The Department of Aeronautics and Astronautics (AeroAstro) students, faculty, and staff share a passion for air and space vehicles, the technologies that enable them, and the missions they fulfill.

Aerospace is an intellectually challenging, economically important, and exciting field. AeroAstro’s mission is to prepare engineers for success and leadership in the conception, design, implementation, and operation of aerospace and related engineering systems. This is achieved through commitment to educational excellence and to the creation of critical aerospace vehicle and information engineering technologies, and the engineering of complex high-performance systems.

AeroAstro, which traces its roots to 1914 (even earlier if you count MIT’s 1896 wind tunnel), is the oldest program of its kind in the United States. The department maintains a tradition of strong scholarship and solving complex challenges. The campus community comprises people whose careers have included astronaut, Air Force secretary, NASA deputy administrator and chief technologist, Air Force chief scientist, aerospace executives, and corporate founders. AeroAstro alumni/ae are entrepreneurs who start their own businesses, policy-makers shaping the direction of future research and development, educators sharing a passion for learning, and researchers pushing technology’s boundaries.

Working closely with student, alumni/ae, industry, government, and academic stakeholders, AeroAstro created a landmark educational initiative for its degree programs, an education model that has spread to more than 100 universities worldwide. This 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.

Graduates with an aerospace engineering degree find careers in commercial and military aircraft and spacecraft engineering, space exploration, air- and space-based telecommunication, autonomous vehicle and system design, teaching, research, military service, and related technology-intensive fields such as transportation, information, and the environment. The comprehensive technical education, with its strong emphasis on understanding complex systems, is also excellent preparation for careers in business, law, medicine, and public service.

AeroAstro supports labs and centers across campus. Three of particular note are the Learning Laboratory for Complex Systems, Building 31 (Sloan Laboratories), and the Wright Brothers Wind Tunnel.

- The Learning Laboratory for Complex Systems’ Arthur Gelb Laboratory features an extensive machine shop, composites fabrication facility, electronics design lab, and team project areas. Connected to the Gelb Lab is the expansive Gerhard Neumann Hangar, which includes a small wind tunnel, and a workspace for large-scale student projects, such as aircraft, rockets, and autonomous vehicles of all descriptions. The adjacent Robert C. Seams Jr. Laboratory is a community gathering area with meeting and discussion rooms.

- From 1938 until the spring of 2018, the Wright Brothers Wind Tunnel played a key role in the development of aerospace, civil engineering, and architectural systems. In late 2017, it was announced that the tunnel would be dismantled at the end of the spring 2018 term and a new state-of-the-art Wright Brothers Wind Tunnel constructed in its place. This will be the largest and most advanced academic wind tunnel in the US and is expected to be operational in the fall of 2019. All AeroAstro students will be provided the opportunity to perform research in the tunnel.

- Building 31 (Sloan Laboratories) is the new crown jewel of AeroAstro facilities. Reopened in the fall of 2017, fresh from a $52 million renovation, a highlight of Building 31 is the Kresa Center for Autonomous Systems’ massive high-bay facility for testing of aerial robotic systems. Another Building 31 feature is extensive lab and workshop space for Beaver Works, the joint MIT-Lincoln Laboratory center where undergraduates design and build projects for real-world customers.

In looking toward future challenges and opportunities in the aerospace field, the department has identified six strategic thrusts to strengthen and evolve: vehicle design, information sciences, computation, human–system collaboration, atmosphere and space sciences, and complex systems. These are built upon and connected by four strategic thrusts: air transportation, autonomous systems, small satellites, and education By striving for excellence in the underlying core disciplines and emphasizing the collaborative problem solving required for tackling the complex, multidisciplinary problems that characterize this industry, AeroAstro is positioned to respond to these and future opportunities.

**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.

**Information Sector**

Most of the aerospace systems of the future will either revolve around or critically depend upon information technology, and all will exploit information technology to an increasing extent. The missions of many aerospace systems are fundamentally centered on gathering, processing, and transmitting information. Examples where information technology is central include communication satellites, surveillance and reconnaissance aircraft and satellites, planetary rovers, global positioning satellites, the air transportation system, and integrated defense systems. Other aerospace systems also must rely on information technology-intensive subsystems.
to provide important on-board functions, including navigation, autonomous or semi-autonomous guidance and control, cooperative action (including formation flight), and health monitoring systems. Furthermore, almost every aircraft or satellite is one system within a larger system, and information plays a central role in the interoperability of these subsystems.

