

Research Laboratories and Activities

The department's faculty, staff, and students are engaged in a wide variety of research projects. Graduate students participate in all the research projects. Projects are also open to undergraduates through the Undergraduate Research Opportunities Program (UROP) (*http://catalog.mit.edu/mit/undergraduate-education/academic-research-options/undergraduate-research-opportunities-program*). Some projects are carried out in an unstructured environment by individual professors working with a few students. Most projects are found within the departmental laboratories and centers (*http://aeroastro.mit.edu/research-labs*). Faculty also undertake research in or collaborate with colleagues in the Computer Science and Artificial Intelligence Laboratory, Draper Laboratory, Laboratory for Information and Decisions Systems, Lincoln Laboratory, Operations Research Center, Research Laboratory of Electronics, and the Program in Science, Technology, and Society, as well as in interdepartmental laboratories and centers listed in the introduction to the School of Engineering (*http://catalog.mit.edu/schools/engineering*).

Undergraduate Study

Undergraduate study in the department leads to the Bachelor of Science in Aerospace Engineering (Course 16), or the Bachelor of Science in Engineering (Course 16-ENG) at the end of four years.

Bachelor of Science in Aerospace Engineering (Course 16)

This program is designed to prepare the graduate for an entry-level position in aerospace and related fields and for further education at the master's level; it is accredited by the Engineering Accreditation Commission of ABET (*http://www.abet.org*). The program includes an opportunity for a year's study abroad.

The formal learning in the program builds a conceptual understanding in the foundational engineering sciences and professional subjects that span the topics critical to aerospace. This learning takes place within the engineering context of conceiving-designing-implementing-operating (CDIO) aerospace and related complex high-performance systems and products. The skills and attributes emphasized go beyond the formal classroom curriculum and include modeling, design, the ability for self-education, computer literacy, communication and teamwork skills, ethics, and—underlying all of these—appreciation for and understanding of interfaces and connectivity between various disciplines. Opportunities for formal and practical (hands-on) learning in these areas are integrated into the departmental subjects through examples set by the faculty, subject content, and the ability for substantive engagement in the CDIO process in the department's Learning Laboratory for Complex Systems.

The curriculum (*http://catalog.mit.edu/degree-charts/aerospace-engineering-course-16*) includes the General Institute Requirements (GIRs) (*http://catalog.mit.edu/mit/undergraduate-education/general-institute-requirements*) and the departmental program, which covers a fall-spring-fall sequence of subjects called Unified Engineering, subjects in dynamics and principles of automatic control, a statistics and probability subject, a subject in computers and programming, professional area subjects, an experimental project laboratory, and a capstone design subject. The program also includes subject 18.03 Differential Equations.

Unified Engineering is offered in sets of two 12-unit subjects in two successive terms. These subjects are taught cooperatively by several faculty members. Their purpose is to introduce new students to the disciplines and methodologies of aerospace engineering at a basic level, with a balanced exposure to analysis, empirical methods, and design. The areas covered include statics, materials, and structures; thermodynamics and propulsion; fluid mechanics; and signals and systems. Several laboratory experiments are performed and a number of systems problems tying the disciplines together and exemplifying the CDIO process are included.

Unified Engineering is usually taken in the sophomore year, 16.09 Statistics and Probability in the spring of the sophomore year, and the subjects 16.07 Dynamics and 16.06 Principles of Automatic Control respectively in the first and second term of the junior year. Subjects 6.100A Introduction to Computer Science Programming in Python and 6.100B Introduction to Computational Thinking and Data Science can be taken at any time, starting in the first year of undergraduate study, but the fall term of the sophomore year is recommended.

The professional area subjects offer a more complete and in-depth treatment of the materials introduced in the core courses. Students must take four subjects (48 units) from among the professional area subjects, with subjects in at least three areas. Students may choose to complete an option in Aerospace Information Technology by taking at least 36 of the 48 required units from a designated group of subjects specified in the degree chart (*http://catalog.mit.edu/degree-charts/aerospace-engineering-course-16*).

Professional area subjects in the four areas of Fluid Mechanics, Materials and Structures, Propulsion, and Computational Tools represent the advanced aerospace disciplines encompassing the design and construction of airframes and engines. Topics within these disciplines include fluid mechanics, aerodynamics, heat and mass transfer, computational mechanics, flight vehicle aerodynamics, solid mechanics, structural design and analysis, the study of engineering materials, structural dynamics, and propulsion and energy conversion from both fluid/thermal (gas turbines and rockets) and electrical devices.

Professional area subjects in the four areas of Estimation and Control, Computer Systems, Communications Systems, and Humans and Automation are in the broad disciplinary area of information, which plays a dominant role in modern aerospace systems. Topics within these disciplines include feedback, control, estimation, control of flight vehicles, software engineering, human systems engineering, aerospace communications and digital systems, fundamentals of robotics, the way in which humans interact with the vehicle through manual control and supervisory control of telerobotic processes (e.g., modern cockpit systems and human-centered automation), and how planning and real-time decisions are made by machines.

The capstone subjects serve to integrate the various disciplines and emphasize the CDIO context of the AeroAstro curriculum. They also satisfy the Communication Requirement (*http://catalog.mit.edu/mit/undergraduate-education/general-institute-requirements/#communicationrequirementtext*) as Communication-Intensive in the Major (CI-M) subjects. The vehicle and system design subjects require student teams to apply their undergraduate knowledge to the design of an aircraft or spacecraft system. One of these two subjects is required and is typically taken in the second term of the junior year or in the senior year. (The completion of at least two professional area or concentration subjects is the prerequisite for capstone subjects 16.82 and 16.83[J].) The rest of the capstone requirement is satisfied by one of four 12–18 unit subjects or subject sequences, as outlined in the Course 16 degree chart; these sequences satisfy the Institute Laboratory Requirement. In 16.821 and 16.831[J] students build and operate the vehicles or systems developed in 16.82 and 16.83[J]. In 16.405[J], students specify and design a small-scale yet complex robot capable of real-time interaction with the natural world.

To take full advantage of the General Institute Requirements (*http://catalog.mit.edu/mit/undergraduate-education/general-institute-requirements*) and required electives, the department recommends the following: 3.091 Introduction to Solid-State Chemistry for the chemistry requirement; the ecology option of the biology requirement; a subject in economics (e.g., 14.01 Principles of Microeconomics) as part of the HASS Requirement; and elective subjects such as 16.00 Introduction to Aerospace and Design, a mathematics subject (e.g., 18.06 Linear Algebra, 18.075 Methods for Scientists and Engineers, or 18.085 Computational Science and Engineering I), and additional professional area subjects in the departmental program. Please consult the department's Academic Programs Office (Room 33-202) for other elective options.

Bachelor of Science in Engineering (Course 16-ENG)

Course 16-ENG is an engineering degree program designed to offer flexibility within the context of aerospace engineering and is a complement to our Course 16 aerospace engineering degree program. The program leads to the Bachelor of Science in Engineering (*http://catalog.mit.edu/degree-charts/engineering-aeronautics-astronautics-course-16-eng*). The 16-ENG degree is accredited by the Engineering Accreditation Commission of ABET (*http://www.abet.org*). Depending on their interests, Course 16-ENG students can develop a deeper level of understanding and skill in a field of engineering that is relevant to multiple disciplinary areas (e.g., robotics and control, computational engineering, mechanics, or engineering management), or a greater understanding and skill in an interdisciplinary area (e.g., energy, environment and sustainability, or transportation). This is accomplished first through a rigorous foundation within core aerospace engineering disciplines, followed by a six-subject concentration tailored to the student's interests, and completed with hands-on aerospace engineering lab and capstone design subjects.

The core of the 16-ENG degree is very similar to the core of the 16 degree. A significant part of the 16-ENG curriculum consists of electives (72 units) chosen by the student to provide in-depth study of a field of the student's choosing. A wide variety of concentrations are possible in which well-selected academic subjects complement a foundation in aerospace engineering and General Institute Requirements. Potential concentrations include aerospace software engineering, autonomous systems, communications, computation and sustainability, computational engineering, embedded systems and networks, energy, engineering management, environment, space exploration, and transportation. AeroAstro faculty have developed specific recommendations in these areas; details are available from the AeroAstro Academic Programs Office (Room 33-202) and on the departmental website. However, concentrations are not limited to those listed above. Students can design and propose technically oriented concentrations that reflect their own needs and those of society.

The student's overall program must contain a total of at least one and one-half years of engineering content (144 units) appropriate to his or her field of study. The required core, lab, and capstone subjects include 102 units of engineering topics. Thus, concentrations must include at least 42 more units of engineering topics. In addition, each concentration must include 12 units of mathematics or science.

The culmination of the 16-ENG degree program is our aerospace laboratory and capstone subject sequences. The capstone subjects serve to integrate the various disciplines and emphasize the CDIO context of our engineering curriculum. They also satisfy the Communication Requirement as CI-M subjects. The laboratory and capstone options in the 16-ENG degree are identical to those in the Course 16 degree program (see the description of this program for additional details on the laboratory and capstone sequences).

Double Major

Students may pursue two majors under the Double Major Program (*http://catalog.mit.edu/mit/undergraduate-education/academic-programs/majors*). In particular, some students may wish to combine a professional education in aeronautics and astronautics with a liberal education that links the development and practice of science and engineering to their social, economic, historical, and cultural contexts. For them, the Department of Aeronautics and Astronautics and the Program in Science, Technology, and Society offer a double major program (*http://catalog.mit.edu/schools/humanities-arts-social-sciences/science-technology-society*) that combines majors in both fields.

Other Undergraduate Opportunities

Undergraduate Research Opportunities Program

To take full advantage of the unique research environment of MIT, undergraduates, including first-year students, are encouraged to become involved in the research activities of the department through the Undergraduate Research Opportunities Program (UROP) (*http://catalog.mit.edu/mit/undergraduate-education/academic-research-options/undergraduate-research-opportunities-program*). Many of the faculty actively seek undergraduates to become a part of their research teams. Visit research centers' websites to learn more about available research opportunities. For more information, contact Marie Stuppard (*mas@mit.edu*) in the AeroAstro Academic Programs Office, Room 33-202, 617-253-2279.

Advanced Undergraduate Research Opportunities Program

Juniors and seniors in Course 16 may participate in an advanced undergraduate research program, SuperUROP (*https://superurop.mit.edu*), which was launched as a collaborative effort between the Department of Electrical Engineering and Computer Science (EECS) and the Undergraduate Research Opportunities Program (UROP) (*http://catalog.mit.edu/mit/undergraduate-education/academic-research-options/undergraduate-research-opportunities-program*). For more information, contact Joyce Light (*jlight@mit.edu*), AeroAstro Headquarters, (617) 253-8408, or visit the website.

Undergraduate Practice Opportunities Program

The Undergraduate Practice Opportunities Program (UPOP) (*http://upop.mit.edu*) is a program sponsored by the School of Engineering and administered through the Office of the Dean of Engineering. Open to all School of Engineering sophomores, this program provides students an opportunity to develop engineering and business skills while working in industry, nonprofit organizations, or government agencies. UPOP consists of three parts: an intensive one-week engineering practice workshop offered during IAP, 10–12 weeks of summer employment, and a written report and oral presentation in the fall. Students are paid during their periods of residence at the participating companies and also receive academic credit in the program. There are no obligations on either side regarding further employment.

Summer Internship Program

The Summer Internship Program provides undergraduates in the department the opportunity to apply the skills they are learning in the classroom in paid professional positions with employers throughout the United States. During recruitment periods, representatives from firms in the aerospace industry will visit the department and offer information sessions and technical talks specifically geared to Course 16 students. Often, student résumés are collected and interviews conducted for summer internships as well as long-term employment. Employers wishing to offer an information session or seeking candidates for openings in their company may contact Marie Stuppard (*mas@mit.edu*), 617-253-2279.

Students are also encouraged to take advantage of other career resources available through the MIT Career Advising and Professional Development Office (CAPD) or through the MIT International Science and Technology Initiatives (MISTI). AeroAstro students can also apply through MISTI to participate in the Imperial College London-MIT Summer Research Exchange Program. CAPD coordinates several annual career fairs and offers a number of workshops, including workshops on how to navigate a career fair as well as critique on résumé writing and cover letters.

Year Abroad Program

Through the MIT International Science and Technology Initiatives (MISTI) students can apply to study abroad in the junior year. In particular, the department participates in an academic exchange with the University of Pretoria, South Africa, and with Imperial College, United Kingdom. In any year-abroad experience, students enroll in the academic cycle of the host institution and take courses in the local language. They plan their course of study in advance; this includes securing credit commitments in exchange for satisfactory performance abroad. A grade average of B or better is normally required of participating AeroAstro students.

For more information, contact Marie Stuppard (*mas@mit.edu*). Also refer to Undergraduate Education (*http://catalog.mit.edu/mit/undergraduate-education/academic-research-options/other-universities/#studyabroadtext*) for more details on the exchange programs.

Massachusetts Space Grant Consortium

MIT leads the NASA-supported Massachusetts Space Grant Consortium (MASGC) in partnership with Boston University, Bridgewater State University, Harvard University, Framingham State University, Northeastern University, Mount Holyoke College, Olin College of Engineering, Tufts University, University of Massachusetts (Amherst, Dartmouth, and Lowell), Wellesley College, Williams College, Worcester State University, Worcester Polytechnic Institute, Boston Museum of Science, the Christa McAuliffe Center, the Maria Mitchell Observatory, and the Five College Astronomy Department. The program has the principal objective of stimulating and supporting student interest, especially that of women and underrepresented minorities, in space engineering and science at all educational levels, primary through graduate. The program offers a number of activities to this end, including support of undergraduate and graduate students to carry out research projects at their home institutions, support for student travel to present conference papers, and summer workshops for pre-college teachers. The program coordinates and supports the placement of students in summer positions at NASA centers for summer academies and research opportunities. MASGC also participates in a number of public outreach and education policy initiatives in Massachusetts to increase public awareness and inform legislators about the importance of science, technology, engineering, and math education in the state.

