Course 16-ENG degree requirements description

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS

DESCRIPTION OF COURSE 16-ENG DEGREE REQUIREMENTS

S.B. in Engineering -- ABET ACCREDITED

Summary

This document describes the undergraduate degree program, Course 16-ENG, which became effective in the 2010-2011 academic year. Included here are:

- the 16-ENG program description
- the 16-ENG degree chart describing the program requirements
- the requirements for concentrations and details of pre-defined concentrations

Sample subject selections for students entering the program at various stages in their academic studies (i.e. Fall sophomore year, Spring sophomore year, Fall junior year) can be found at: https://aeroastro.mit.edu/education/undergraduate-degrees-requirements/.

Additional questions on the degree program can be sent to Ms. Marie Stuppard (Course 16 AcademicPrograms Administrator, mas@mit.edu), or Prof. N. Roy (Course 16 Undergraduate Chair, nroy@mit.edu).

Program Description

Course 16-ENG is an engineering degree program designed to offer flexibility within the context of aerospace engineering and is a complement to our aerospace engineering degree program (16).

The program leads to the degree "Bachelor of Science in Engineering as Recommended by the Department of Aeronautics and Astronautics. Depending on their interests, Course 16-ENG students can develop (i) a deeper level of understanding and skill in a field of engineering that is relevant to multiple disciplinary areas (e.g., autonomous systems, computational engineering, mechanics, or engineering management), or (ii) 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 6-subject concentration tailored to the student's interests, and completed with hands-on aerospace engineering lab and capstone design subjects, which also satisfy the Institute Lab and CI-M requirements

The core of the 16-ENG degree is similar to the core of the Course 16 degree, specifically including: Unified Engineering (16.001-004); Differential Equations (18.03); a programming subject (6.100A-6.100B or 6.100A-16.C20J); and either feedback control (16.06) or dynamics (16.07). Probability and Statistics (16.09) is not required for the 16ENG program, but students who opt to take 16.09 have the option of using it to satisfy the 16-ENG math/science requirement.

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. The AeroAstro faculty have developed several concentrations in the areas of aerospace software engineering; autonomous systems; communications, embedded systems and networks; computational engineering; computational methods for sustainability, energy; engineering management; environment; space exploration; and transportation. Details on each concentration are provided further below. In addition to these pre-defined concentrations, students can design and propose technically oriented concentrations that reflect their own needs and those of society.

A student's overall program must contain a total of at least one and one-half years of engineering content (144 units) appropriate to the student's field of study. The required core, lab, and capstone subjects include 96-102 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 Conceive-Design-Implement-Operate (CDIO) context of our engineering curriculum. They also satisfy the Institute Communication-Intensive in the Major (CI-M) requirement as well as the Institute Lab requirement. The specific options available to students are identical to those in the Course 16 degree program (also see the Course 16 degree requirements for additional details on the laboratory and capstone sequences). In addition, the Institute requires that all majors be allowed to take additional subjects (normally 48 units) in areas of interest to a student, i.e.., additional math or HASS classes, graduate-level subjects, UROP-for-credit, independent study. The units in a subject that fulfills a student's GIR or departmental requirement cannot also be counted as an unrestrictive elective.

Students are expected to complete the prerequisites for all subjects in their 16-ENG program of study.

16-ENG Degree Chart

Bachelor of Science in Engineering / Course 16-ENG	
General Institute Requirements (GIRs)	Subjects
Science Requirement	6
Humanities, Arts, and Social Sciences Requirement	8
Restricted Electives in Science and Technology (REST) Requirement [can be satisfied from among 6.100A-6.100B or 6.100A-16.C20J; 6.1000, 18.03, 16.001 in the Departmental Program]	2
Laboratory Requirement [can be satisfied by either 16.405J, 16.811, 16.821, 16.831J. Subjects that satisfy the Institute Lab, CIM, and REST requirements for other majors do not replace the Course 16 Lab, CIM, and REST subjects listed here.]	1

Total GIRS 17

Communication Requirement

The program includes a Communication Requirement of 4 subjects: 2 subjects designated as Communication Intensive in Humanities, Arts, and Social Sciences (CI-H); and 2 subjects designated as Communication Intensive in the Major (CI-M). See the Laboratory and Capstone section below for specific options.