Faculty members in the Information Sector teach and perform research on a broad range of areas, including guidance, navigation, control, autonomy, communication, networks, and real-time mission-critical software and hardware. In many instances, the functions provided by aerospace information systems are critical to life or mission success. The complex nature of an aerospace system can either be simplified by the use of information technologies or can become significantly more complicated through the misuse of information technologies. Hence, safety, fault-tolerance, verification, and validation are significant areas of inquiry. Ongoing research in this sector includes autonomy and robotics, command and control of multiple unmanned/autonomous vehicles, space and airborne communication systems and networks, and software development methods for flight and mission-critical systems, investigation of air traffic management, and design of robust and adaptive control algorithms.

The Information Sector has strong linkages to the department’s Aerospace Systems Sector, particularly on issues related to how humans interact with aerospace vehicles. Other common interests include the safety aspects of large, mission-critical software systems, the design and operation of ground and air transportation systems, and the design and operation of satellite systems. The sector also has linkages with the Vehicles Technology Sector through a common interest in research on unmanned aerial vehicles. Moreover, the sector has strong links to the Department of Electrical Engineering and Computer Science and the Institute for Data, Systems, and Society through joint teaching and collaborative research in communication, networks, control, robotic systems, optimization, numerical techniques, and algorithms.

Aerospace Systems Sector
The Aerospace Systems sector is responsible for instruction and research in systems engineering, a discipline that denotes the methodologies used in the architecting, design, manufacture, and operation of the highly complex and demanding systems in the field of aeronautics and astronautics. The sector consists of faculty members with research specialties in this area, as well as faculty affiliates who contribute to the full disciplinary strength of the department.

The systems approach considers all factors important to the performance, economic viability, manufacture, acceptability, and operation of engineering systems—technical, social, environmental, production, financial, and safety aspects—and attempts to find optimal or best-value trade-offs among them while considering risk and uncertainty. The systems engineer must deal simultaneously with these factors, whether the objective is the transport of passengers in commercial aircraft, orbital communications, or the exploration of space, among others.

The Aerospace Systems sector addresses traditional vehicle design issues integrated with other issues, including environmental impact, how humans interact with aerospace vehicles, and information-related aspects. Safety, fault-tolerance, verification, and validation are also significant areas of inquiry. Ongoing research in the sector includes investigation of air traffic management, distributed satellite systems, environmental impact of aerospace systems, enterprise architecture, integrated design of space-based optical systems, micro-gravity research into human physiology, and software development methods for flight and mission-critical systems.

Students interested in systems engineering should develop a strong background in some of the disciplines that support systems analysis, such as probability, statistics, optimization, operations research, manufacturing, and economics. Research labs associated with the activities of this sector include the Man Vehicle Laboratory, Space Systems Laboratory, Lean Advancement Initiative, International Center in Air Transportation, Laboratory for Aviation and the Environment, and the Operations Research Center. Many of the department faculty in this sector are also associated with the Institute for Data, Systems, and Society.

Vehicle Technologies Sector
The design of an aerospace vehicle requires not only depth in a number of disciplines, but also the ability to integrate and optimize across these disciplines so the result is greater than the sum of the individual parts. For the former, the vehicle sector faculty represent, in both research and teaching, a broad suite of disciplines ranging across the fields of computation, fluid mechanics, propulsion, materials, and structures. For the latter, there is strong interest in, and many successful examples of, collaborations that bring these different disciplines together to solve important problems beyond the reach of a single faculty member.

The research footprint of the sector spans from fundamental engineering science to design techniques to the rigorous engineering of complex vehicle components and systems. One specific embodiment of such “intellectual vertical integration” has been the development of a first-principles conceptual design procedure for advanced aircraft. There is also substantive research engagement with industry, both in sponsorship of projects and through collaboration.