For more information, contact Helen Halaris, Massachusetts Space Grant Consortium program coordinator, 617-258-5546.

Inquiries

For additional information concerning academic and undergraduate research programs in the department, suggested four-year undergraduate programs, and interdisciplinary programs, contact Marie Stuppard (*mas@mit.edu*), 617-253-2279.

Graduate Study

Graduate study in the Department of Aeronautics and Astronautics includes graduate-level subjects in Course 16 and others at MIT, and research work culminating in a thesis. Degrees are awarded at the master's and doctoral levels. The range of subject matter is described under Sectors of Instruction (p. 3). Departmental research centers' websites offer information on research interests. Detailed information may be obtained from the Department Academic Programs Office or from individual faculty members.

Admission Requirements

In addition to the general requirements for admission to the Graduate School, applicants to the Department of Aeronautics and Astronautics should have a strong undergraduate background in the fundamentals of engineering and mathematics as described in the Undergraduate Study section.

International students whose language of instruction has not been English in their primary and secondary schooling must pass the Test of English as a Foreign Language (TOEFL) with a minimum score of 100 out of 120, or the International English Language Testing System (IELTS) with a minimum score of 7 out of 9 to be considered for admission to this department. TOEFL waivers are not accepted. No other exams fulfill this requirement.

New graduate students are normally admitted as candidates for the degree of Master of Science. Admission to the doctoral program is offered through a two-step process to students who have been accepted for graduate study: 1) passing performance on a course-based field evaluation (FE); 2) a faculty review consisting of an examination of the student's achievements, including an assessment of the quality of past research work and evaluation of the student's academic record in light of the performance on the FE.

The Department of Aeronautics and Astronautics requires that all entering graduate students demonstrate satisfactory English writing ability by taking the Graduate Writing Examination offered by the Comparative Media Studies/Writing Program. The examination is usually administered in July, and all entering candidates must take the examination electronically at that time. Students with deficient skills must complete remedial training specifically designed to fulfill their individual needs. The remedial training prescribed by the CMS/Writing Program must be completed by the end of the first Independent Activities Period following initial registration in the graduate program or, in some cases, in the spring term of the first year of the program.

All incoming graduate students whose native language is not English are required to take the Department of Humanities English Evaluation Test (EET) offered at the start of each regular term. This test is a proficiency examination designed to indicate areas where deficiencies may still exist and recommend specific language subjects available at MIT.

Degree Requirements

All entering students are provided with additional information concerning degree requirements, including lists of recommended subjects, thesis advising, research and teaching assistantships, and course and thesis registration.

Degrees Offered

Master of Science in Aeronautics and Astronautics

The Master of Science (SM) degree is a one- to two-year graduate program with a beginning research or design experience represented by the SM thesis. This degree prepares the graduate for an advanced position in the aerospace field, and provides a solid foundation for future doctoral study.

The general requirements for the Master of Science degree (*http://catalog.mit.edu/mit/graduate-education/general-degree-requirements*) are cited in the section on General Degree Requirements for graduate students. The specific departmental requirements include at least 66 graduate subject units, typically in subjects relevant to the candidate's area of technical interest. Of the 66 units, at least 21 units must be in departmental subjects. To be credited toward the degree, graduate subjects must carry a grade of B or better. In addition, a 24-unit thesis is required beyond the 66 units of coursework. Full-time students normally must be in residence one full academic year. Special students admitted to the SM program in this department must enroll in and satisfactorily complete at least two graduate subjects while in residence (i.e., after being admitted as a degree candidate) regardless of the number of subjects completed before admission to the program. Students holding research assistantships typically require a longer period of residence.

In addition, the department's SM program requires one graduate-level mathematics subject. The requirement is satisfied only by graduate-level subjects on the list approved by the department graduate committee. The specific choice of math subjects is arranged individually by each student in consultation with their faculty advisor.

Doctor of Philosophy and Doctor of Science in Aeronautics and Astronautics Fields

AeroAstro offers the doctor of philosophy and doctor of science (PhD and ScD) degrees in aeronautics and astronautics and in other fields of specialization (*http://catalog.mit.edu/schools/engineering/#degreesandprogramstext*). The doctoral program emphasizes in-depth study, with a significant research project in a focused area. The admission process for the department's doctoral program is described previously in this section under Admission Requirements. The PhD or ScD degree is awarded after completion of an individual course of study, submission and defense of a thesis proposal, and submission and defense of a thesis embodying an original research contribution.

All doctoral students must fulfill MIT's General Degree Requirements (*http://catalog.mit.edu/mit/graduate-education/general-degree-requirements*). The general program requirements for the PhD and ScD degrees in aeronautics and astronautics (*http://catalog.mit.edu/degree-charts/phd-aeronautics-astronautics*) are outlined in this degree chart. Additional information (*http://mit.edu/aeroastro/academics/grad/forms/New_Doctoral_Booklet.pdf*) is available on the department website. After successful admission to the doctoral program, the doctoral candidate selects a field of study and research in consultation with the thesis supervisor and forms a doctoral thesis committee, which assists in the formulation of the candidate's research and study programs and monitors their progress. Demonstrated competence for original research at the forefront of aerospace engineering is the final and main criterion for granting the doctoral degree. The candidate's thesis serves in part to demonstrate such competence and, upon completion, is defended orally in a presentation to the faculty of the department, who may then recommend that the degree be awarded.

Interdisciplinary Programs

The department participates in several interdisciplinary fields at the graduate level, which are of special importance for aeronautics and astronautics in both research and the curriculum.

Aeronautics, Astronautics, and Statistics

The Interdisciplinary Doctoral Program in Statistics provides training in statistics, including classical statistics and probability as well as computation and data analysis, to students who wish to integrate these valuable skills into their primary academic program. The program is administered jointly by the departments of Aeronautics and Astronautics, Economics, Mathematics, Mechanical Engineering, Physics, and Political Science, and the Statistics and Data Science Center within the Institute for Data, Systems, and Society. It is open to current doctoral students in participating departments. For more information, including department-specific requirements, see the full program description (*http://catalog.mit.edu/interdisciplinary/graduate-programs/phd-statistics*) under Interdisciplinary Graduate Programs.

Air Transportation

For students interested in a career in flight transportation, a program is available that incorporates a broader graduate education in disciplines such as economics, management, and operations research than is normally pursued by candidates for degrees in engineering. Graduate research emphasizes one of the four areas of flight transportation: airport planning and design, air traffic control, air transportation systems analysis, and airline economics and management, with subjects selected appropriately from those available in the departments of Aeronautics and Astronautics, Civil and Environmental Engineering, Economics, and the interdepartmental Master of Science in Transportation (MST) program. Doctoral students may pursue a PhD with specialization in air transportation in the Department of Aeronautics and Astronautics or in the interdepartmental PhD program in transportation or in the PhD program of the Operations Research Center (see the section on Graduate Programs in Operations Research under Research and Study).

Biomedical Engineering

The department offers opportunities for students interested in biomedical instrumentation and physiological control systems where the disciplines involved in aeronautics and astronautics are applied to biology and medicine. Graduate study combining aerospace engineering with biomedical engineering may be pursued through the Bioastronautics program offered as part of the Medical Engineering and Medical Physics PhD program in the Institute for Medical Engineering and Science (IMES) via the Harvard-MIT Program in Health Sciences and Technology (HST).

Students wishing to pursue a degree through HST must apply to that graduate program. At the master's degree level, students in the department may specialize in biomedical engineering research, emphasizing space life sciences and life support, instrumentation and control, or in human factors engineering and in instrumentation and statistics. Most biomedical engineering research in the Department of Aeronautics and Astronautics is conducted in the Man Vehicle Laboratory.

Computational Science and Engineering

The Master of Science in Computational Science and Engineering (CSE SM) (*https://cse.mit.edu/programs/sm*) is an interdisciplinary program for students interested in the development, analysis, and application of computational approaches to science and engineering. The curriculum is designed with a common core serving all science and engineering disciplines and an elective component focusing on specific disciplinary topics. Students may pursue the CSE SM as a standalone degree or as leading to the CSE PhD program described below.

The Interdisciplinary Doctoral Program in Computational Science and Engineering (CSE PhD) (*https://cse.mit.edu/programs/phd*) allows students to specialize at the doctoral level in a computation-related field of their choice through focused coursework and a thesis through one of the participating host departments in the School of Engineering or School of Science. The program is administered jointly by the Center for Computational Science and Engineering (CCSE) and the host departments; the emphasis of thesis research activities is the development of new computational methods and/or the innovative application of computational techniques to important problems in engineering and science.

For more information, see the program descriptions under Interdisciplinary Graduate Programs.

Joint Program with the Woods Hole Oceanographic Institution

The Joint Program with the Woods Hole Oceanographic Institution (WHOI) (*http://mit.whoi.edu*) is intended for students whose primary career objective is oceanography or oceanographic engineering. Students divide their academic and research efforts between the campuses of MIT and WHOI. Joint Program students are assigned an MIT faculty member as academic advisor; thesis research may be supervised by MIT or WHOI faculty. While in residence at MIT, students follow a program similar to that of other students in their home department. The program is described in more detail (*http://catalog.mit.edu/interdisciplinary/graduate-programs/joint-program-woods-hole-oceanographic-institution*) under Interdisciplinary Graduate Programs.

Leaders for Global Operations

The 24-month Leaders for Global Operations (LGO) (*http://catalog.mit.edu/interdisciplinary/graduate-programs/leaders-global-operations*) program combines graduate degrees in engineering and management for those with previous postgraduate work experience and strong undergraduate degrees in a technical field. During the two-year program, students complete a six-month internship at one of LGO's partner companies, where they conduct research that forms the basis of a dual-degree thesis. Students finish the program with two MIT degrees: an MBA (or SM in management) and an SM from one of seven engineering programs, some of which have optional or required LGO tracks. After graduation, alumni lead strategic initiatives in high-tech, operations, and manufacturing companies.

System Design and Management

The System Design and Management (SDM) (*http://sdm.mit.edu*) program is a partnership among industry, government, and the university for educating technically grounded leaders of 21st-century enterprises. Jointly sponsored by the School of Engineering and the Sloan School of Management, it is MIT's first degree program to be offered with a distance learning option in addition to a full-time in-residence option.

Technology and Policy

The Master of Science in Technology and Policy is an engineering research degree with a strong focus on the role of technology in policy analysis and formulation. The Technology and Policy Program (TPP) (*http://tpp.mit.edu*) curriculum provides a solid grounding in technology and policy by combining advanced subjects in the student's chosen technical field with courses in economics, politics, quantitative methods, and social science. Many students combine TPP's curriculum with complementary subjects to obtain dual degrees in TPP and either a specialized branch of engineering or an applied social science such as political science or urban studies and planning. See the program description (*http://catalog.mit.edu/schools/mit-schwarzman-college-computing/data-systems-society*) under the Institute for Data, Systems, and Society.

Financial Support

Financial assistance for graduate study may be in the form of fellowships or research or teaching assistantships. Both fellowship students and research assistants work with a faculty supervisor on a specific research assignment of interest, which generally leads to a thesis. Teaching assistants are appointed to work on specific subjects of instruction.

A special relationship exists between the department and the Charles Stark Draper Laboratory. This relationship affords fellowship opportunities for SM and PhD candidates who perform their research as an integral part of ongoing projects at Draper. Faculty from the department maintain close working relationships with researchers at Draper, and thesis research at Draper performed by Draper fellows can be structured to fulfill MIT residency requirements. Further information on Draper can be found in the section on Research and Study.

Inquiries

For additional information concerning admissions, financial aid and assistantship, and academic, research, and interdisciplinary programs in the department, contact the AeroAstro Student Services Office, Room 33-202, 617-253-0043.