Subject names below are followed by credit units, and by prerequisites, if any (co-requisites are in italics)

Departmental Core	84 units

16.001 Unified Engineering: Materials & Structures, 12, REST; Calculus II (GIR); 16.002; 18.03 or 18.032
16.002 Unified Engineering: Signals & Systems, 12; Calculus II (GIR), 16.001; Physics II (GIR); 18.03 or 18.032
16.003 Unified Engineering: Fluid Dynamics, 12; Calculus II (GIR); Physics II (GIR); 18.03 or 18.032; 16.004
16.004 Unified Engineering: Thermodynamics, 12; Calculus II (GIR); Physics II (GIR); 18.03 or 18.032; 16.003; Chemistry (GIR)
6.1000 Intro to Programming & Computer Science; 12, REST (GIR)
or
6.100A Intro to Computer Science Programming in Python, 6, ½ REST, and
6.100B Intro to Computational Thinking & Data Science, 6, ½ REST, or
16.C20J Intro to Computational Science & Engineering, 6, ½ REST
18.03 Differential Equations, 12, REST; Calculus II (GIR), or
18.032 Differential Equations, 12, REST; Calculus II (GIR)
16.06 Principles of Automatic Control, 12; 16.002
or
16.07 Dynamics, 12; 16.001 or 16.002; 16.003 or 16.004

Concentration Subjects	72 units

These electives define a concentrated area of study and must be chosen with the written approval of the student's concentration advisor and of the Course 16 Undergraduate Office for a self-defined concentration. A minimum of 42 units of engineering topics and a minimum of 12 units of mathematics or science topics must be included in the 72 units of concentration electives. In all cases, the concentration subjects must be clearly related to the theme of the concentration.

Capstone and Laboratory Subjects	24 units

One of the following capstone subjects (CIM):
16.82 **Flight Vehicle Engineering,** 12, a minimum of two concentration subjects
16.83J **Space Systems Engineering**, 12; a minimum of two concentration subjects
16.85 **Design and Testing of Autonomous Vehicles**, 16.405J; coreq 16.35, 16.410, or permission of instructor

Plus one of the following laboratory subjects (Lab + CIM):

Robotics
16.405J Robotics: Science & Systems, 12, 1.00 or 6.100A; 2.003, 6.1010, 6.1210, or 16.06; or permission of instructor
Advanced Manufacturing
16.811 Propulsion System Prototyping and Testing for Aerospace Engineers, 12, 16.001, 16.002, 16.003, 16.004
Flight Vehicle Development
16.821 Flight Vehicle Development, 12, permission of instructor
Space Systems Development
16.831J Space Systems Development I, 12, permission of instructor

Departmental Program Units That Also Satisfy the GIRS	(-36)

Unrestricted Electives	48

Total Units Beyond the GIRs Required for S.B. Degree	192

Notes:
No subject can be counted both as part of the 17-subject GIRs and as part of the 192 units beyond the GIRs. Exceptions are department subjects that satisfy the CI-M requirement. Every subject in the student's departmental program will count towards one or the other, but not both. As noted earlier, the Institute requires that all students be allowed to take additional subjects (normally 48 units) in areas of interest to a student, i.e., additional math or HASS classes, graduate-level subjects, UROP-for-credit, independent study. Units in a subject that fulfills a student's GIR or departmental requirement cannot also be counted towards the unrestricted elective units.