Topics of current interest include aviation and ground transportation climate and air quality impacts; computational design and simulation of fluid, material, and structural systems, including computational aerodynamics and, more broadly, numerical methods, optimization, and uncertainty quantification for large-scale engineering systems; composite materials and structures, including nano-engineered composites; simulation of the dynamic deformation and failure response of materials, with application to concepts and material for force protection, physics of plasma,
and electrospay space propulsion with particular application to microthrusters; turbomachinery and internal flows in fluid machinery; gas turbine engines; and aero-acoustics. Beyond these topics, there is outreach and interest in leveraging our skills into applications that lie outside the traditional boundaries of aerospace.

Research laboratories affiliated with the sector include the Aerospace Computational Design Laboratory, Gas Turbine Laboratory, Laboratory for Aviation and the Environment, Nano-Engineered Composite Aerospace Structures Consortium, Laboratory for Aviation and the Environment, and Space Propulsion Laboratory.

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 (http://catalog.mit.edu/mit/undergraduate-education/general-institute-requirements) and the departmental program. The departmental program includes 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 projects 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 16.06 Principles of Automatic Control and 16.07 Dynamics in the first term of the junior year. 6.00 Introduction to Computer Science and Programming 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 16.83[J], students build and operate the vehicles or systems developed in 16.82 and 16.83[J]. In 16.621/16.622, students conceive, design, and execute an original experimental research project in collaboration with a partner and a faculty advisor. 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 as Recommended by the Department of Aeronautics and Astronautics (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 as recommended by the Department of Aeronautics and Astronautics (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](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](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](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](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](http://catalog.mit.edu/mit/undergraduate-education/academic-research-options/undergraduate-research-opportunities-program)). More information is available online or by contacting Joyce Light (jlight@mit.edu), AeroAstro Headquarters, Room 33-207, (617) 253-8408.

**Undergraduate Practice Opportunities Program**

The Undergraduate Practice Opportunities Program (UPOP) ([http://upop.mit.edu](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 Career Advising and Professional Development or through the MIT International Science and Technology Initiatives (MISTI). AeroAstro students can apply to participate in the Imperial College London-MIT Summer Research Exchange Program.

Career Advising and Professional Development coordinates several annual career fairs and offers workshops on how to navigate these fairs, as well as critique on résumé writing and cover letters.

**Year Abroad Program**

Through the MIT Global Education Office, students can apply to study abroad in the junior year. In particular, the department participates in the University of Pretoria-MIT Exchange program. 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](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, Mount Holyoke College, Northeastern University, Olin College of Engineering, Roxbury Community College, 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 sponsorship of undergraduate research projects, support for student travel to present conference papers, a January internship at the Kennedy Space Center, an annual public lecture by a distinguished member of the aerospace community, and summer workshops for pre-college teachers.

An important function of the program is coordinating placement of students in summer positions at NASA centers for summer academies and research opportunities. MASC 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 the program coordinator of the Massachusetts Space Grant Consortium, Helen Halaris (halaris@mit.edu), 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.

All applicants to the graduate program in Aeronautics and Astronautics also must submit the Graduate Record Examination (GRE) test results.

New graduate students are normally admitted as candidates for the degree of Master of Science. Admission to the doctoral program is offered to students who have been accepted for graduate study through a two-step process:

1. Passing performance on the field exam (FE). The standard for passing the FE is the demonstration of superior intellectual ability through skillful use of concepts, including synthesis of multiple concepts, in foundational, graduate-level material in a field of aerospace engineering.

2. Granting of admission to the doctoral program through 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 FE examination is offered once each year, during the January Independent Activities Period. Students who wish to be considered for the doctoral program must take the FE before the fourth term following initial registration in the graduate program.

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 are cited in the section on General Degree Requirements (http://catalog.mit.edu/mit/graduate-education/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
AeroAstro offers doctoral degrees (PhD and ScD) that emphasize 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 doctoral 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.

The general requirements for this degree are given in the section on General Degree Requirements (http://catalog.mit.edu/mit/graduate-education/general-degree-requirements). A detailed description of the program requirements is outlined in a booklet titled The Doctoral Program (http://mit.edu/aeroastro/academics/grad/forms/New_Doctoral_Booklet.pdf). 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 his or her 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, 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, who may apply to enroll in the program at any time after the end of their first year. For more information, 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.