Faculty and Teaching Staff

Steven Barrett, PhD
H. N. Slater Professor in Aeronautics and Astronautics
Head, Department of Aeronautics and Astronautics

Professors

Hamsa Balakrishnan, PhD
William E. Leonhard (1940) Professor
Professor of Aeronautics and Astronautics
Member, Institute for Data, Systems, and Society
(On leave)

Kerri Cahoy, PhD
Professor of Aeronautics and Astronautics
Professor of Earth, Atmospheric and Planetary Sciences

Edward F. Crawley, ScD
Ford Foundation Professor of Engineering
Professor of Aeronautics and Astronautics

David L. Darmofal, PhD
Jerome C. Hunsaker Professor
Professor of Aeronautics and Astronautics

Olivier L. de Weck, PhD
Professor of Aeronautics and Astronautics

Mark Drela, PhD
Terry J. Kohler Professor
Professor of Aeronautics and Astronautics
(On leave)

Edward M. Greitzer, PhD
H. N. Slater Professor in Aeronautics and Astronautics

Steven Hall, ScD
Professor of Aeronautics and Astronautics

R. John Hansman Jr, PhD
T. Wilson (1953) Professor in Aeronautics

Wesley L. Harris, PhD
Charles Stark Draper Professor of Aeronautics and Astronautics

Daniel E. Hastings, PhD
Cecil and Ida Green Professor in Education
Professor of Aeronautics and Astronautics
Interim Institute Community and Equity Officer
Interim Associate Provost for Faculty Advancement
Member, Institute for Data, Systems, and Society

Jonathan P. How, PhD
Richard Cockburn Maclaurin Professor in Aeronautics and Astronautics

Sertac Karaman, PhD
Professor of Aeronautics and Astronautics
Member, Institute for Data, Systems, and Society

Nancy G. Leveson, PhD
Jerome C. Hunsaker Professor in Aeronautics and Astronautics
Professor of Aeronautics and Astronautics

Paulo C. Lozano, PhD
M. Alemán-Velasco Professor
Professor of Aeronautics and Astronautics

Youssef M. Marzouk, PhD
Professor of Aeronautics and Astronautics
Member, Institute for Data, Systems, and Society

David W. Miller, ScD
Jerome C. Hunsaker Professor
Professor of Aeronautics and Astronautics

David A. Mindell, PhD
Frances and David Dibner Professor in the History of Engineering and Manufacturing
Professor of Aeronautics and Astronautics

Eytan H. Modiano, PhD
Richard Cockburn Maclaurin Professor in Aeronautics and Astronautics
Professor of Aeronautics and Astronautics
Member, Institute for Data, Systems, and Society
(On leave)

Dava Newman, PhD
Apollo Professor of Astronautics and Engineering Systems
Member, Institute for Data, Systems, and Society
Affiliate Faculty, Institute for Medical Engineering and Science
Member, Health Sciences and Technology Faculty

Jaime Peraire, PhD
H. N. Slater Professor in Aeronautics and Astronautics
Member, Institute for Data, Systems, and Society

Raúl Radovitzky, PhD
Jerome C. Hunsaker Professor in Aeronautics and Astronautics
Professor of Aeronautics and Astronautics

Nicholas Roy, PhD
Professor of Aeronautics and Astronautics
(On leave)

Sara Seager, PhD
Class of 1941 Professor of Planetary Sciences
Professor of Physics
Professor of Aeronautics and Astronautics
(On leave, spring)

Julie A. Shah, PhD
H. N. Slater Professor in Aeronautics and Astronautics
Professor of Aeronautics and Astronautics

Zoltan S. Spakovszky, PhD
T. A Wilson Professor in Aeronautics and Astronautics
Professor of Aeronautics and Astronautics

Russell L. Tedrake, PhD
Toyota Professor
Professor of Computer Science and Engineering
Professor of Aeronautics and Astronautics
Professor of Mechanical Engineering

Ian A. Waitz, PhD
Jerome C. Hunsaker Professor
Professor of Aeronautics and Astronautics
Vice Chancellor for Undergraduate and Graduate Education

Brian L. Wardle, PhD
Professor of Aeronautics and Astronautics

Brian C. Williams, PhD
Professor of Aeronautics and Astronautics

Moe Z. Win, PhD
Professor of Aeronautics and Astronautics
Member, Institute for Data, Systems, and Society

Associate Professors
Luca Carlone, PhD
Boeing Professor
Associate Professor of Aeronautics and Astronautics
Member, Institute for Data, Systems, and Society

Richard Linares, PhD
Rockwell International Career Development Professor
Associate Professor of Aeronautics and Astronautics

Qiqi Wang, PhD
Associate Professor of Aeronautics and Astronautics

Assistant Professors
Zachary Cordero, PhD
Esther and Harold E. Edgerton Professor
Assistant Professor of Aeronautics and Astronautics
(On leave, spring)

Chuchu Fan, PhD
Leonardo Professor
Assistant Professor of Aeronautics and Astronautics

Carmen Guerra García, PhD
Charles Stark Draper Professor
Assistant Professor of Aeronautics and Astronautics

Adrián Lozano-Durán, PhD
Boeing Professor
Assistant Professor of Aeronautics and Astronautics

Lonnie Petersen, MD, PhD
Charles Stark Draper Professor
Assistant Professor of Aeronautics and Astronautics
Core Faculty, Institute for Medical Engineering and Science

Professors of the Practice
Jeffrey A. Hoffman, PhD
Professor of the Practice of Aeronautics and Astronautics

Robert Liebeck, PhD
Professor of the Practice of Aerospace Engineering

Visiting Professors
Moriba Jah, PhD
Martin Luther King, Jr. Visiting Professor of Aeronautics and Astronautics

Sonya T. Smith, PhD
Martin Luther King, Jr. Visiting Professor of Aeronautics and Astronautics

Senior Lecturers
Charles Oman, PhD
Senior Lecturer in Aeronautics and Astronautics

Rudrapatna V. Ramnath, PhD
Senior Lecturer in Aeronautics and Astronautics

Jayant Sabnis, PhD
Senior Lecturer in Aeronautics and Astronautics

Lecturers
Javier deLuis, PhD
Lecturer of Aeronautics and Astronautics

Brian Nield, PhD
Lecturer of Aeronautics and Astronautics

Technical Instructors
Todd Billings
Senior Technical Instructor of Aeronautics and Astronautics

David Robertson, BEng
Senior Technical Instructor of Aeronautics and Astronautics

Research Staff

Senior Research Engineers
Choon S. Tan, PhD
Senior Research Engineer of Aeronautics and Astronautics

Principal Research Scientists
Rebecca A. Masterson, PhD
Principal Research Scientist of Aeronautics and Astronautics

Ngoc Cuong Nguyen, PhD
Principal Research Scientist of Aeronautics and Astronautics

Raymond L. Speth, PhD
Principal Research Scientist of Aeronautics and Astronautics

Research Engineers
Steven R. Allmaras, PhD
Research Engineer of Aeronautics and Astronautics

Matthew Boyd, PhD
Research Engineer of Aeronautics and Astronautics

Marshall C. Galbraith, PhD
Research Engineer of Aeronautics and Astronautics

David Gonzalez Cuadrado, PhD
Research Engineer of Aeronautics and Astronautics

John Thomas, PhD
Research Engineer of Aeronautics and Astronautics

Research Scientists
Luiz Henrique Acauan, PhD
Research Scientist of Aeronautics and Astronautics

Florian Allroggen, PhD
Research Scientist of Aeronautics and Astronautics

Andrew Menching Liu, PhD
Research Scientist of Aeronautics and Astronautics

Leonid Pogorelyuk, PhD
Research Scientist of Aeronautics and Astronautics

Paul Serra, PhD
Research Scientist of Aeronautics and Astronautics

Afreen Siddiqi, PhD
Research Scientist of Aeronautics and Astronautics

Peng Mun Siew, PhD
Research Scientist of Aeronautics and Astronautics

Rajat Rajendrad Talak, PhD
Research Scientist of Aeronautics and Astronautics

Parker Vascik, PhD
Research Scientist of Aeronautics and Astronautics

Ferran Vidal-Codina, PhD
Research Scientist of Aeronautics and Astronautics

Research Specialists
Matthew Pearlson, MS
Research Specialist of Aeronautics and Astronautics

Professors Emeriti

John J. Deyst Jr, ScD
Professor Emeritus of Aeronautics and Astronautics

Steven Dubowsky, PhD
Professor Emeritus of Mechanical Engineering
Professor Emeritus of Aeronautics and Astronautics

Alan H. Epstein, PhD
Richard Cockburn Maclaurin Professor Emeritus
Professor Emeritus of Aeronautics and Astronautics

Walter M. Hollister, ScD
Professor Emeritus of Aeronautics and Astronautics

Manuel Martínez-Sánchez, PhD
Professor Emeritus of Aeronautics and Astronautics

Earll M. Murman, PhD
Ford Professor of Engineering Emeritus
Professor Emeritus of Aeronautics and Astronautics

Amedeo R. Odoni, PhD
T. Wilson (1953) Professor Emeritus
Professor Emeritus of Aeronautics and Astronautics
Professor Emeritus of Civil and Environmental Engineering

Thomas B. Sheridan, ScD
Professor Emeritus of Engineering and Applied Psychology
Professor Emeritus of Aeronautics and Astronautics

Robert Simpson, PhD
Professor Emeritus of Aeronautics and Astronautics

Sheila E. Widnall, ScD
Institute Professor Emerita
Professor Emerita of Aeronautics and Astronautics

16.00 Introduction to Aerospace and Design
Prereq: None
U (Spring)
Not offered regularly; consult department
2-2-2 units

Highlights fundamental concepts and practices of aerospace engineering through lectures on aeronautics, astronautics, and the principles of project design and execution. Provides training in the use of Course 16 workshop tools and 3-D printers, and in computational tools, such as CAD. Students engage in teambuilding during an immersive, semester-long project in which teams design, build, and fly radio-controlled lighter-than-air (LTA) vehicles. Emphasizes connections between theory and practice and introduces students to fundamental systems engineering practices, such as oral and written design reviews, performance estimation, and post-flight performance analysis.
J. A. Hoffman, R. J. Hansman

16.001 Unified Engineering: Materials and Structures
Prereq: Calculus II (GIR) and Physics I (GIR); *Coreq: 16.002 and 18.03*
U (Fall)
5-1-6 units. REST

Presents fundamental principles and methods of materials and structures for aerospace engineering, and engineering analysis and design concepts applied to aerospace systems. Topics include statics; analysis of trusses; analysis of statically determinate and indeterminate systems; stress-strain behavior of materials; analysis of beam bending, buckling, and torsion; material and structural failure, including plasticity, fracture, fatigue, and their physical causes. Experiential lab and aerospace system projects provide additional aerospace context.
R. Radovitzky, D. L. Darmofal

16.002 Unified Engineering: Signals and Systems
Prereq: Calculus II (GIR); *Coreq: Physics II (GIR), 16.001, and (18.03 or 18.032)*
U (Fall)
5-1-6 units

Presents fundamental principles and methods of signals and systems for aerospace engineering, and engineering analysis and design concepts applied to aerospace systems. Topics include linear and time invariant systems; convolution; Fourier and Laplace transform analysis in continuous and discrete time; modulation, filtering, and sampling; and an introduction to feedback control. Experiential lab and system projects provide additional aerospace context. Labs, projects, and assignments involve the use of software such as MATLAB and/or Python.
J. P. How

16.003 Unified Engineering: Fluid Dynamics
Prereq: Calculus II (GIR), Physics II (GIR), and (18.03 or 18.032); *Coreq: 16.004*
U (Spring)
5-1-6 units

Presents fundamental principles and methods of fluid dynamics for aerospace engineering, and engineering analysis and design concepts applied to aerospace systems. Topics include aircraft and aerodynamic performance, conservation laws for fluid flows, quasi-one-dimensional compressible flows, shock and expansion waves, streamline curvature, potential flow modeling, an introduction to three-dimensional wings and induced drag. Experiential lab and aerospace system projects provide additional aerospace context.
D. L. Darmofal

16.004 Unified Engineering: Thermodynamics and Propulsion
Prereq: Calculus II (GIR), Physics II (GIR), and (18.03 or 18.032); *Coreq: Chemistry (GIR) and 16.003*
U (Spring)
5-1-6 units

Presents fundamental principles and methods of thermodynamics for aerospace engineering, and engineering analysis and design concepts applied to aerospace systems. Topics include thermodynamic state of a system, forms of energy, work, heat, the first law of thermodynamics, heat engines, reversible and irreversible processes, entropy and the second law of thermodynamics, ideal and non-ideal cycle analysis, two-phase systems, and introductions to thermochemistry and heat transfer. Experiential lab and aerospace system projects provide additional aerospace context.
Z. S. Spakovszky, D. L. Darmofal

Core Undergraduate Subjects

16.06 Principles of Automatic Control
Prereq: 16.002
U (Spring)
3-1-8 units

Introduction to design of feedback control systems. Properties and advantages of feedback systems. Time-domain and frequency-domain performance measures. Stability and degree of stability. Root locus method, Nyquist criterion, frequency-domain design, and some state space methods. Strong emphasis on the synthesis of classical controllers. Application to a variety of aerospace systems. Hands-on experiments using simple robotic systems.
S. R. Hall

16.07 Dynamics
Prereq: (16.001 or 16.002) and (16.003 or 16.004)
U (Fall)
4-0-8 units

Fundamentals of Newtonian mechanics. Kinematics, particle dynamics, motion relative to accelerated reference frames, work and energy, impulse and momentum, systems of particles and rigid body dynamics. Applications to aerospace engineering including introductory topics in orbital mechanics, flight dynamics, inertial navigation and attitude dynamics.
R. Linares

16.09 Statistics and Probability
Prereq: Calculus II (GIR)
U (Spring)
4-0-8 units

Introduction to statistics and probability with applications to aerospace engineering. Covers essential topics, such as sample space, discrete and continuous random variables, probability distributions, joint and conditional distributions, expectation, transformation of random variables, limit theorems, estimation theory, hypothesis testing, confidence intervals, statistical tests, and regression.
Y. M. Marzouk

Mechanics and Physics of Fluids

16.100 Aerodynamics
Prereq: 16.003 and 16.004
U (Fall)
3-1-8 units

Extends fluid mechanic concepts from Unified Engineering to aerodynamic performance of wings and bodies in sub/supersonic regimes. Addresses themes such as subsonic potential flows, including source/vortex panel methods; viscous flows, including laminar and turbulent boundary layers; aerodynamics of airfoils and wings, including thin airfoil theory, lifting line theory, and panel method/interacting boundary layer methods; and supersonic and hypersonic airfoil theory. Material may vary from year to year depending upon focus of design problem.
D. L. Darmofal

16.101 Topics in Fluids
Prereq: Permission of department
U (IAP; partial term)
Units arranged
Can be repeated for credit.