Please refer to the current MIT Course Catalogue for subject descriptions, term(s) offered, alternate prerequisites and co-requisites, and an explanation of credit units/hours. Also see the Course 16 *Planned Calendar for Capstone and Lab Subjects*.
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Departmental Concentrations:

Pre-Defined Concentrations

As noted above, the department has established the following concentrations: aerospace software engineering; autonomous systems; communications, embedded systems and networks; computational engineering; computational sustainability; energy; engineering management; environment; space exploration; and transportation. Details on each concentration, including subject requirements, are provided further below. Pre-defined concentrations and their contents are expected to evolve over time in response to curriculum availability, student interest, coordination across the School of Engineering, and broader aerospace and societal trends.

Self-Designed Concentrations

Students also have the opportunity to design and propose technically oriented concentrations that will benefit their career. Self-designed concentrations must have a theme relevant to aerospace and must contain a coherent set of subjects.

To select or propose a concentration, please fill out the Course 16-ENG Enrollment Form/Program of Study available under "Undergraduate Forms and Documents".

All concentrations must be approved by a concentration advisor and also by the Course 16 Undergraduate Office when a concentration is self-designed.

Requirements for Departmental Concentrations

Course requirements for pre-defined as well as self-designed concentrations are as follows—

- Concentrations must include at least 6 subjects (72 units) forming a cohesive program of study within the concentration. First-year level subjects may not be included.
- UROPs (credit or paid) may not be included.
- Concentration subjects must be letter-graded, or designated P/NR by students who enter MIT in Fall 2020 and later.
- Subjects listed in the Course Catalog under PDF grading will count as unrestricted electives.
- Concentration subjects cannot also satisfy General Institute Requirements (GIRS).
- Concentrations must include 3.5 engineering subjects (42 units). Note: this is the bare minimum and is set by the ABET requirement for 144 units of engineering topics. The 16-ENG program covers 8.5 engineering subjects (four subjects from Unified, one from either 6.1000, 6.100A-6.100B or 6.100A-16.C20J, one from either 16.06 or 16.07, and 2.5 from the capstone/lab).
- Concentrations must include one subject in math or science (12 units) to satisfy the ABET math and science requirement. Basic math and science subjects may be included only if they are prerequisites to a higher-level engineering subject in the concentration or are specified within the guidelines of a pre-defined concentration; otherwise, such **subjects can** be taken as unrestricted electives.
- Concentrations must have relevance to aerospace and related engineering systems.

As these requirements may be difficult to manage, the role of concentration advisors - particularly advisors for students pursuing individually tailored concentrations - will be critical. Specific pre-defined concentrations such as Computational Engineering and Engineering Management are examples of concentrations where the satisfaction of the ABET engineering requirement will have to be carefully monitored. The assigning of advisors for students in 16-ENG will be based on the concentrations they select.

Departmental Oversight of Concentrations:

The departmental oversight of the pre-defined and self-designed concentrations will rest with the department's Undergraduate Committee. This committee has authority for approving (or not) pre-defined and self-designed concentrations.

Pre-Defined Concentrations and Their Subject Requirements

Concentration in Aerospace Software Engineering

Faculty Points of Contact and Concentration Advisors: N.G. Leveson, B.C. Williams (on sabbatical AY25-26))

The 16-ENG concentration in Aerospace Software Engineering is designed for students who wish to connect a foundation in aerospace engineering with greater depth in topics related to the development of real-time aerospace software, including aircraft, spacecraft and satellites, and air transportation systems. Students within this concentration will develop the skills to design and analyze advanced software systems and learn how to apply them to aerospace systems. Through a strong combination of theory and applied work, graduates of this concentration will be well suited to pursue graduate school or a career in industry.

To satisfy the SB Engineering degree requirements, at least 42 units must be drawn from engineering subjects (subjects with at least a joint listing in an engineering department), and 12 units must be from math/science content areas.

Subject Requirements for the Aerospace Software Engineering Concentration
(Note: students may propose to substitute other classes for those on any of the following lists.)