**Computation for Design and Optimization**
The Computation for Design and Optimization (CDO) ([http://computationalengineering.mit.edu/education](http://computationalengineering.mit.edu/education)) program offers a master’s degree to students interested in the analysis and application of computational approaches to designing and operating engineered systems. The curriculum is designed with a common core serving all engineering disciplines and an elective component focusing on specific applications. Current MIT graduate students may pursue a CDO master’s degree in conjunction with a department-based master’s or PhD program. For more information, see the full program description ([http://catalog.mit.edu/interdisciplinary/graduate-programs/computation-design-optimization](http://catalog.mit.edu/interdisciplinary/graduate-programs/computation-design-optimization)) under Interdisciplinary Graduate Programs.

**Computational Science and Engineering**
The Computational Science and Engineering (CSE) ([http://computationalengineering.mit.edu/education](http://computationalengineering.mit.edu/education)) program allows students to specialize at the doctoral level in a computation-related field of their choice through focused coursework and a doctoral thesis through a number of participating host departments. The CSE program is administered jointly by the Center for Computational Engineering (CCE) and the host departments, with the emphasis of thesis research activities being 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 full program description ([http://catalog.mit.edu/interdisciplinary/graduate-programs/computational-science-engineering](http://catalog.mit.edu/interdisciplinary/graduate-programs/computational-science-engineering)) 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](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 under Interdisciplinary Graduate Programs ([http://catalog.mit.edu/interdisciplinary/graduate-programs/joint-program-woods-hole-oceanographic-institution](http://catalog.mit.edu/interdisciplinary/graduate-programs/joint-program-woods-hole-oceanographic-institution)).

**Leaders for Global Operations**
The 24-month Leaders for Global Operations (LGO) ([http://lgo.mit.edu](http://lgo.mit.edu)) 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 take on leadership roles at top global manufacturing and operations companies.

**System Design and Management**
The System Design and Management (SDM) ([http://sdm.mit.edu](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](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. For additional information, see the program description under the Institute for Data, Systems, and Society ([http://catalog.mit.edu/schools/engineering/data-systems-society](http://catalog.mit.edu/schools/engineering/data-systems-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 assistantships, and academic, research, and interdisciplinary programs in the department, contact Beth Marois (bethamar@mit.edu), Room 33-202, 617-253-0043.

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Wallace E. Vandervelde, ScD
Professor Emeritus of Aeronautics and Astronautics
Laurence R. Young, ScD
Apollo Program Professor Emeritus of Astronautics
Professor Emeritus of Health Sciences and Technology

16.00 Introduction to Aerospace and Design
Prereq: None
U (Spring)
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) and Physics II (GIR); Coreq: 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; transform analysis; and modulation, filtering, and sampling. Experiential lab and aerospace system projects provide additional aerospace context.

H. Balakrishnan, D. L. Darmofal

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
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.

C. Guerra-Garcia, D. L. Darmofal

Core Undergraduate Subjects

16.06 Principles of Automatic Control
Prereq: 16.002 and (16.003 or 16.004)
U (Fall)
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.  
D. W. Miller, S. E. Widnall

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 and Propulsion  
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 material in fluids or 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 program. Requires prior approval. Consult department.  
N. Roy

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

16.120 Compressible Internal Flow  
Prereq: 2.25 or permission of instructor  
Acad Year 2018-2019: Not offered  
Acad Year 2019-2020: G (Spring; first half of term)  
3-0-3 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

16.121 Analytical Subsonic Aerodynamics  
Prereq: 2.25, 18.085, or permission of instructor  
G (Fall; partial term)  
3-0-3 units  
W. L. Harris
16.122 Analytical High Speed Aerodynamics
Prereq: 2.25, 18.085, or permission of instructor
G (Spring; partial term)
3-0-3 units
W. L. Harris

16.13 Aerodynamics of Viscous Fluids
Prereq: 16.100, 16.110, or permission of instructor
Acad Year 2018-2019: G (Spring)
Acad Year 2019-2020: Not offered
3-0-9 units
M. Drela