Provides credit for work on undergraduate-level material in fluids outside of regularly scheduled subjects. Intended for transfer credit and study abroad. Credit may be used to satisfy specific degree requirements in the Course 16 and Course 16-ENG programs. Requires prior approval. Consult department.
Y. M. Marzouk

16.110 Flight Vehicle Aerodynamics
Prereq: 16.100 or permission of instructor
G (Fall)
3-1-8 units

Aerodynamic flow modeling and representation techniques. Potential farfield approximations. Airfoil and lifting-surface theory. Laminar and turbulent boundary layers and their effects on aerodynamic flows. Nearfield and farfield force analysis. Subsonic, transonic, and supersonic compressible flows. Experimental methods and measurement techniques. Aerodynamic models for flight dynamics.
M. Drela

16.120 Compressible Internal Flow
Prereq: 2.25 or permission of instructor
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Spring)
3-0-9 units

Internal compressible flow with applications in propulsion and fluid systems. Control volume analysis of compressible flow devices. Compressible channel flow and extensions, including effects of shock waves, momentum, energy and mass addition, swirl, and flow non-uniformity on Mach numbers, flow regimes, and choking.
E. M. Greitzer

16.122 Aerothermodynamics
Prereq: 2.25, 18.085, or permission of instructor
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Spring)
3-0-9 units

Analysis of external inviscid and viscous hypersonic flows over thin airfoils, lifting bodies of revolution, wedges, cones, and blunt nose bodies. Analyses formulated using singular perturbation and multiple scale methods. Hypersonic equivalence principle. Hypersonic similarity. Newtonian approximation. Curved, detached shock waves. Crocco theorem. Entropy layers. Shock layers. Blast waves. Hypersonic boundary layers.
W. L. Harris

16.13 Aerodynamics of Viscous Fluids
Prereq: 16.100, 16.110, or permission of instructor
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Spring)
3-0-9 units

Boundary layers as rational approximations to the solutions of exact equations of fluid motion. Physical parameters influencing laminar and turbulent aerodynamic flows and transition. Effects of compressibility, heat conduction, and frame rotation. Influence of boundary layers on outer potential flow and associated stall and drag mechanisms. Numerical solution techniques and exercises.
M. Drela

16.18 Fundamentals of Turbulence (16.950)
Prereq: 2.25 or permission of instructor
G (Fall)
3-0-9 units

Introduces the fundamentals of turbulent flows, i.e., the chaotic motion of gases and liquids, along with the mathematical tools for turbulence research. Topics range from the classic viewpoint of turbulence to the theories developed in the last decade. Combines theory, data science, and numerical simulations, and is designed for a wide audience in the areas of aerospace, mechanical engineering, geophysics, and astrophysics.
A. Lozano-Duran

Materials and Structures

16.20 Structural Mechanics
Prereq: 16.001
U (Spring)
5-0-7 units

Applies solid mechanics to analysis of high-technology structures. Structural design considerations. Review of three-dimensional elasticity theory; stress, strain, anisotropic materials, and heating effects. Two-dimensional plane stress and plane strain problems. Torsion theory for arbitrary sections. Bending of unsymmetrical section and mixed material beams. Bending, shear, and torsion of thin-wall shell beams. Buckling of columns and stability phenomena. Introduction to structural dynamics. Exercises in the design of general and aerospace structures.
B. Wardle

16.201 Topics in Materials and Structures
Prereq: Permission of department
U (Fall, IAP, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Provides credit for undergraduate-level work in materials and structures outside of regularly scheduled subjects. Intended for transfer credit and study abroad. Credit may be used to satisfy specific degree requirements in the Course 16 program. Requires prior approval. Consult M. A. Stuppard.
J. P. How

16.202 Manufacturing with Advanced Composite Materials
Prereq: None
U (Fall)
Not offered regularly; consult department
1-3-2 units

Introduces the methods used to manufacture parts made of advanced composite materials with work in the Technology Laboratory for Advanced Composites. Students gain hands-on experience by fabricating, machining, instrumenting, and testing graphite/epoxy specimens. Students also design, build, and test a composite structure as part of a design contest. Lectures supplement laboratory sessions with background information on the nature of composites, curing, composite machining, secondary bonding, and the testing of composites.
P. A. Lagace

16.221[J] Structural Dynamics
Same subject as 1.581[J], 2.060[J]
Subject meets with 1.058
Prereq: 18.03 or permission of instructor
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Fall)
3-1-8 units

Examines response of structures to dynamic excitation: free vibration, harmonic loads, pulses and earthquakes. Covers systems of single- and multiple-degree-of-freedom, up to the continuum limit, by exact and approximate methods. Includes applications to buildings, ships, aircraft and offshore structures. Students taking graduate version complete additional assignments.
T. Cohen

16.223[J] Mechanics of Heterogeneous Materials
Same subject as 2.076[J]
Prereq: 2.002, 3.032, 16.20, or permission of instructor
Acad Year 2023-2024: G (Fall)
Acad Year 2024-2025: Not offered
3-0-9 units

Mechanical behavior of heterogeneous materials such as thin-film microelectro- mechanical systems (MEMS) materials and advanced filamentary composites, with particular emphasis on laminated structural configurations. Anisotropic and crystallographic elasticity formulations. Structure, properties and mechanics of constituents such as films, substrates, active materials, fibers, and matrices including nano- and micro-scale constituents. Effective properties from constituent properties. Classical laminated plate theory for modeling structural behavior including extrinsic and intrinsic strains and stresses such as environmental effects. Introduction to buckling of plates and nonlinear (deformations) plate theory. Other issues in modeling heterogeneous materials such as fracture/failure of laminated structures.
B. L. Wardle, S-G. Kim

16.225[J] Computational Mechanics of Materials
Same subject as 2.099[J]
Prereq: Permission of instructor
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Spring)
3-0-9 units

Formulation of numerical (finite element) methods for the analysis of the nonlinear continuum response of materials. The range of material behavior considered includes finite deformation elasticity and inelasticity. Numerical formulation and algorithms include variational formulation and variational constitutive updates; finite element discretization; constrained problems; time discretization and convergence analysis. Strong emphasis on the (parallel) computer implementation of algorithms in programming assignments. The application to real engineering applications and problems in engineering science are stressed throughout. Experience in either C++, C, or Fortran required.
R. Radovitzky

16.230[J] Plates and Shells: Static and Dynamic Analysis
Same subject as 2.081[J]
Prereq: 2.071, 2.080[J], or permission of instructor
G (Spring)
3-1-8 units

See description under subject 2.081[J].
T. Sapsis

16.235 Design with High Temperature Materials
Prereq: Permission of instructor
G (Spring)
3-0-9 units

Introduction to materials design for high-temperature applications. Fundamental principles of thermodynamics and kinetics of the oxidation and corrosion of materials in high-temperature, chemically aggressive environments. Relationship of oxidation theory to design of metals (iron-, cobalt-, nickel-, refractory- and intermetallic alloys), ceramics, composites (metal-, ceramic- and carbon-matrix, coated materials). Relationships between deformation mechanisms (creep, viscoelasticity, thermoelasticity) and microstructure for materials used at elevated temperature. Discussions of high-temperature oxidation, corrosion, and damage problems that occur in energy and aerospace systems.
Z. C. Cordero

Information and Control Engineering

16.30 Feedback Control Systems
Subject meets with 16.31
Prereq: 16.06 or permission of instructor
U (Fall)
4-1-7 units

Studies state-space representation of dynamic systems, including model realizations, controllability, and observability. Introduces the state-space approach to multi-input-multi-output control system analysis and synthesis, including full state feedback using pole placement, linear quadratic regulator, stochastic state estimation, and the design of dynamic control laws. Also covers performance limitations and robustness. Extensive use of computer-aided control design tools. Applications to various aerospace systems, including navigation, guidance, and control of vehicles. Laboratory exercises utilize a palm-size drone. Students taking graduate version complete additional assignments.
S. R. Hall, C. Fan

16.301 Topics in Control, Dynamics, and Automation
Prereq: Permission of department
U (Fall, IAP, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Provides credit for work on undergraduate-level material in control and/or dynamics and/or automation outside of regularly scheduled subjects. Intended for transfer credit and study abroad. Credit may be used to satisfy specific degree requirements in the Course 16 program. Requires prior approval. Consult department.
J. P. How

16.31 Feedback Control Systems
Subject meets with 16.30
Prereq: 16.06 or permission of instructor
G (Fall)
3-1-8 units

Graduate-level version of 16.30; see description under 16.30. Includes additional homework questions, laboratory experiments, and a term project beyond 16.30 with a particular focus on the material associated with state-space realizations of MIMO transfer function (matrices); MIMO zeros, controllability, and observability; stochastic processes and estimation; limitations on performance; design and analysis of dynamic output feedback controllers; and robustness of multivariable control systems.
S. R. Hall, C. Fan

16.32 Principles of Optimal Control and Estimation
Prereq: 16.31
G (Spring)
3-0-9 units

Fundamentals of optimal control and estimation for discrete and continuous systems. Briefly reviews constrained function minimization and stochastic processes. Topics in optimal control theory include dynamic programming, variational calculus, Pontryagin's maximum principle, and numerical algorithms and software. Topics in estimation include least-squares estimation, and the Kalman filter and its extensions for estimating the states of dynamic systems. May include an individual term project.
J. P. How

16.332 Formal Methods for Safe Autonomous Systems
Prereq: Permission of instructor
G (Spring)
3-0-9 units

Covers formal methods for designing and analyzing autonomous systems. Focuses on both classical and state-of-the-art rigorous methods for specifying, modeling, verifying, and synthesizing various behaviors for systems where embedded computing units monitor and control physical processes. Additionally, covers advanced material on combining formal methods with control theory and machine learning theory for modern safety critical autonomous systems powered by AI techniques such as robots, self-driving cars, and drones. Strong emphasis on the use of various mathematical and software tools to provide safety, soundness, and completeness guarantees for system models with different levels of fidelity.
C. Fan

16.338[J] Dynamic Systems and Control
Same subject as 6.7100[J]
Prereq: 6.3000 and 18.06
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Spring)
4-0-8 units

See description under subject 6.7100[J].
M. A. Dahleh, A. Megretski

16.343 Spacecraft and Aircraft Sensors and Instrumentation
Prereq: Permission of instructor
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Spring)
3-0-9 units

Covers fundamental sensor and instrumentation principles in the context of systems designed for space or atmospheric flight. Systems discussed include basic measurement system for force, temperature, pressure; navigation systems (Global Positioning System, Inertial Reference Systems, radio navigation), air data systems, communication systems; spacecraft attitude determination by stellar, solar, and horizon sensing; remote sensing by incoherent and Doppler radar, radiometry, spectrometry, and interferometry. Also included is a review of basic electromagnetic theory and antenna design and discussion of design considerations for flight. Alternate years.
K. Cahoy

16.346 Astrodynamics
Prereq: 18.03
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Spring)
3-0-9 units

Fundamentals of astrodynamics; the two-body orbital initial-value and boundary-value problems with applications to space vehicle navigation and guidance for lunar and planetary missions with applications to space vehicle navigation and guidance for lunar and planetary missions including both powered flight and midcourse maneuvers. Topics include celestial mechanics, Kepler's problem, Lambert's problem, orbit determination, multi-body methods, mission planning, and recursive algorithms for space navigation. Selected applications from the Apollo, Space Shuttle, and Mars exploration programs.
S. E. Widnall, R. Linares

16.35 Real-Time Systems and Software
Prereq: 1.00 or 6.100B
U (Spring)
3-0-9 units

Concepts, principles, and methods for specifying and designing real-time computer systems. Topics include concurrency, real-time execution implementation, scheduling, testing, verification, real-time analysis, and software engineering concepts. Additional topics include operating system architecture, process management, and networking.
J. Shah

16.355[J] Concepts in the Engineering of Software
Same subject as IDS.341[J]
Prereq: Permission of instructor
G (Spring)
3-0-9 units

Reading and discussion on issues in the engineering of software systems and software development project design. Includes the present state of software engineering, what has been tried in the past, what worked, what did not, and why. Topics may differ in each offering, but are chosen from the software process and life cycle; requirements and specifications; design principles; testing, formal analysis, and reviews; quality management and assessment; product and process metrics; COTS and reuse; evolution and maintenance; team organization and people management; and software engineering aspects of programming languages. Enrollment may be limited.
N. G. Leveson

16.36 Communication Systems and Networks
Subject meets with 16.363
Prereq: (6.3000 or 16.002) and (6.3700 or 16.09)
U (Spring)
3-0-9 units

Introduces the fundamentals of digital communications and networking. Topics include elements of information theory, sampling and quantization, coding, modulation, signal detection and system performance in the presence of noise. Study of data networking includes multiple access, reliable packet transmission, routing and protocols of the internet. Concepts discussed in the context of aerospace communication systems: aircraft communications, satellite communications, and deep space communications. Students taking graduate version complete additional assignments.
E. H. Modiano

16.363 Communication Systems and Networks
Subject meets with 16.36
Prereq: (6.3000 or 16.004) and (6.3700 or 16.09)
G (Spring)
3-0-9 units

Introduces the fundamentals of digital communications and networking, focusing on the study of networks, including protocols, performance analysis, and queuing theory. Topics include elements of information theory, sampling and quantization, coding, modulation, signal detection and system performance in the presence of noise. Study of data networking includes multiple access, reliable packet transmission, routing and protocols of the internet. Concepts discussed in the context of aerospace communication systems: aircraft communications, satellite communications, and deep space communications. Students taking graduate version complete additional assignments.
E. H. Modiano

16.37[J] Data-Communication Networks
Same subject as 6.7450[J]
Prereq: 6.3700 or 18.204
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Fall)
3-0-9 units

See description under subject 6.7450[J].
E. Modiano

16.391 Statistics for Engineers and Scientists
Prereq: Calculus II (GIR), 18.06, 6.431, or permission of instructor
G (Fall)
3-0-9 units

Rigorous introduction to fundamentals of statistics motivated by engineering applications. Topics include exponential families, order statistics, sufficient statistics, estimation theory, hypothesis testing, measures of performance, notions of optimality, analysis of variance (ANOVA), simple linear regression, and selected topics.
M. Win

16.393 Statistical Communication and Localization Theory
Prereq: None
G (Spring)
3-0-9 units

Rigorous introduction to statistical communication and localization theory, covering essential topics such as modulation and demodulation of signals, derivation of optimal receivers, characterization of wireless channels, and devising of ranging and localization techniques. Applies decision theory, estimation theory, and modulation theory to the design and analysis of modern communication and localization systems exploring synchronization, diversity, and cooperation. Selected topics will be discussed according to time schedule and class interest.
M. Z. Win

16.395 Principles of Wide Bandwidth Communication
Prereq: 6.3010, 16.36, or permission of instructor
G (Fall)
Not offered regularly; consult department
3-0-9 units