1. Discrete Math:
Pick one course from the following list:
- 6.1200J/18.062J: Mathematics for Computer Science [M/S].
- 6.1400J/18.400J: Computability, and Complexity Theory [M/S].
- 6.1220J/18.410J): Design and Analysis of Algorithms [M/S].

2. Algorithm Design and Analysis:
Pick two courses from the following list:
- 6.1020 Elements of Software Construction [E]
- 6.1210: Introduction to Algorithms [E]
- 16.30: Feedback Control Systems [E]

3. Foundations in Software Engineering and Aerospace Engineering

Pick 3 courses from the following list:
- 6.1800: Computer Systems Engineering [E]
- 16.35: Real-time Systems and Software [E]
- 16.400: Human Systems Engineering [E]
- 16.63J/IDS.045J: System Safety [E]

Concentration in Autonomous Systems

Faculty Points of Contact: J.P. How, N. Roy, B. Williams (on leave AY25-26)

Concentration Advisors: A. Bobu, L. Carlone, C. Fan, S.R. Hall, J.P. How, S. Karaman, N. Roy, J.A. Shah

The 16-ENG concentration in Autonomous Systems is designed for students who wish to connect a foundation in aerospace engineering with greater depth in topics related to automated real-time decision making, robotics, embedded systems, controls and human-machine interaction. Students within this concentration will develop the skills to design and analyze advanced planning and control systems and learn how to apply them to autonomous systems, including autonomous vehicles and robots. Through a strong combination of theory and applied work, graduates of this concentration will be well suited to pursue graduate school or a career in industry.

To satisfy the SB Engineering degree requirements, at least 42 units must be drawn from engineering subjects (subjects with at least a joint listing in an engineering department), and 12 units must be from math/science content areas.

Subject Requirements for the Autonomous Systems Concentration

1 Discrete Math, Probability and Statistics:
Pick either:
- 6.1200J/18.062J: Mathematics for Computer Science [M/S] or one of:
- 6.3700 Introduction to Probability [M/S].
- 16.09: Statistics and Probability [M/S].

2 Foundations
Pick three courses from the following list:
- 6.1210: Introduction to Algorithms [E].
- 16.06: Principles of Automatic Control [E] (counted only if not taken as part of the SB Engineering core).
- 16.30: Feedback Control Systems [E].
- 16.410: Principles of Autonomy and Decision Making [E].

3 Technology Areas
Select one of the following three technology areas and select two courses from that area:
1 Robotics
- 2.12: Introduction to Robotics [E]
* 6.4200J/16.405J: Robotics Science and Systems I [E]* (If 6.4200/16.405 is selected as a concentration subject, it cannot also be used to satisfy the Lab/CI-M requirement.)

* 16.35: Real-time Systems and Software [E]

2 Embedded Systems

- 6.2000: Circuits and Electronics [E].
- 6.2050: Digital Systems Lab [E].
- 6.2060: Microcomputer Project Laboratory [E].
- 16.35: Real-time Systems and Software [E].
- 16.36: Communication, Systems and Networks [E].

3 **Humans, Systems and Automation**

- 1.041: Transportation Foundations & Methods [E]
- 6.4120J/9.66J: Computational Cognitive Science [E].
- 9.00: Introduction to Psychological Science [S].
- 9.01: Introduction to Neuroscience [S].
- 16.400: Human Systems Engineering [E].

Concentration in Communications, Embedded Systems and Networks

Faculty Points of Contact and Concentration Advisors: E.H. Modiano, M.Z. Win

The 16-ENG concentration in Communications, Embedded Systems and Networks is designed for students who wish to connect a foundation in aerospace engineering with greater depth in topics related to communication systems and networks, and networked embedded systems.

Students within this concentration will develop the skills needed to design and analyze communication systems and networks and to learn how to apply them to space, air and terrestrial communications, as well as to embedded computer systems. Through a strong combination of theory and applied work, graduates of this concentration will be well suited to pursue graduate school or a career in industry.