Materials and Structures

16.20 Structural Mechanics
Prereq: 16.001
U (Spring)
5-0-7 units
P. A. Lagace

16.201 Topics in Materials and Structures
Prereq: Permission of department
U (Spring)
Units arranged
Can be repeated for credit.
Provides credit for 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 department.
N. Roy

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
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
Same subject as 2.076[J]
Prereq: 2.002, 3.032, 16.20, or permission of instructor
Acad Year 2018-2019: G (Fall)
Acad Year 2019-2020: 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

Same subject as 2.099[J]
Prereq: Permission of instructor
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

16.30 Feedback Control Systems
Subject meets with 16.31
Prereq: 6.302 or 16.06
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. Karaman

16.301 Topics in Control, Dynamics, and Automation
Prereq: Permission of department
U (Fall, Spring)
Units arranged
Can be repeated for credit.
Provides credit for work on 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.
N. Roy

16.31 Feedback Control Systems
Subject meets with 16.30
Prereq: 6.302 or 16.06
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. Karaman
16.32 Principles of Optimal Control and Estimation
Prereq: 16.31 and 18.0851
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.
S. R. Hall

16.338[J] Dynamic Systems and Control
Same subject as 6.241[J]
Prereq: 6.003 and 18.06
G (Spring)
4-0-8 units
See description under subject 6.241[J].
M. A. Dahleh, A. Megretski

16.343 Spacecraft and Aircraft Sensors and Instrumentation
Prereq: Permission of instructor
Acad Year 2018-2019: G (Spring)
Acad Year 2019-2020: Not offered
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
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

16.35 Real-Time Systems and Software
Prereq: 1.00 or 6.0002
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

Same subject as IDS.341[J]
Prereq: Permission of instructor
Acad Year 2018-2019: Not offered
Acad Year 2019-2020: 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.
N. G. Leveson
16.36 Communication Systems and Networks
Subject meets with 16.363
Prereq: (6.003 or 16.002) and (6.041B 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: (6.003 or 16.004) and (6.041B 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 6.263[J]
Prereq: 6.041B or 18.204
G (Fall)
3-0-9 units
See description under subject 6.263[J].
E. Modiano

16.391[J] Statistics for Engineers and Scientists
Same subject as 6.434[I]
Prereq: Calculus II (GIR), 6.431B, 18.06, or permission of instructor
G (Fall)
3-0-9 units
See description under subject 6.434[I].
M. Win, J. N. Tsitsiklis

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: 6.011, 16.36, or permission of instructor
Acad Year 2018-2019: Not offered
Acad Year 2019-2020: G (Fall)
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: 6.041B, 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.
L. A. Stirling
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 student work on undergraduate-level material 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 department.
N. Roy

16.405[J] Robotics: Science and Systems
Same subject as 6.141[J]
Prereq: ((1.00 or 6.0001) and (2.003[J], 6.006, 6.009, or 16.06)) or permission of instructor
U (Spring)
2-6-4 units. Institute LAB
See description under subject 6.141[J]. Enrollment limited.
L. Carlone, S. Karaman

16.410 Principles of Autonomy and Decision Making
Subject meets with 16.413
Prereq: 6.0002 or 6.01
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.
B. C. Williams

16.412[J] Cognitive Robotics
Same subject as 6.834[J]
Prereq: (6.034 or 16.413) and (6.041B, 6.042[J], 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 Principles of Autonomy and Decision Making
Subject meets with 16.410
Prereq: 6.0002, 6.01, 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
Prereq: 16.413
G (Fall)
Not offered regularly; consult department
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.

Staff

16.422 Human Supervisory Control of Automated Systems
Prereq: Permission of instructor
Acad Year 2018-2019: Not offered
Acad Year 2019-2020: G (Fall)
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 underwater 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 2018-2019: Not offered
Acad Year 2019-2020: 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

16.430[J] Sensory-Neural Systems: Spatial Orientation from End Organs to Behavior and Adaptation
Same subject as HST.514[J]
Prereq: Permission of instructor
Acad Year 2018-2019: Not offered
Acad Year 2019-2020: G (Spring)
3-0-9 units

See description under subject HST.514[J].