Introduction to the principles of wide bandwidth wireless communication, with a focus on ultra-wide bandwidth (UWB) systems. Topics include the basics of spread-spectrum systems, impulse radio, Rake reception, transmitted reference signaling, spectral analysis, coexistence issues, signal acquisition, channel measurement and modeling, regulatory issues, and ranging, localization and GPS. Consists of lectures and technical presentations by students.
M. Z. Win

Humans and Automation

16.400 Human Systems Engineering
Subject meets with 16.453[J], HST.518[J]
Prereq: 6.3700, 16.09, or permission of instructor
U (Fall)
3-0-9 units

Provides a fundamental understanding of human factors that must be taken into account in the design and engineering of complex aviation, space, and medical systems. Focuses primarily on derivation of human engineering design criteria from sensory, motor, and cognitive sources. Includes principles of displays, controls and ergonomics, manual control, the nature of human error, basic experimental design, and human-computer interaction in supervisory control settings. Students taking graduate version complete a research project with a final written report and oral presentation.
Staff

16.401 Topics in Communication and Software
Prereq: Permission of department
U (Fall, IAP, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Provides credit for undergraduate-level work in communications and/or software outside of regularly scheduled subjects. Intended for transfer credit and study abroad. Credit may be used to satisfy specific degree requirements in the Course 16 program. Requires prior approval. Consult M. A. Stuppard.
J. P. How

16.405[J] Robotics: Science and Systems
Same subject as 2.124[J], 6.4200[J]
Prereq: ((1.00 or 6.100A) and (2.003[J], 6.1010, 6.1210, or 16.06)) or permission of instructor
U (Spring)
2-6-4 units. Institute LAB

See description under subject 6.4200[J]. Enrollment limited.
L. Carlone, S. Karaman, D. Hadfield-Manell, J. Leonard

16.410[J] Principles of Autonomy and Decision Making
Same subject as 6.4130[J]
Subject meets with 6.4132[J], 16.413[J]
Prereq: 6.100B or 6.9080
U (Fall)
4-0-8 units

Surveys decision making methods used to create highly autonomous systems and decision aids. Applies models, principles and algorithms taken from artificial intelligence and operations research. Focuses on planning as state-space search, including uninformed, informed and stochastic search, activity and motion planning, probabilistic and adversarial planning, Markov models and decision processes, and Bayesian filtering. Also emphasizes planning with real-world constraints using constraint programming. Includes methods for satisfiability and optimization of logical, temporal and finite domain constraints, graphical models, and linear and integer programs, as well as methods for search, inference, and conflict-learning. Students taking graduate version complete additional assignments.
H. E. Shrobe

16.412[J] Cognitive Robotics
Same subject as 6.8110[J]
Prereq: (6.4100 or 16.413[J]) and (6.1200[J], 6.3700, or 16.09)
G (Spring)
3-0-9 units

Highlights algorithms and paradigms for creating human-robot systems that act intelligently and robustly, by reasoning from models of themselves, their counterparts and their world. Examples include space and undersea explorers, cooperative vehicles, manufacturing robot teams and everyday embedded devices. Themes include architectures for goal-directed systems; decision-theoretic programming and robust execution; state-space programming, activity and path planning; risk-bounded programming and risk-bounded planners; self-monitoring and self-diagnosing systems, and human-robot collaboration. Student teams explore recent advances in cognitive robots through delivery of advanced lectures and final projects, in support of a class-wide grand challenge. Enrollment may be limited.
B. C. Williams

16.413[J] Principles of Autonomy and Decision Making
Same subject as 6.4132[J]
Subject meets with 6.4130[J], 16.410[J]
Prereq: 6.100B, 6.9080, or permission of instructor
G (Fall)
3-0-9 units

Surveys decision making methods used to create highly autonomous systems and decision aids. Applies models, principles and algorithms taken from artificial intelligence and operations research. Focuses on planning as state-space search, including uninformed, informed and stochastic search, activity and motion planning, probabilistic and adversarial planning, Markov models and decision processes, and Bayesian filtering. Also emphasizes planning with real-world constraints using constraint programming. Includes methods for satisfiability and optimization of logical, temporal and finite domain constraints, graphical models, and linear and integer programs, as well as methods for search, inference, and conflict-learning. Students taking graduate version complete additional assignments.
B. C. Williams

16.420 Planning Under Uncertainty
Subject meets with 6.4110
Prereq: 16.413[J]
G (Fall)
3-0-9 units

Concepts, principles, and methods for planning with imperfect knowledge. Topics include state estimation, planning in information space, partially observable Markov decision processes, reinforcement learning and planning with uncertain models. Students will develop an understanding of how different planning algorithms and solutions techniques are useful in different problem domains. Previous coursework in artificial intelligence and state estimation strongly recommended.
N. Roy, Staff

16.422 Human Supervisory Control of Automated Systems
Prereq: Permission of instructor
Acad Year 2023-2024: G (Fall)
Acad Year 2024-2025: Not offered
3-1-8 units

Principles of supervisory control and telerobotics. Different levels of automation are discussed, as well as the allocation of roles and authority between humans and machines. Human-vehicle interface design in highly automated systems. Decision aiding. Trade-offs between human control and human monitoring. Automated alerting systems and human intervention in automatic operation. Enhanced human interface technologies such as virtual presence. Performance, optimization, and social implications of the human-automation system. Examples from aerospace, ground, and undersea vehicles, robotics, and industrial systems.
J. A. Shah

16.423[J] Aerospace Biomedical and Life Support Engineering
Same subject as HST.515[J], IDS.337[J]
Prereq: 16.06, 16.400, or permission of instructor
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Spring)
3-0-9 units

Fundamentals of human performance, physiology, and life support impacting engineering design and aerospace systems. Topics include effects of gravity on the muscle, skeletal, cardiovascular, and neurovestibular systems; human/pilot modeling and human/machine design; flight experiment design; and life support engineering for extravehicular activity (EVA). Case studies of current research are presented. Assignments include a design project, quantitative homework sets, and quizzes emphasizing engineering and systems aspects.
D. J. Newman

16.445[J] Entrepreneurship in Aerospace and Mobility Systems
Same subject as STS.468[J]
Prereq: Permission of instructor
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Fall)
3-0-9 units

Examines concepts and procedures for new venture creation in aerospace and mobility systems, and other arenas where safety, regulation, and infrastructure are significant components. Includes space systems, aviation, autonomous vehicles, urban aerial mobility, transit, and similar arenas. Includes preparation for entrepreneurship, founders' dilemmas, venture finance, financial modeling and unit economics, fundraising and pitching, recruiting, problem definition, organizational creation, value proposition, go-to-market, and product development. Includes team-based final projects on problem definition, technical innovation, and pitch preparation.
D. A. Mindell

16.453[J] Human Systems Engineering
Same subject as HST.518[J]
Subject meets with 16.400
Prereq: 6.3700, 16.09, or permission of instructor
G (Fall)
3-0-9 units

Provides a fundamental understanding of human factors that must be taken into account in the design and engineering of complex aviation, space, and medical systems. Focuses primarily on derivation of human engineering design criteria from sensory, motor, and cognitive sources. Includes principles of displays, controls and ergonomics, manual control, the nature of human error, basic experimental design, and human-computer interaction in supervisory control settings. Students taking graduate version complete a research project with a final written report and oral presentation.
L. A. Stirling

16.456[J] Biomedical Signal and Image Processing
Same subject as 6.8800[J], HST.582[J]
Subject meets with 6.8801[J], HST.482[J]
Prereq: (6.3700 and (2.004, 6.3000, 16.002, or 18.085)) or permission of instructor
Acad Year 2023-2024: G (Spring)
Acad Year 2024-2025: Not offered
3-1-8 units

See description under subject 6.8800[J].
J. Greenberg, E. Adalsteinsson, W. Wells

16.459 Bioengineering Journal Article Seminar
Prereq: None
G (Fall, Spring)
1-0-1 units
Can be repeated for credit.

Each term, the class selects a new set of professional journal articles on bioengineering topics of current research interest. Some papers are chosen because of particular content, others are selected because they illustrate important points of methodology. Each week, one student leads the discussion, evaluating the strengths, weaknesses, and importance of each paper. Subject may be repeated for credit a maximum of four terms. Letter grade given in the last term applies to all accumulated units of 16.459.
Staff

16.470 Statistical Methods in Experimental Design
Prereq: 6.3700, 16.09, or permission of instructor
G (Spring)
3-0-9 units

Statistically based experimental design inclusive of forming hypotheses, planning and conducting experiments, analyzing data, and interpreting and communicating results. Topics include descriptive statistics, statistical inference, hypothesis testing, parametric and nonparametric statistical analyses, factorial ANOVA, randomized block designs, MANOVA, linear regression, repeated measures models, and application of statistical software packages.
Staff

16.475 Human-Computer Interface Design Colloquium
Prereq: None
G (Fall)
Not offered regularly; consult department
2-0-2 units

Provides guidance on design and evaluation of human-computer interfaces for students with active research projects. Roundtable discussion on developing user requirements, human-centered design principles, and testing and evaluating methodologies. Students present their work and evaluate each other's projects. Readings complement specific focus areas. Team participation encouraged. Open to advanced undergraduates.
Staff

16.485 Visual Navigation for Autonomous Vehicles
Prereq: 16.32 or permission of instructor
G (Fall)
3-2-7 units

Covers the mathematical foundations and state-of-the-art implementations of algorithms for vision-based navigation of autonomous vehicles (e.g., mobile robots, self-driving cars, drones). Topics include geometric control, 3D vision, visual-inertial navigation, place recognition, and simultaneous localization and mapping. Provides students with a rigorous but pragmatic overview of differential geometry and optimization on manifolds and knowledge of the fundamentals of 2-view and multi-view geometric vision for real-time motion estimation, calibration, localization, and mapping. The theoretical foundations are complemented with hands-on labs based on state-of-the-art mini race car and drone platforms. Culminates in a critical review of recent advances in the field and a team project aimed at advancing the state-of-the-art.
L. Carlone, J. How, K. Khosoussi

Propulsion and Energy Conversion

16.50 Aerospace Propulsion
Prereq: 16.003 and (2.005 or 16.004)
U (Spring)
3-0-9 units

Presents aerospace propulsive devices as systems, with functional requirements and engineering and environmental limitations. Requirements and limitations that constrain design choices. Both air-breathing and rocket engines covered, at a level which enables rational integration of the propulsive system into an overall vehicle design. Mission analysis, fundamental performance relations, and exemplary design solutions presented.
S. Barrett, J. Sabnis

16.501 Topics in Propulsion (New)
Prereq: Permission of department
U (IAP, Spring)
Units arranged
Can be repeated for credit.

Provides credit for work on undergraduate-level material in propulsion outside of regularly scheduled subjects. Intended for transfer credit and study abroad. Credit may be used to satisfy specific degree requirements in the Course 16 and Course 16-ENG programs. Requires prior approval. Consult department.
Y. M. Marzouk

16.511 Aircraft Engines and Gas Turbines
Prereq: 16.50 or permission of instructor
G (Fall)
3-0-9 units

Performance and characteristics of aircraft jet engines and industrial gas turbines, as determined by thermodynamic and fluid mechanic behavior of engine components: inlets, compressors, combustors, turbines, and nozzles. Discusses various engine types, including advanced turbofan configurations, limitations imposed by material properties and stresses. Emphasizes future design trends including reduction of noise, pollutant formation, fuel consumption, and weight.
E. M. Greitzer

16.512 Rocket Propulsion
Prereq: 16.50 or permission of instructor
Acad Year 2023-2024: G (Fall)
Acad Year 2024-2025: Not offered
3-0-9 units

Chemical rocket propulsion systems for launch, orbital, and interplanetary flight. Modeling of solid, liquid-bipropellant, and hybrid rocket engines. Thermochemistry, prediction of specific impulse. Nozzle flows including real gas and kinetic effects. Structural constraints. Propellant feed systems, turbopumps. Combustion processes in solid, liquid, and hybrid rockets. Cooling; heat sink, ablative, and regenerative.
C. Guerra-Garcia

16.522 Space Propulsion
Prereq: 8.02 or permission of instructor
Acad Year 2023-2024: G (Spring)
Acad Year 2024-2025: Not offered
3-3-6 units

Reviews rocket propulsion fundamentals. Discusses advanced concepts in space propulsion with emphasis on high-specific impulse electric engines. Topics include advanced mission analysis; the physics and engineering of electrothermal, electrostatic, and electromagnetic schemes for accelerating propellant; and orbital mechanics for the analysis of continuous thrust trajectories. Laboratory term project emphasizes the design, construction, and testing of an electric propulsion thruster.
P. C. Lozano

16.530 Advanced Propulsion Concepts
Prereq: 16.50, 16.511, 16.512, or 16.522
Acad Year 2023-2024: G (Spring)
Acad Year 2024-2025: Not offered
3-0-9 units

Considers the challenge of achieving net-zero climate impacts, as well as the opportunities presented by the resurgence of investment in new or renewed ideas. Explores advanced propulsion concepts that are not in use or well-developed, but that have established operation principles and could either contribute to environmental performance or are applicable to new aerospace services. Topics vary but may include: electric and turbo-electric aircraft propulsion; batteries, cryogenic fuels, and biofuels; combustion and emissions control concepts; propulsion for UAVs and urban air mobility; propulsion for supersonic and hypersonic vehicles; reusable space access vehicle propulsion; and propulsion in very low earth orbit. Includes a project to evaluate an advanced propulsion concept.
S. Barrett, J. J. Sabnis, Z. Spakovszky

16.540 Internal Flows in Turbomachines
Prereq: 2.25 or permission of instructor
Acad Year 2023-2024: G (Spring)
Acad Year 2024-2025: Not offered
3-0-9 units

Internal fluid motions in turbomachines, propulsion systems, ducts and channels, and other fluid machinery. Useful basic ideas, fundamentals of rotational flows, loss sources and loss accounting in fluid devices, unsteady internal flow and flow instability, flow in rotating passages, swirling flow, generation of streamwise vorticity and three-dimensional flow, non-uniform flow in fluid components.
E. M. Greitzer

16.55[J] Ionized Gases
Same subject as 22.64[J]
Prereq: 8.02 or permission of instructor
G (Fall)
3-0-9 units

Properties and behavior of low-temperature plasmas for energy conversion, plasma propulsion, and gas lasers. Equilibrium of ionized gases: energy states, statistical mechanics, and relationship to thermodynamics. Kinetic theory: motion of charged particles, distribution function, collisions, characteristic lengths and times, cross sections, and transport properties. Gas surface interactions: thermionic emission, sheaths, and probe theory. Radiation in plasmas and diagnostics.
C. Guerra Garcia

Other Undergraduate Subjects

16.UR Undergraduate Research
Prereq: None
U (Fall, IAP, Spring, Summer)
Units arranged [P/D/F]
Can be repeated for credit.