To satisfy the SB Engineering degree requirements, at least 42 units must be drawn from engineering subjects (subjects with at least a joint listing in an engineering department), and 12 units must be from math/science content areas.

Subject Requirements for the Communications, Embedded Systems and Networks Concentration

All students must take one subject in each of the following areas:

1**. Probability and Discrete Mathematics:** Select one class from the following list.
16.09 Statistics and Probability [M/S].
6.3700 Introduction to Probability I-II [M/S].
6.1200J Mathematics for Computer Science [M/S].

2. Foundations

All students in this concentration must take the following course.
16.36 Communications Systems and Networks [E]

3. Technology Electives

Select 4 classes from the following list:
2.110 Information, Entropy, and Computation [E]
6.1210 Introduction to Algorithms [E]
6.300 Signal Processing [E]

6.3010 Signals, Systems and Inference [E]
6.1800 Computer Systems Engineering [E]
6.1220 Design and Analysis of Algorithms [E]
6.2050 Introduction to Digital Systems Lab [E]
6.3260 Networks [E]
6.3800 Introduction to Inference [E]
16.06: Principles of Automatic Control [E]
16.30 Feedback Control Systems [E]
16.35 Real-time Systems and Software [E]
16.37 Data Networks [E]
16.400 Human Systems Engineering [E]
16.410 Principles of Autonomy and Decision Making [E]

Concentration in Computational Engineering

Faculty Point of Contact: Y.M. Marzouk

Concentration Advisors: D. Darmofal, J. Peraire, R. Radovitzky, Q. Wang, B.C. Williams (on leave AY25-26)

The Computational Engineering Concentration is designed for students who wish to gain a strong foundation in the computational methods that are employed throughout a range of engineering and science fields, including aerospace engineering. Graduates of this concentration will be prepared to apply computational methods (e.g., for prediction, optimization, control and data assimilation) for the analysis and design of engineering systems and will have a solid background in the fundamental mathematics and computer science that underpin this field. To satisfy the SB Engineering degree requirements, at least 42 units must be drawn from engineering subjects (subjects with at least a joint listing in an engineering department), and 12 units must be from math/science content areas.

Subject Requirements for the Computational Engineering Concentration

Foundational content (4 classes)

Linear algebra: 18.06 (M/S)
Numerical methods for simulation and design: 1.021 (E) or 16.90 (E) or 18.303 (M/S)

At least 2 subjects drawn from different areas from the following list:
Probability and statistics: 1.010 (E) or 6.3700 (M/S) or 16.09 (M/S) or 18.600 (M/S)
Numerical analysis: 18.330 (M/S)
Optimization and decision-making: 15.053 (E), 16.410 (E)
Discrete mathematics and algorithms: 6.1200 (M/S)

Elective content (2 classes)

Any two 12-unit subjects with a focus on:
* a discipline in which computation is applied, e.g., aerodynamics (16.100), control (16.30), propulsion (16.50), structural mechanics (16.20), etc; and/or

* advanced computational engineering methods

Concentration in Computational Sustainability

Faculty Points of Contact: Y.M. Marzouk, B.C. Williams (on leave AY25-26)

Concentration Advisors: Y.M. Marzouk, B.C. Williams, D. Varon

The 16-ENG Computational Sustainability Concentration focuses on computational methods for balancing environmental, economic, and societal needs for a sustainable future. Through this concentration, students explore the major problem domains that impact global sustainability, those technologies and processes that offer

the greatest opportunity to increase sustainability in these domains, and the fundamental computational methods that support these technologies and processes.

While the subjects identified below offer a guideline, each student must meet with a concentration advisor, listed above, to devise and agree upon a coherent sequence of subjects. This sequence is split evenly between a computational core and a set of subjects that place computation in the context of a problem of sustainability. The computational core comprises three subjects, one on mathematical modeling, one on simulation-based prediction, and one on decision making. The student will typically round out his or her concentration with a coherent sequence of subjects focused on a sustainability problem domain, such as energy, transportation, or water resource management. This sequence will contain two modeling and technology subjects and one policy subject.