K. Faisal, L. Young

Same subject as STS.470[J]
Prereq: 16.400, 16.453[J], or permission of instructor
Acad Year 2018-2019: Not offered
Acad Year 2019-2020: G (Fall)
3-0-9 units

Examines relationships between human-occupied, remotely operated, and autonomous systems in the extreme environments of the deep ocean, air, and spaceflight. Uses a mix of historical, sociological, and engineering perspectives, examines different forms of human presence in each type of system and how they relate to each other in time and space, including: physical hand-on-the-stick flying, supervisory control, remote operation, systems design, programming autonomous systems, management. Emphasis on networks of people interacting in networks of organizations through networks of machines.

D. A. Mindell

Same subject as HST.518[J]
Subject meets with 16.400
Prereq: 6.041B, 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 6.555[J], HST.582[J]
Subject meets with 6.026[J], HST.482[J]
Prereq: (6.041A or permission of instructor) and (2.004, 6.003, 16.002, or 18.085)
G (Spring)
3-3-6 units
See description under subject HST.582[J].
J. Greenberg, E. Adalsteinsson, W. Wells

16.459 Bioengineering Journal Article Seminar
Prereq: None
G (Fall, Spring)
Not offered regularly; consult department
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: 6.041B, 16.09, or permission of instructor
Acad Year 2018-2019: Not offered
Acad Year 2019-2020: 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

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

16.511 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 2018-2019: Not offered
Acad Year 2019-2020: G (Fall)
3-0-9 units


C. Guerra-Garcia

16.522 Space Propulsion
Prereq: 16.50 or permission of instructor
Acad Year 2018-2019: G (Fall)
Acad Year 2019-2020: Not offered
3-3-6 units

Reviews rocket propulsion fundamentals. Discusses advanced concepts in rocket propulsion ranging from chemical engines to electrical engines. Topics include advanced mission analysis, physics and engineering of microthrusters, solid propellant rockets, electrothermal, electrostatic, and electromagnetic schemes for accelerating propellant. Some coverage is given of satellite power systems and their relation to propulsion systems. Laboratory work emphasizes design and characterization of electric propulsion engines.

P. C. Lozano

16.540 Internal Flows in Turbomachines
Prereq: 2.25 or permission of instructor
Acad Year 2018-2019: Not offered
Acad Year 2019-2020: G (Spring)
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 Ionized Gases
Prereq: 8.02 or permission of instructor
Acad Year 2018-2019: Not offered
Acad Year 2019-2020: G (Fall)
3-0-9 units


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.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: 2.EPW or permission of instructor
U (Fall, Spring)
0-0-1 units

See description under subject 2.EPE.

Staff

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: None
U (Fall, IAP)
1-0-0 units

See description under subject 2.EPW. Enrollment limited.

Staff
16.685 Special Subject in Aeronautics and Astronautics
Prereq: Permission of instructor
Unit (IAP, Spring)
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 M. A. Stuppard

16.686 Special Subject in Aeronautics and Astronautics
Prereq: Permission of instructor
Unit (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

16.688 Special Subject in Aeronautics and Astronautics
Prereq: None
Unit (Fall, Spring)
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
Acad Year 2018-2019: Not offered
Acad Year 2019-2020: U (Fall)
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.
S. R. Hall, J. L. Craig, P. C. Lozano, S. E. Widnall

16.622 Experimental Projects II
Prereq: 16.621
Unit (Fall, Spring)
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 System Safety (New)
Same subject as IDS.045
Prereq: None
Acad Year 2018-2019: Not offered
Acad Year 2019-2020: U (Fall)
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

16.64 Flight Measurement Laboratory
Prereq: 16.002
Unit (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
16.650 Engineering Leadership Lab
Engineering School-Wide Elective Subject.
Offered under: 6.911, 16.650
Subject meets with 6.913[J], 16.667[J]
Prereq: None. Coreq: 6.912; or permission of instructor
U (Fall, Spring)
0-2-1 units
Can be repeated for credit.
L. McGonagle, J. Feiler