Undergraduate research opportunities in aeronautics and astronautics.
Consult M. A. Stuppard

16.C20[J] Introduction to Computational Science and Engineering
Same subject as 9.C20[J], 18.C20[J], CSE.C20[J]
Prereq: 6.100A; *Coreq: 8.01 and 18.01*
U (Fall, Spring; second half of term)
3-0-3 units
Credit cannot also be received for 6.100B

Provides an introduction to computational algorithms used throughout engineering and science (natural and social) to simulate time-dependent phenomena; optimize and control systems; and quantify uncertainty in problems involving randomness, including an introduction to probability and statistics. Combination of 6.100A and 16.C20[J] counts as REST subject.
D. L. Darmofal, N. Seethapathi

16.C25[J] Real World Computation with Julia (New)
Same subject as 1.C25[J], 6.C25[J], 12.C25[J], 18.C25[J], 22.C25[J]
Prereq: 6.100A, 18.03, and 18.06
U (Fall)
3-0-9 units

See description under subject 18.C25[J].
A. Edelman, R. Ferrari, B. Forget, C. Leiseron,Y. Marzouk, J. Williams

16.EPE UPOP Engineering Practice Experience
Engineering School-Wide Elective Subject.
Offered under: 1.EPE, 2.EPE, 3.EPE, 6.EPE, 8.EPE, 10.EPE, 15.EPE, 16.EPE, 20.EPE, 22.EPE
Prereq: None
U (Fall, Spring)
0-0-1 units
Can be repeated for credit.

See description under subject 2.EPE. Application required; consult UPOP website for more information.
K. Tan-Tiongco, D. Fordell

16.EPW UPOP Engineering Practice Workshop
Engineering School-Wide Elective Subject.
Offered under: 1.EPW, 2.EPW, 3.EPW, 6.EPW, 10.EPW, 16.EPW, 20.EPW, 22.EPW
Prereq: 2.EPE
U (IAP, Spring)
1-0-0 units

See description under subject 2.EPW. Enrollment limited to those in the UPOP program.
K. Tan-Tiongco, D. Fordell

16.S685 Special Subject in Aeronautics and Astronautics
Prereq: Permission of instructor
U (IAP; partial term)
Units arranged [P/D/F]
Can be repeated for credit.

Basic undergraduate topics not offered in regularly scheduled subjects. Subject to approval of faculty in charge. Prior approval required.
Consult Y. M. Marzouk

16.S686 Special Subject in Aeronautics and Astronautics
Prereq: Permission of instructor
U (Fall, Spring)
Units arranged
Can be repeated for credit.

Opportunity for study or lab work related to aeronautics and astronautics not covered in regularly scheduled subjects. Subject to approval of faculty in charge. Prior approval required.
Consult M. A. Stuppard

16.S688 Special Subject in Aeronautics and Astronautics
Prereq: None
U (Fall, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Opportunity for study or lab work related to aeronautics and astronautics but not covered in regularly scheduled subjects. Prior approval required.
Consult M. A. Stuppard

16.621 Experimental Projects I
Prereq: None. *Coreq: 16.06 or 16.07*
U (Fall)
Not offered regularly; consult department
2-1-3 units

First in a two-term sequence that addresses the conception and design of a student-defined or selected experimental research project carried out by two-person team under faculty advisement. Principles of research hypothesis formulation and assessment, experimental measurements and error analysis, and effective report writing and oral presentation, with instruction both in-class and on an individual and team basis. Selection and detailed planning of a research project, including in-depth design of experimental procedure that is then carried through to completion in 16.622.
Staff

16.622 Experimental Projects II
Prereq: 16.621
U (Spring)
Not offered regularly; consult department
1-7-4 units. Institute LAB

Execution of research project experiments based on the plan developed in 16.621. Working with their faculty advisor and course staff, student teams construct their experiment, carry out measurements of the relevant phenomena, analyze the data, and then apply the results to assess the research hypothesis. Includes instruction on effective report writing and oral presentations culminating in a written final report and formal oral presentation.
S. R. Hall, J. L. Craig, P. C. Lozano, S. E. Widnall

16.63[J] System Safety
Same subject as IDS.045[J]
Prereq: None
U (Fall)
Not offered regularly; consult department
3-0-9 units. REST

Introduces the concepts of system safety and how to analyze and design safer systems. Topics include the causes of accidents in general, and recent major accidents in particular; hazard analysis, safety-driven design techniques; design of human-automation interaction; integrating safety into the system engineering process; and managing and operating safety-critical systems.
N. Leveson

16.632 Introduction to Autonomous Machines
Prereq: None. *Coreq: 2.086 or 6.100A*
U (Fall, IAP)
2-2-2 units

Experiential seminar provides an introduction to the fundamental aspects of robust autonomous machines that includes an overall systems/component-level overview. Projects involve hands-on investigations with a variety of sensors and completely functioning, small-scale autonomous machines utilized for in-class implementation/testing of control algorithms. Students should have concurrent or prior programming experience. Preference to students in the NEET Autonomous Machines thread.
J. P. How, S. Karaman, G. Long

16.633 NEET Junior Seminar: Autonomous Machines
Prereq: None
U (Fall)
1-1-1 units

Project-based seminar provides instruction on how to program basic autonomy algorithms for a micro aerial vehicle equipped with a camera. Begins by introducing the constituent hardware and components of a quadrotor drone. As this subject progresses, the students practice using simple signal processing, state estimation, control, and computer vision algorithms for mobile robotics. Students program the micro aerial vehicle to compete in a variety of challenges. Limited to students in the NEET Autonomous Machines thread.
J. P. How, S. Karaman, G. Long

16.634 NEET Senior Seminar: Autonomous Machines
Prereq: None
U (Fall)
1-1-1 units

Provides a foundation for students taking 16.84 as part of the NEET Autonomous Machines thread. Through a set of focused activities, students determine the autonomous system they will design, which includes outlining the materials, facilities, and resources they need to create the system. Limited to students in the NEET Autonomous Machines thread or with instructor's permission.
J. P. How, S. Karaman, G. Long

16.64 Flight Measurement Laboratory
Prereq: 16.002
U (Spring)
2-2-2 units

Opportunity to see aeronautical theory applied in real-world environment of flight. Students assist in design and execution of simple engineering flight experiments in light aircraft. Typical investigations include determination of stability derivatives, verification of performance specifications, and measurement of navigation system characteristics. Restricted to students in Aeronautics and Astronautics.
R. J. Hansman

16.645[J] Dimensions of Geoengineering
Same subject as 1.850[J], 5.000[J], 10.600[J], 11.388[J], 12.884[J], 15.036[J]
Prereq: None
G (Fall; first half of term)
Not offered regularly; consult department
2-0-4 units

See description under subject 5.000[J]. Limited to 100.
J. Deutch, M. Zuber

16.650 Engineering Leadership Lab
Engineering School-Wide Elective Subject.
Offered under: 6.9110, 16.650
Subject meets with 6.9130[J], 16.667[J]
Prereq: None. *Coreq: 6.9120*; or permission of instructor
U (Fall, Spring)
0-2-1 units
Can be repeated for credit.

See description under subject 6.9110. Preference to students enrolled in the Bernard M. Gordon-MIT Engineering Leadership Program.
L. McGonagle, J. Feiler

16.651 Engineering Leadership
Engineering School-Wide Elective Subject.
Offered under: 6.9120, 16.651
Prereq: None. *Coreq: 6.9110*; or permission of instructor
U (Fall, Spring)
1-0-2 units
Can be repeated for credit.

See description under subject 6.9120. Preference to first-year students in the Gordon Engineering Leadership Program.
J. Magarian

16.653 Management in Engineering
Engineering School-Wide Elective Subject.
Offered under: 2.96, 6.9360, 10.806, 16.653
Prereq: None
U (Fall)
3-1-8 units

See description under subject 2.96. Restricted to juniors and seniors.
H. S. Marcus, J.-H. Chun

16.66 MATLAB Skills for Aeronautics and Astronautics
Prereq: None
U (Fall; first half of term)
Not offered regularly; consult department
1-0-2 units

Introduction to basic MATLAB skills in programming, analysis, and plotting. Recommended for sophomores without previous MATLAB experience. Preference to Course 16 majors.
Staff

16.6621[J] Introduction to Design Thinking and Innovation in Engineering
Same subject as 2.7231[J], 6.9101[J]
Prereq: None
U (Fall, Spring; first half of term)
2-0-1 units

See description under subject 6.9101[J]. Enrollment limited to 25; priority to first-year students.
B. Kotelly

16.662A Design Thinking and Innovation Leadership for Engineers
Engineering School-Wide Elective Subject.
Offered under: 2.723A, 6.910A, 16.662A
Prereq: None
U (Fall, Spring; first half of term)
2-0-1 units

See description under subject 6.910A.
B. Kotelly

16.662B Design Thinking and Innovation Project
Engineering School-Wide Elective Subject.
Offered under: 2.723B, 6.910B, 16.662B
Prereq: 6.910A
U (Fall, Spring; second half of term)
2-0-1 units

See description under subject 6.910B.
B. Kotelly

16.667 Engineering Leadership Lab
Engineering School-Wide Elective Subject.
Offered under: 6.9130, 16.667
Subject meets with 6.9110[J], 16.650[J]
Prereq: 6.910A, 6.9110, 6.9120, or permission of instructor
U (Fall, Spring)
0-2-4 units
Can be repeated for credit.

See description under subject 6.9130. Preference to students enrolled in the second year of the Gordon-MIT Engineering Leadership Program.
L. McGonagle, J. Feiler

16.669 Project Engineering
Engineering School-Wide Elective Subject.
Offered under: 6.9140, 16.669
Prereq: (6.910A and (6.9110 or 6.9120)) or permission of instructor
U (IAP)
4-0-0 units

See description under subject 6.9140. Preference to students in the Bernard M. Gordon-MIT Engineering Leadership Program.
O. de Weck, J. Feiler, L. McGonagle, R. Rahaman

16.671[J] Leading Innovation in Teams
Same subject as 6.9150[J]
Prereq: None
U (Spring)
Not offered regularly; consult department
3-0-6 units

See description under subject 6.9150[J]. Enrollment limited to seating capacity of classroom. Admittance may be controlled by lottery.
D. Nino, J. Schindall

16.676 Ethics for Engineers
Engineering School-Wide Elective Subject.
Offered under: 1.082, 2.900, 6.9320, 10.01, 16.676, 22.014
Subject meets with 6.9321, 20.005
Prereq: None
U (Fall, Spring)
2-0-4 units

See description under subject 10.01.
D. A. Lauffenberger, B. L. Trout

16.680 Project in Aeronautics and Astronautics
Prereq: None
U (Fall, IAP, Spring)
Not offered regularly; consult department
Units arranged [P/D/F]
Can be repeated for credit.

Opportunity to work on projects related to aerospace engineering outside the department. Requires prior approval.
Consult M. A. Stuppard

16.681 Topics in Aeronautics and Astronautics
Prereq: None
U (Fall, Spring, Summer)
Units arranged
Can be repeated for credit.

Opportunity for study or laboratory project work not available elsewhere in the curriculum. Topics selected in consultation with the instructor.
Consult M. A. Stuppard

16.682 Selected Topics in Aeronautics and Astronautics
Prereq: None
U (IAP)
Units arranged
Can be repeated for credit.

Study by qualified students. Topics selected in consultation with the instructor. Prior approval required.
Consult M. A. Stuppard

16.683 Seminar in Aeronautics and Astronautics
Prereq: None
U (Fall, IAP, Spring)
Not offered regularly; consult department
2-0-0 units
Can be repeated for credit.

Speakers from campus and industry discuss current activities and advances in aeronautics and astronautics. Restricted to Course 16 students.
Consult M. A. Stuppard

16.687 Selected Topics in Aeronautics and Astronautics
Prereq: None
U (IAP; partial term)
Units arranged [P/D/F]
Can be repeated for credit.

Study by qualified students. Topics selected in consultation with the instructor. Prior approval required.
Consult M. A. Stuppard

16.691 Practicum Experience
Prereq: None
U (Fall, IAP, Spring, Summer)
Units arranged [P/D/F]
Can be repeated for credit.