Students are encouraged to elect 16.06 (Principles of Automatic Control) to satisfy the 16ENG core requirements; this subject will provide a foundation for subsequent subjects on decision-making and optimization.

To satisfy the SB Engineering degree requirements, at least 42 units must be drawn from engineering subjects (subjects with at least a joint listing in an engineering department), and 12 units must be drawn from math/science content areas.

Subject Requirements for the Concentration in Computational Sustainability

Part A. Computational Core:

Students will select one subject from each of the three areas below.

1. 16.410 Principles of Autonomy and Decision-Making
2. 16.90 Computational Methods for Aerospace Engineering
3. One of the following subjects in mathematics:
    a. 6.3700 Introduction to Probability I-II
    b. 6.1200J Mathematics for Computer Science
    c. 16.09 Statistics and Probability

d. 18.06 Linear Algebra

Part B. Sustainability Problem Area

Students will select two modeling and technology subjects and one policy subject that support a focused problem domain. Problem domains and their corresponding technology areas include:

- Human-built systems and human impact: design, optimization, modeling and impact monitoring of human built systems; transportation systems including urban mobility and air traffic management; energy and resource management; energy auditing and upgrades; renewable energy sources; mining; housing and infrastructure; urban planning and land use; sustainable communities and cities; methodologies for developing countries and measurement of economic, environmental, and societal impacts (e.g., lifecycle analysis, ecological footprint, general equilibrium modeling)
- Ecosystem monitoring and modeling: remote sensing and earth observing systems; in situ sensing including airborne and deep-sea mobile platforms; sensor networks; models of ecosystem structure and function; assimilating models from data, such as atmospheric, oceanographic, and subsurface models; species distribution and migration; invasive species; emerging diseases; and ecosystem services.
- Pollution production and ecosystem management: policy and decision making for managing the atmosphere, water, soils, fisheries, forestry, and agriculture; greenhouse gas emissions, toxic pollutants, and agricultural runoff.
- Economics and human behavior: human wellbeing, poverty and disease, and overpopulation; modeling, decision making, management policy and mechanism design.

Concentration in Energy

Faculty Point of Contact: Z.S. Spakovszky

Concentration Advisors: M. Folk, Y.M. Marzouk, J. Peraire, D. Varon, B.L. Wardle, B.C. Williams (on leave AY25-26)

The 16-ENG Energy Concentrationis designed for students who wish to connect a foundation in aerospace engineering with a greater depth in energy technologies for conversion, storage, utilization and efficient operations. It is aimed at the analysis, design, implementation, and operation of efficient and sustainable energy systems addressing the global energy challenge. The subjects offered in this concentration focus on (1) the conversion of energy from different fossil, renewable and nuclear sources, (2) propulsion and energy utilization in land, sea and air transportation, (3) residential and industrial applications, and (4) integration and operation of propulsion and power systems while addressing environmental and economical constraints. By selecting appropriate subjects in this concentration (and typically taking some additional subjects) students may also obtain a Minor in Energy Studies. Except for the specification of 2.006 (Thermal-Fluids Engineering) and 12.300J (Global Change Science) as required subjects and the addition of operations and control, the 16-ENG Energy concentration is similar to the Course 2-A Energy concentration.