16.651 Engineering Leadership
Engineering School-Wide Elective Subject.
Offered under: 6.912, 16.651
Prereq: None. Coreq: 6.911; or permission of instructor
U (Fall, Spring)
1-0-2 units
Can be repeated for credit.
J. Magarian, J. Schindall, L. McGonagle

16.653 Management in Engineering
Engineering School-Wide Elective Subject.
Offered under: 2.96, 6.930, 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)
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

16.662 Engineering Innovation and Design
Engineering School-Wide Elective Subject.
Offered under: 2.723, 6.902, 16.662
Prereq: None
U (Fall, Spring)
2-1-3 units
See description under subject 6.902.
B. Kotelly

16.667 Engineering Leadership Lab
Engineering School-Wide Elective Subject.
Offered under: 6.913, 16.667
Subject meets with 6.911[J], 16.650[J]
Prereq: 6.911
U (Fall, Spring)
0-2-4 units
Can be repeated for credit.
L. McGonagle, J. Feiler

16.669 Project Engineering
Engineering School-Wide Elective Subject.
Offered under: 6.914, 16.669
Prereq: 6.911 or permission of instructor
U (IAP)
1-2-1 units
O. de Weck, J. Feiler, L. McGonagle

16.671[J] Leading Innovation in Teams
Same subject as 6.915[J]
Prereq: None
Acad Year 2018-2019: Not offered
Acad Year 2019-2020: U (Spring)
3-0-6 units
See description under subject 6.915[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, 6.904, 10.01, 16.676, 22.014  
Subject meets with 6.9041, 20.005  
Prereq: None  
U (Fall, Spring)  
2-0-4 units  
See description under subject 10.01.  
D. Doneson, B. L. Trout

16.680 Project in Aeronautics and Astronautics  
Prereq: None  
U (IAP)  
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, IAP, Spring)  
Not offered regularly; consult department  
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 (Fall, IAP, Spring)  
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)  
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 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 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 2018-2019: Not offered  
Acad Year 2019-2020: 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

16.72 Air Traffic Control
Prereq: Permission of instructor
Acad Year 2018-2019: Not offered
Acad Year 2019-2020: 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

16.75[J] Airline Management
Same subject as 1.234[J]
Prereq: 16.71[J]
Acad Year 2018-2019: G (Spring)
Acad Year 2019-2020: Not offered
3-0-9 units

Overview of airline management decision processes, with a focus on economic issues and their relationship to operations planning models and decision support tools. Application of economic models of demand, pricing, costs, and supply to airline markets and networks. Examination of industry practice and emerging methods for fleet planning, route network design, scheduling, pricing and revenue management, with emphasis on the interactions between the components of airline management and profit objectives in competitive environments. Students participate in a competitive airline management simulation game as part of the subject requirements.

P. P. Belobaba

Prereq: Chemistry (GIR) and (1.060B, 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

16.763[J] Air Transportation Operations Research
Same subject as 1.233[J]
Prereq: 6.431B, 15.093[J], 16.71[J], or permission of instructor
Acad Year 2018-2019: Not offered
Acad Year 2019-2020: G (Spring)
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)
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: Permission of instructor
Acad Year 2018-2019: G (Fall)
Acad Year 2019-2020: Not offered
3-0-9 units
See description under subject 1.231[J].
R. de Neufville, A. R. Odoni

Aerospace Systems

16.82 Flight Vehicle Engineering
Prereq: Permission of instructor
U (Fall)
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

16.821 Flight Vehicle Development
Prereq: Permission of instructor
Acad Year 2018-2019: U (Spring)
Acad Year 2019-2020: Not offered
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

16.83[J] Space Systems Engineering
Same subject as 12.43[J]
Prereq: Permission of instructor
U (Spring)
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.
Staff
16.831[J] Space Systems Development
Same subject as 12.431[J]
Prereq: Permission of instructor
Acad Year 2018-2019: Not offered
Acad Year 2019-2020: U (Spring)
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

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

General introduction to systems engineering using the classical V-model. Topics include stakeholder analysis, requirements definition, system architecture and concept generation, trade-space exploration and concept selection, human factors, 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 and contain both aeronautical and astronautical applications. Prepares students for the systems field exam in the Department of Aeronautics and Astronautics.