For Course 16 students participating in curriculum-related off-campus experiences in aerospace engineering and related areas. Before enrolling, a student must have an offer from a company or organization; must identify an appropriate supervisor in the AeroAstro department who, along with the off-campus supervisor, evaluate the student's performance; and must receive prior approval from the AeroAstro department. At the conclusion of the training, the student submits a substantive final report for review and approval by the MIT supervisor. Can be taken for up to 3 units. Contact the AeroAstro Undergraduate Office for details on procedures and restrictions.
Consult M. Stuppard

Flight Transportation

16.707[J] The History of Aviation
Same subject as STS.467[J]
Prereq: Permission of instructor
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Spring)
3-0-9 units

See description under subject STS.467[J].
D. Mindell

16.71[J] The Airline Industry
Same subject as 1.232[J], 15.054[J]
Prereq: None
G (Fall)
3-0-9 units

Overview of the global airline industry, focusing on recent industry performance, current issues and challenges for the future. Fundamentals of airline industry structure, airline economics, operations planning, safety, labor relations, airports and air traffic control, marketing, and competitive strategies, with an emphasis on the interrelationships among major industry stakeholders. Recent research findings of the MIT Global Airline Industry Program are showcased, including the impacts of congestion and delays, evolution of information technologies, changing human resource management practices, and competitive effects of new entrant airlines. Taught by faculty participants of the Global Airline Industry Program.
P. P. Belobaba, H. Balakrishnan, A. I. Barnett, R. J. Hansman, T. A. Kochan

16.715 Aerospace, Energy, and the Environment
Prereq: Chemistry (GIR) and (1.060, 2.006, 10.301, 16.003, 16.004, or permission of instructor)
G (Fall)
3-0-9 units

Addresses energy and environmental challenges facing aerospace in the 21st century. Topics include: aircraft performance and energy requirements, propulsion technologies, jet fuels and alternative fuels, lifecycle assessment of fuels, combustion, emissions, climate change due to aviation, aircraft contrails, air pollution impacts of aviation, impacts of supersonic aircraft, and aviation noise. Includes an in-depth introduction to the relevant atmospheric and combustion physics and chemistry with no prior knowledge assumed. Discussion and analysis of near-term technological, fuel-based, regulatory and operational mitigation options for aviation, and longer-term technical possibilities.
S. Barrett

16.72 Air Traffic Control
Prereq: Permission of instructor
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Fall)
3-0-9 units

Introduces the various aspects of present and future Air Traffic Control systems. Descriptions of the present system: systems-analysis approach to problems of capacity and safety; surveillance, including NAS and ARTS; navigation subsystem technology; aircraft guidance and control; communications; collision avoidance systems; sequencing and spacing in terminal areas; future directions and development; critical discussion of past proposals and of probable future problem areas. Requires term paper.
H. Balakrishnan

16.763[J] Air Transportation Operations Research
Same subject as 1.233[J]
Prereq: 6.3702, 15.093[J], 16.71[J], or permission of instructor
Acad Year 2023-2024: G (Spring)
Acad Year 2024-2025: Not offered
3-0-9 units

Presents a unified view of advanced quantitative analysis and optimization techniques applied to the air transportation sector. Considers the problem of operating and managing the aviation sector from the perspectives of the system operators (e.g., the FAA), the airlines, and the resultant impacts on the end-users (the passengers). Explores models and optimization approaches to system-level problems, airline schedule planning problems, and airline management challenges. Term paper required.
H. Balakrishnan, C. Barnhart, P. P. Belobaba

16.767 Introduction to Airline Transport Aircraft Systems and Automation
Prereq: Permission of instructor
G (IAP)
Not offered regularly; consult department
3-2-1 units

Intensive one-week subject that uses the Boeing 767 aircraft as an example of a system of systems. Focuses on design drivers and compromises, system interactions, and human-machine interface. Morning lectures, followed by afternoon desktop simulator sessions. Critique and comparison with other transport aircraft designs. Includes one evening at Boston Logan International Airport aboard an aircraft. Enrollment limited.
C. M. Oman, B. Nield

16.781[J] Planning and Design of Airport Systems
Same subject as 1.231[J], IDS.670[J]
Prereq: None
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Fall)
3-0-9 units

Focuses on current practice, developing trends, and advanced concepts in airport design and planning. Considers economic, environmental, and other trade-offs related to airport location, as well as the impacts of emphasizing "green" measures. Includes an analysis of the effect of airline operations on airports. Topics include demand prediction, determination of airfield capacity, and estimation of levels of congestion; terminal design; the role of airports in the aviation and transportation system; access problems; optimal configuration of air transport networks and implications for airport development; and economics, financing, and institutional aspects. Special attention to international practice and developments.
R. de Neufville, A. R. Odoni

Aerospace Systems

16.810 Engineering Design and Rapid Prototyping
Prereq: (6.9110 and 6.9120) or permission of instructor
U (IAP)
3-3-0 units

Builds fundamental skills in engineering design and develops a holistic view of the design process through conceiving, designing, prototyping, and testing a multidisciplinary component or system. Students are provided with the context in which the component or system must perform; they then follow a process to identify alternatives, enact a workable design, and improve the design through multi-objective optimization. The performance of end-state designs is verified by testing. Though students develop a physical component or system, the project is formulated so those from any engineering discipline can participate. The focus is on the design process itself, as well as the complementary roles of human creativity and computational approaches. Designs are built by small teams who submit their work to a design competition. Pedagogy based on active learning, blending lectures with design and manufacturing activities. Limited to 30 students. Preference given to students in the Gordon-MIT Engineering Leadership Program.
O. L. de Weck, J. Magarian

16.82 Flight Vehicle Engineering
Prereq: Permission of instructor
U (Spring)
3-3-6 units

Design of an atmospheric flight vehicle to satisfy stated performance, stability, and control requirements. Emphasizes individual initiative, application of fundamental principles, and the compromises inherent in the engineering design process. Includes instruction and practice in written and oral communication, through team presentations and a written final report. Course 16 students are expected to complete two professional or concentration subjects from the departmental program before taking this capstone. Offered alternate Spring and Fall terms.
R. J. Hansman, M. Drela

16.821 Flight Vehicle Development
Prereq: Permission of instructor
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: U (Spring)
2-10-6 units. Institute LAB

Focuses on implementation and operation of a flight system. Emphasizes system integration, implementation, and performance verification using methods of experimental inquiry, and addresses principles of laboratory safety. Students refine subsystem designs and fabricate working prototypes. Includes component integration into the full system with detailed analysis and operation of the complete vehicle in the laboratory and in the field, as well as experimental analysis of subsystem performance, comparison with physical models of performance and design goals, and formal review of the overall system design. Knowledge of the engineering design process is helpful. Provides instruction in written and oral communication.
R. J. Hansman, M. Drela

16.83[J] Space Systems Engineering
Same subject as 12.43[J]
Prereq: Permission of instructor
U (Fall)
3-3-6 units

Design of a complete space system, including systems analysis, trajectory analysis, entry dynamics, propulsion and power systems, structural design, avionics, thermal and environmental control, human factors, support systems, and weight and cost estimates. Students participate in teams, each responsible for an integrated vehicle design, providing experience in project organization and interaction between disciplines. Includes several aspects of team communication including three formal presentations, informal progress reports, colleague assessments, and written reports. Course 16 students are expected to complete two professional or concentration subjects from the departmental program before taking this capstone. Offered alternate fall and spring terms.
K. Cahoy

16.831[J] Space Systems Development
Same subject as 12.431[J]
Prereq: Permission of instructor
Acad Year 2023-2024: U (Spring)
Acad Year 2024-2025: Not offered
2-10-6 units. Institute LAB

Students build a space system, focusing on refinement of sub-system designs and fabrication of full-scale prototypes. Sub-systems are integrated into a vehicle and tested. Sub-system performance is verified using methods of experimental inquiry, and is compared with physical models of performance and design goals. Communication skills are honed through written and oral reports. Formal reviews include the Implementation Plan Review and the Acceptance Review. Knowledge of the engineering design process is helpful.
Staff

16.839[J] Operating in the Lunar Environment
Same subject as MAS.839[J]
Prereq: Permission of instructor
G (Spring)
Not offered regularly; consult department
2-2-8 units

See description under subject MAS.839[J]. Enrollment limited; admission by application.
J. Hoffman, A. Ekblaw

16.84 Advanced Autonomous Robotic Systems
Prereq: 6.4200[J] or permission of instructor
U (Spring)
2-6-4 units

Students design an autonomous vehicle system to satisfy stated performance goals. Emphasizes both hardware and software components of the design and implementation. Entails application of fundamental principles and design engineering in both individual and group efforts. Students showcase the final design to the public at the end of the term.
J. P. How, S. Karaman

16.842 Fundamentals of Systems Engineering
Prereq: Permission of instructor
G (Fall)
2-0-4 units

General introduction to systems engineering for aerospace and more general electro-mechanical-cyber systems. Built on the V-model as well as an agile approach. Topics include stakeholder analysis, requirements definition, system architecture and concept generation, trade-space exploration and concept selection, design definition and optimization, system integration and interface management, system safety, verification and validation, and commissioning and operations. Discusses the trade-offs between performance, life-cycle cost and system operability. Readings based on systems engineering standards. Individual homework assignments apply concepts from class. Prepares students for the systems field exam in the Department of Aeronautics and Astronautics.
E. F. Crawley

16.851 Introduction to Satellite Engineering
Prereq: Permission of instructor
G (Fall; first half of term)
2-0-4 units

Covers the principles and governing equations fundamental to the design, launch, and operation of artificial satellites in Earth's orbit and beyond. Material includes the vis-viva equation; the rocket equation; basic orbital maneuvers, including Hohmann transfers; bielliptic trajectories, as well as spiral transfers; the link budget equation; spacecraft power and propulsion; thermal equilibrium and interactions of spacecraft with the space environment, such as aerodynamic drag; electrostatic charging; radiation; and meteorids. Spacecraft are initially treated parametrically as point masses and then as rigid bodies subject to Euler's equations of rotational motion. Serves as a prerequisite for more advanced material in satellite engineering, including the technological implementation of various subsystems. Lectures are offered in a hybrid format, in person and remote.
K. Cahoy, O. L. de Weck

16.853 Advanced Satellite Engineering
Prereq: 16.66 and 16.851
G (Fall; second half of term)
2-0-4 units

Advanced material in satellite engineering, including the physical implementation of spacecraft hardware and software in payloads and bus subsystems, including structures, attitude determination and control, electrical power systems (EPS), control and data handling (CDH), guidance navigation and control (GNC), thermal management, communications, and others. Examples of spacecraft technologies and design tradeoffs are highlighted based on past, current, and future missions. Emphasis on mission success and identification and preventation of spacecraft and mission failures modes. Prepares students for the design of Earth observation as well as interplanetary science missions. Advanced assignments require computational skills in Matlab or Python and short presentations. Guest speakers from NASA and industry. Serves as a basis for the field examination in space systems.
K. Cahoy

16.854 Spacecraft Laboratory
Prereq: 16.851 and permission of instructor
G (Spring; second half of term)
1-2-3 units

Practical work in a spacecraft laboratory environment, including learning about cleanroom environments, satellite integration, and testing. Topics include handling of electrostatic discharge (ESD) sensitive electronics, working in a cleanroom, performing spacecraft component and qualification testing using shaker tables to simulate launch and deployment loads, thermal and vacuum testing, and designing and executing a successful spacecraft/instrument test campaign. Emphasis on obtaining laboratory data from sensors such as accelerometers, thermal sensors, and small satellite hardware, and comparing expected results against actual behaviors. Students carry out exercises in small teams and submit digital laboratory reports.
R. A. Masterson

16.855[J] Systems Architecting Applied to Enterprises
Same subject as EM.429[J], IDS.336[J]
Prereq: Permission of instructor
G (Spring)
3-0-9 units

See description under subject IDS.336[J].
D. Rhodes

16.857[J] Asking How Space Enabled Designs Advance Justice and Development
Same subject as MAS.858[J]
Prereq: None
G (Fall)
3-0-9 units

See description under subject MAS.858[J]. Limited to 15.
D. Wood

16.858 Introduction to Discrete Math and Systems Theory for Engineers
Prereq: Permission of instructor
Acad Year 2023-2024: G (Fall)
Acad Year 2024-2025: Not offered
3-0-9 units

General discrete math topics include mathematical reasoning, combinatorial analysis, discrete structures (sets, permutations, relations, graphs, trees, and finite state machines), algorithmic thinking and complexity, modeling computation (languages and grammars, finite state machines), and Boolean algebra. Emphasis is on the use of the basic principles to solve engineering problems rather than applying formulae or studying the theoretical mathematical foundations of the topics. Real aerospace engineering examples are used. Enrollment may be limited.
N. Leveson, O. de Weck, J. Thomas

16.861 Engineering Systems Analysis for Design
Engineering School-Wide Elective Subject.
Offered under: 1.146, 16.861, EM.422, IDS.332
Prereq: Permission of instructor
G (Fall)
3-0-9 units
Credit cannot also be received for EM.423[J], IDS.333[J]

See description under subject IDS.332. Enrollment limited.
R. de Neufville

16.863[J] System Safety Concepts
Same subject as IDS.340[J]
Prereq: Permission of instructor
G (Fall)
3-0-9 units

Covers important concepts and techniques in designing and operating safety-critical systems. Topics include the nature of risk, formal accident and human error models, causes of accidents, fundamental concepts of system safety engineering, system and software hazard analysis, designing for safety, fault tolerance, safety issues in the design of human-machine interaction, verification of safety, creating a safety culture, and management of safety-critical projects. Includes a class project involving the high-level system design and analysis of a safety-critical system. Enrollment may be limited.
N. G. Leveson

16.88[J] Prototyping our Sci-Fi Space Future: Designing & Deploying Projects for Zero Gravity Flights
Same subject as MAS.838[J]
Prereq: Permission of instructor
G (Fall)
2-2-8 units

See description under subject MAS.838[J]. Enrollment limited; admission by application.
J. Paradiso, A. Ekblaw

16.885 Aircraft Systems Engineering
Prereq: Permission of instructor
Acad Year 2023-2024: G (Fall)
Acad Year 2024-2025: Not offered
3-1-8 units

Holistic view of the aircraft as a system, covering basic systems engineering, cost and weight estimation, basic aircraft performance, safety and reliability, life cycle topics, aircraft subsystems, risk analysis and management, and system realization. Small student teams retrospectively analyze an existing aircraft covering: key design drivers and decisions; aircraft attributes and subsystems; operational experience. Oral and written versions of the case study are delivered. Focuses on a systems engineering analysis of the Space Shuttle. Studies both design and operations of the shuttle, with frequent lectures by outside experts. Students choose specific shuttle systems for detailed analysis and develop new subsystem designs using state of the art technology.
R. J. Hansman, W. Hoburg