Subject Requirements for the Energy Concentration

Foundational Content (3 subjects)
1.067[J]/10.421[J]/IDS.065[J] Energy Systems for Climate Change Mitigation (E) (Mi)

2.006 Thermal-Fluids Engineering II (E) (Mi)
12.300J Global Change Science (MS) (Mi) or 12.021 Earth Science, Energy, and the Environment (MS) (Mi)

Plus 1 subject from the following list:
2.51 Intermediate Heat and Mass Transfer (MS)
2.570 Nano-to-Macro Transport Processes (E) (Mi)
2.60J/10.390J Fundamentals of Advanced Energy Conversion (E) (Mi)
2.650J/10.291J/22.081J Introduction to Sustainable Energy (E) (Mi)
5.601 Thermodynamics I (6 units) **and** 5.602 Thermodynamics II and Kinetics (6 units) (MS) (Mi) 8.21 Physics of Energy (MS) (Mi)

Energy Conversion and Utilization Technologies
(3 subjects) The three subjects do not need to be in the same area.

Transportation
2.612 Marine Power and Propulsion (E) (Mi)
16.50 Aerospace Propulsion (E)

Electromagnetic and Electrochemical Power Systems
6.2200 Introduction to Electrical Power Systems (E) (Mi)
6.2220 Power Electronics Laboratory (E) (Mi)
6.2530 Introduction to Nanoelectronics (E) (Mi)
6.7120 Principles of Modeling, Computing & Control for Decarbonized Electric Energy Systems (E) (Mi) 10.426 Electrochemical Energy Systems (E)

Resources
2.813 Energy, Materials, and Manufacturing (E) (Mi)
2.814 Exploring Sustainability at Different Scale (E) (Mi)

Solar
2.627 Fundamentals of Photovoltaics (E) (Mi)

Nuclear
22.05 Neutron Physics and Radiation Transport (MS)
22.06 Engineering of Nuclear Systems (E) (Mi)
22.061 Fusion Energy (E) (Mi)
22.033 Nuclear Systems Design Project (15 units) (E) (Mi)

Residential and Industrial Applications
4.401J/1.564 Environmental Technologies in Buildings (Mi)
4.441 From the Solar House to Net Zero Buildings (Mi)

Sustainable Operation and Control

16.06 Principles of Automatic Control (E) (if not taken as part of the SB Engineering core)
16.30 Feedback Control Systems (E)
16.410 Principles of Autonomy and Decision Making (E)

Societal, Economic and Political Context:
Optional subjects on broader societal, economic, and political aspects of energy

1.801J Environmental Law, Policy, and Economics: Pollution Prevention and Control (Mi)
10.04 A Philosophical History of Energy (Mi)

11.165 Urban Energy Systems and Policy (Mi)
11.149 Decarbonizing Urban Mobility (Mi)
14.42 Environmental Policy and Economics (Mi)
14.44J/15.037J Energy Economics and Policy (Mi)
STS.032 Energy, Environment, and Society

Project Experiences (0-1 subject)
Optional project experiences in energy
10.27 Energy Engineering Projects Laboratory (E) (Mi)

EC.711J/2.651J D-Lab: Intro to Energy in Global Development (Mi)

Concentration in Engineering Management

Faculty Point of Contact: E.M. Greitzer

Concentration Advisors: H. Balakrishnan, O. L. de Weck, E.M. Greitzer

Engineering Management deals with the engineering relationships between the management tasks of planning, organization, leadership, and control, and the human elements of production, research, and service organizations. It also deals with the stochastic nature of these management systems, as well as the integration of management systems into different technological environments. The Concentration in Engineering Management has been created for students who are aiming their career plans towards roles in management in aerospace or related industries.

To satisfy the SB Engineering degree requirements, there must be at least 42 units of engineering content in the subjects chosen. The subjects in the chosen program need to be assessed on a subject-by-subject basis with a faculty point of contact as well as with the student's advisor, because not all subjects of

interest (see below) have their units counted towards engineering content. In addition to the engineering subjects, twelve (12) units must be from math/science content areas.

Students pursuing the Engineering Management Concentration may also wish to consider a Minor in Management Science or a Minor in Management. (Some subjects in a concentration may also be counted towards a minor.)