E. F. Crawley

16.851 Satellite Engineering
Prereq: Permission of instructor
G (Fall)
3-0-9 units

Fundamentals of satellite engineering design, including distributed satellite. Studies orbital environment. Analyzes problems of station keeping, attitude control, communications, power generation, structural design, thermal balance, and subsystem integration. Considers trade-offs among weight, efficiency, cost, and reliability. Discusses choice of design parameters, such as size, weight, power levels, temperature limits, frequency, and bandwidth. Examples taken from current satellite systems.

K. Cahoy

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

See description under subject IDS.336[J].

D. Rhodes

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

See description under subject IDS.332. Enrollment limited.

R. de Neufville

Same subject as IDS.340[J]
Prereq: Permission of instructor
Acad Year 2018-2019: Not offered
Acad Year 2019-2020: 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.

N. G. Leveson
**16.885 Aircraft Systems Engineering**  
Prereq: Permission of instructor  
G (Fall)  
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 2018-2019: Not offered  
Acad Year 2019-2020: 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*

**16.888[J] Multidisciplinary Design Optimization**  
Same subject as IDS.338[J]  
Prereq: 18.085 or permission of instructor  
Acad Year 2018-2019: Not offered  
Acad Year 2019-2020: G (Spring)  
3-1-8 units  
See description under subject IDS.338[J].  
*O. de Weck*

**16.89[J] Space Systems Engineering**  
Same subject as IDS.339[J]  
Prereq: 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, J. A. Hoffman*

**16.895[J] Engineering Apollo: The Moon Project as a Complex System**  
Same subject as STS.471[J]  
Prereq: Permission of instructor  
Acad Year 2018-2019: G (Spring)  
Acad Year 2019-2020: 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: 6.041B 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*

**16.910[J] Introduction to Numerical Simulation**  
Same subject as 2.096[J], 6.336[J]  
Prereq: 18.03 or 18.06  
G (Fall)  
3-6-3 units  
See description under subject 6.336[J].  
*L. Daniel*
Same subject as 2.097[J], 6.339[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.
Q. Wang, S. Groth

16.930 Advanced Topics in Numerical Methods for Partial Differential Equations
Prereq: 16.920[J]
Acad Year 2018-2019: Not offered
Acad Year 2019-2020: 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: (6.431B and 16.920[J]) or permission of instructor
Acad Year 2018-2019: G (Fall)
Acad Year 2019-2020: Not offered
3-0-9 units
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

Department of Aeronautics and Astronautics | 31
16.980 Advanced Project  
Prereq: Permission of instructor  
G (Fall)  
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, Spring, Summer)  
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, 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

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 6.928[J], 15.674[J]  
Prereq: None  
G (Fall, Spring)  
3-0-6 units  
See description under subject 6.928[J].  
D. Nino, J. Schindall

16.995 Doctoral Research and Communication Seminar (New)  
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

16.999 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)  
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, 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 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)
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 (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.S498 Advanced Special Subject in Humans and Automation
Prereq: Permission of instructor
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. 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, 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. 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
16.5798 Advanced Special Subject in Flight Transportation
Prereq: Permission of instructor
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.
Consult M. A. Stuppard

16.5799 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

16.5890 Advanced Special Subject in Aerospace Systems
Prereq: Permission of instructor
G (Fall, IAP, 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

16.5893 Advanced Special Subject in Aerospace Systems
Prereq: None
G (Fall, IAP, 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

16.5896 Advanced Special Subject in Aerospace Systems
Prereq: Permission of instructor
G (Fall, IAP)
Units arranged
Organized lecture or laboratory subject consisting of material not available in regularly scheduled subjects. Prior approval required.
Consult M. A. Stuppard

16.5897 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

16.5898 Advanced Special Subject in Aerospace Systems
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 D. Miller

16.5899 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.
Consult M. A. Stuppard

16.5948 Advanced Special Subject in Computation
Prereq: Permission of instructor
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.
Consult M. A. Stuppard

16.5949 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, 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, IAP, 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