16.886 Air Transportation Systems Architecting
Prereq: Permission of instructor
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Fall)
3-2-7 units

Addresses the architecting of air transportation systems. Focuses on the conceptual phase of product definition including technical, economic, market, environmental, regulatory, legal, manufacturing, and societal factors. Centers on a realistic system case study and includes a number of lectures from industry and government. Past examples include the Very Large Transport Aircraft, a Supersonic Business Jet and a Next Generation Cargo System. Identifies the critical system level issues and analyzes them in depth via student team projects and individual assignments. Overall goal is to produce a business plan and a system specifications document that can be used to assess candidate systems.
R. J. Hansman

16.887[J] Technology Roadmapping and Development
Same subject as EM.427[J]
Prereq: Permission of instructor
G (Fall)
3-0-9 units

Provides a review of the principles, methods and tools of technology management for organizations and technologically-enabled systems including technology forecasting, scouting, roadmapping, strategic planning, R&D project execution, intellectual property management, knowledge management, partnering and acquisition, technology transfer, innovation management, and financial technology valuation. Topics explain the underlying theory and empirical evidence for technology evolution over time and contain a rich set of examples and practical exercises from aerospace and other domains, such as transportation, energy, communications, agriculture, and medicine. Special topics include Moore's law, S-curves, the singularity and fundamental limits to technology. Students develop a comprehensive technology roadmap on a topic of their own choice.
O. L. de Weck

16.888[J] Multidisciplinary Design Optimization
Same subject as EM.428[J], IDS.338[J]
Prereq: 18.085 or permission of instructor
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Spring)
3-1-8 units

Systems modeling for design and optimization. Selection of design variables, objective functions and constraints. Overview of principles, methods and tools in multidisciplinary design optimization (MDO). Subsystem identification, development and interface design. Design of experiments (DOE). Review of linear (LP) and non-linear (NLP) constrained optimization formulations. Scalar versus vector optimization problems. Karush-Kuhn-Tucker (KKT) conditions of optimality, Lagrange multipliers, adjoints, gradient search methods, sensitivity analysis, geometric programming, simulated annealing, genetic algorithms and particle swarm optimization. Constraint satisfaction problems and isoperformance. Non-dominance and Pareto frontiers. Surrogate models and multifidelity optimization strategies. System design for value. Students execute a term project in small teams related to their area of interest.
O. de Weck

16.89[J] Space Systems Engineering
Same subject as IDS.339[J]
Prereq: 16.842, 16.851, or permission of instructor
G (Spring)
4-2-6 units

Focus on developing space system architectures. Applies subsystem knowledge gained in 16.851 to examine interactions between subsystems in the context of a space system design. Principles and processes of systems engineering including developing space architectures, developing and writing requirements, and concepts of risk are explored and applied to the project. Subject develops, documents, and presents a conceptual design of a space system including a preliminary spacecraft design.
E. F. Crawley

16.891 Space Policy Seminar
Prereq: Permission of instructor
G (Spring)
2-0-4 units

Explores current and historical issues in space policy, highlighting NASA, DOD, and international space agencies. Covers NASA's portfolios in exploration, science, aeronautics, and technology. Discusses US and international space policy. NASA leadership, public private partnerships, and innovation framework are presented. Current and former government and industry leaders provide an "inside the beltway perspective." Study of Congress, the Executive, and government agencies results in weekly policy memos. White papers authored by students provide policy findings and recommendations to accelerate human spaceflight, military space, space technology investments, and space science missions. Intended for graduate students and advanced undergraduates interested in technology policy. Enrollment may be limited.
D. J. Newman, D. E. Hastings

16.893 Engineering the Space Shuttle
Prereq: None
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Fall)
4-0-8 units

Detailed historical and technical study of the Space Shuttle, the world's first reusable spacecraft, through lectures by the people who designed, built and operated it. Examines the political, economic and military factors that influenced the design of the Shuttle; looks deeply into the it's many subsystems; and explains how the Shuttle was operated. Lectures are both live and on video. Students work on a final project related to space vehicle design.
J. A. Hoffman

16.895[J] Engineering Apollo: The Moon Project as a Complex System
Same subject as STS.471[J]
Prereq: None
Acad Year 2023-2024: G (Fall)
Acad Year 2024-2025: Not offered
4-0-8 units

See description under subject STS.471[J].
D. Mindell

Computation

16.90 Computational Modeling and Data Analysis in Aerospace Engineering
Prereq: 16.001, 16.002, 16.003, 16.004, or permission of instructor;
Coreq: 6.3700 or 16.09
U (Spring)
4-0-8 units

Introduces principles, algorithms, and applications of computational techniques arising in aerospace engineering. Techniques include numerical integration of systems of ordinary differential equations; numerical discretization of partial differential equations; probabilistic modeling; and computational aspects of estimation and inference. Example applications will include modeling, design, and data analysis.
Q. Wang

16.901 Topics in Computation
Prereq: None
U (Fall, Spring; second half of term)
Not offered regularly; consult department
Units arranged

Provides credit for undergraduate-level work in computation outside of regularly scheduled subjects. Intended for transfer credit and study abroad. Credit may be used to satisfy specific degree requirements in the Course 16 program. Requires prior approval. Consult M. A. Stuppard.
J. P. How

16.910[J] Introduction to Modeling and Simulation
Same subject as 2.096[J], 6.7300[J]
Prereq: 18.03 or 18.06
G (Fall)
3-6-3 units

See description under subject 6.7300[J].
L. Daniel

16.920[J] Numerical Methods for Partial Differential Equations
Same subject as 2.097[J], 6.7330[J]
Prereq: 18.03 or 18.06
G (Fall)
3-0-9 units

Covers the fundamentals of modern numerical techniques for a wide range of linear and nonlinear elliptic, parabolic, and hyperbolic partial differential and integral equations. Topics include mathematical formulations; finite difference, finite volume, finite element, and boundary element discretization methods; and direct and iterative solution techniques. The methodologies described form the foundation for computational approaches to engineering systems involving heat transfer, solid mechanics, fluid dynamics, and electromagnetics. Computer assignments requiring programming.
J. Peraire

16.930 Advanced Topics in Numerical Methods for Partial Differential Equations
Prereq: 16.920[J]
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Spring)
3-0-9 units

Covers advanced topics in numerical methods for the discretization, solution, and control of problems governed by partial differential equations. Topics include the application of the finite element method to systems of equations with emphasis on equations governing compressible, viscous flows; grid generation; optimal control of PDE-constrained systems; a posteriori error estimation and adaptivity; reduced basis approximations and reduced-order modeling. Computer assignments require programming.
J. Peraire

16.940 Numerical Methods for Stochastic Modeling and Inference
Prereq: (6.3702 and 16.920[J]) or permission of instructor
Acad Year 2023-2024: G (Fall)
Acad Year 2024-2025: Not offered
3-0-9 units

Advanced introduction to numerical methods for treating uncertainty in computational simulation. Draws examples from a range of engineering and science applications, emphasizing systems governed by ordinary and partial differential equations. Uncertainty propagation and assessment: Monte Carlo methods, variance reduction, sensitivity analysis, adjoint methods, polynomial chaos and Karhunen-Loève expansions, and stochastic Galerkin and collocation methods. Interaction of models with observational data, from the perspective of statistical inference: Bayesian parameter estimation, statistical regularization, Markov chain Monte Carlo, sequential data assimilation and filtering, and model selection.
Y. M. Marzouk

Other Graduate Subjects

16.THG Graduate Thesis
Prereq: Permission of department
G (Fall, IAP, Spring, Summer)
Units arranged
Can be repeated for credit.

Program of research leading to an SM, EAA, PhD, or ScD thesis; to be arranged by the student with an appropriate MIT faculty member, who becomes thesis supervisor. Restricted to students who have been admitted into the department.
Y. M. Marzouk

16.971 Practicum Experience
Prereq: None
G (Fall, IAP, Spring, Summer)
Units arranged [P/D/F]
Can be repeated for credit.

For Course 16 students participating in curriculum-related off-campus experiences in aerospace engineering and related areas. Before enrolling, a student must have an offer from a company or organization; must identify an appropriate supervisor in the AeroAstro department who, along with the off-campus supervisor, evaluate the student's work; and must receive prior approval from the AeroAstro department. At the conclusion of the training, the student submits a substantive final report for review and approval by the MIT supervisor. Can be taken for up to 3 units. Contact the AeroAstro Graduate Office for details on procedures and restrictions.
Consult B.Marois

16.980 Advanced Project
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Study, original investigation, or lab project work level by qualified students. Topics selected in consultation with instructor. Prior approval required.
Consult M. A. Stuppard

16.981 Advanced Project
Prereq: Permission of instructor
G (Fall, IAP, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Study, original investigation, or lab project work by qualified students. Topics selected in consultation with instructor. Prior approval required.
Consult M. A. Stuppard

16.984 Seminar
Prereq: None
G (Fall, IAP, Spring)
Not offered regularly; consult department
2-0-0 units
Can be repeated for credit.

Discussion of current interest topics by staff and guest speakers. Prior approval required. Restricted to Course 16 students.
Consult M. A. Stuppard

16.985[J] Global Operations Leadership Seminar
Same subject as 2.890[J], 10.792[J], 15.792[J]
Prereq: None
G (Fall, Spring)
2-0-0 units
Can be repeated for credit.

See description under subject 15.792[J]. Preference to LGO students.
T. Roemer

16.990[J] Leading Creative Teams
Same subject as 6.9280[J], 15.674[J]
Prereq: Permission of instructor
G (Fall, Spring)
3-0-6 units

See description under subject 6.9280[J]. Enrollment limited.
D. Nino, J. Wu

16.995 Doctoral Research and Communication Seminar
Prereq: Permission of instructor
G (Fall, Spring)
2-0-1 units

Presents fundamental concepts of technical communication. Addresses how to articulate a research problem, as well as the communication skills necessary to reach different audiences. The primary focus is on technical presentations, but includes aspects of written communication. Students give two technical talks during the term, and provide oral and written feedback to each other. Enrollment may be limited.
Staff

16.997 How To Do Excellent Research
Prereq: Permission of instructor
Acad Year 2023-2024: Not offered
Acad Year 2024-2025: G (Fall)
1-0-2 units

Presents and discusses skills valuable for starting research in the department, including time management; reading, reviewing, and writing technical papers; how to network in a research setting, how to be effective in a research group, and how to get good mentoring. In-class peer review is expected. Students write a final paper on one or more of the class topics. Enrollment is limited.
D. E. Hastings

16.999 Teaching in Aeronautics and Astronautics
Prereq: None
G (Fall, Spring)
Units arranged
Can be repeated for credit.

For qualified students interested in gaining teaching experience. Classroom, tutorial, or laboratory teaching under the supervision of a faculty member. Enrollment limited by availability of suitable teaching assignments. Consult department.
E. H. Modiano

16.S198 Advanced Special Subject in Mechanics and Physics of Fluids
Prereq: Permission of instructor
G (Fall, Spring; second half of term)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled fluids subjects. Prior approval required.
Consult M. A. Stuppard

16.S199 Advanced Special Subject in Mechanics and Physics of Fluids
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled fluids subjects. Prior approval required.
Consult M. A. Stuppard

16.S298 Advanced Special Subject in Materials and Structures
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled materials and structures subjects. Prior approval required.
Consult M. A. Stuppard

16.S299 Advanced Special Subject in Materials and Structures
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled materials and structures subjects. Prior approval required.
Consult B. L. Wardle

16.S398 Advanced Special Subject in Information and Control
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
Consult M. A. Stuppard

16.S399 Advanced Special Subject in Information and Control
Prereq: Permission of instructor
G (Spring)
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
Consult M. A. Stuppard

16.S498 Advanced Special Subject in Humans and Automation
Prereq: Permission of instructor
G (Fall)
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
Consult M. A. Stuppard

16.S499 Advanced Special Subject in Humans and Automation
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
Consult M. A. Stuppard

16.S598 Advanced Special Subject in Propulsion and Energy Conversion
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
Consult M. A. Stuppard

16.S599 Advanced Special Subject in Propulsion and Energy Conversion
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
Consult M. A. Stuppard

16.S798 Advanced Special Subject in Flight Transportation
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
Consult M. A. Stuppard

16.S799 Advanced Special Subject in Flight Transportation
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
Consult M. A. Stuppard

16.S890 Advanced Special Subject in Aerospace Systems
Prereq: Permission of instructor
G (IAP; partial term)
Units arranged [P/D/F]
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
M. A. Stuppard

16.S893 Advanced Special Subject in Aerospace Systems
Prereq: None
G (Fall, Spring)
Not offered regularly; consult department
Units arranged [P/D/F]
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
M. A. Stuppard

16.S896 Advanced Special Subject in Aerospace Systems
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
Consult Consult: M. A. Stuppard

16.S897 Advanced Special Subject in Aerospace Systems
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
Units arranged

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
M. A. Stuppard

16.S898 Advanced Special Subject in Aerospace Systems
Prereq: Permission of instructor
G (Fall, Spring)
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
Consult D. Miller

16.S899 Advanced Special Subject in Aerospace Systems
Prereq: Permission of instructor
G (Fall, Spring; second half of term)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
Consult M. A. Stuppard

16.S948 Advanced Special Subject in Computation
Prereq: Permission of instructor
G (Spring)
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
Consult M. A. Stuppard

16.S949 Advanced Special Subject in Computation
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
Consult M. A. Stuppard

16.S982 Advanced Special Subject
Prereq: Permission of department
G (Fall, IAP, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
Staff

16.S983 Advanced Special Subject
Prereq: None
G (Fall, Spring)
Not offered regularly; consult department
Units arranged [P/D/F]
Can be repeated for credit.

Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
Consult M. A. Stuppard