Subjects chosen for an engineering management concentration should be consistent with the above description. A limited number of recommended engineering courses are given below, along with a short description, but it is again emphasized that the concentration is not limited to these and that the individual programs should be worked out with the faculty point of contact.

- 3.080: Strategic Materials Selection ([E]
- 6.3700: Intro to Probability I-II ([M/S].
- 15.053: Optimization Methods in Business Analytics ([E]
- 15.075: Statistical Thinking and Data Analysis ([E]
- 15.871: Introduction to System Dynamics ([E] (half term)
- 15.872: System Dynamics II ([E] (half term)
- 16.09: Statistics and Probability ([E]
- 16.653: Management in Engineering ([E]

Other subjects of interest with less engineering units include:

- 14.01 Principles of Microeconomics (no engineering units)

  15.501: Corporate Financial Accounting ([E]

- 15.669 Strategies for People Analytics

Concentration in Environment

Faculty Points of Contact: H. Balakrishnan, Y.M. Marzouk

Concentration Advisors: H. Balakrishnan, R.J. Hansman, Y.M. Marzouk, B.C. Williams (on leave AY25-26)

The 16-ENG Environment Concentration is designed for students who wish to connect a foundation in aerospace engineering with greater depth in topics related to the environment and sustainability. The concentration emphasizes the perspectives of environmental science, technology, and policy. Supporting these perspectives, students will choose subjects focused on understanding and observing natural systems, guiding the intelligent use of natural resources, and understanding the social context of decision-making for sustainability.

While the subjects identified below are a guideline, each student must meet with a concentration advisor, listed above, to devise and agree upon a coherent sequence of subjects. This sequence will typically include breadth—obtained by selecting at least one subject from each area identified below—and a focal area comprising of at least three subjects. To satisfy the SB Engineering degree requirements, at least 42 units must be drawn from engineering subjects (subjects with at least a joint listing in an engineering department), and 12 units must be from math/science content areas.

If subject 16.405J/6.4200J is selected as a concentration subject, it cannot also be used to satisfy the Lab/CI-M requirement.

Subject Requirements for the Environment Concentration:

Choose at least one technology-focused subject:

- 2.650J/10.291J/22.081J Introduction to Sustainable Energy (E)
- 2.813 Energy, Materials, and Manufacturing (E)
- 3.080 Strategic Materials Selection (E)
- 4.021 Design Studio: How to Design (E)
- 6.4200J/16.405J Robotics: Science and Systems I (E)
- 15.053 Optimization Methods Management Science (E)
- 16.410 Principles of Autonomy and Decision Making (E)
- 16.50 Aerospace Propulsion (E)

Choose at least one science-focused subject:

- 1.018J/7.30J/12.031J Fundamentals of Ecology I (M/S)
- 1.020 Modeling and Decision-Making for Sustainability (M/S)
- 1.061 Transport Processes in the Environment I (M/S)
- 1.070AJ/12.320AJ Introduction to Hydrology and Water Resources (M/S), ½ term, and
- 1.070BJ/12.320BJ Introduction to Hydrology Modeling (M/S); ½ term
- 1.071J/12.300J Global Change Science (M/S)
- 1.080 Chemicals in the Environment (M/S)
- 12.009 Non Linear Dynamics: The Natural Environment (M/S)
- 12.021 Earth Science, Energy, and the Environment (M/S)
- 12.086 Modeling Environmental Complexity (M/S)

* 12.301 Climate Science (M/S)
• 12.306J/10.571J Atmospheric Chemistry Models & Climate (M/S)

Choose at least one policy-focused subject:

- 1.801J/11.021J/17.393/ Environmental Law, Policy, and Economics: Pollution Prevention and Control IDS.060J
- 1.802J/11.022J Regulation of Chemicals, Radiation, and Biotechnology (E)
- 12.348J Global Climate Change: Economics, Science, and Policy (M/S)
- 14.42 Environmental Policy and Economics
- 17.181 Sustainability: Political Economy, Science and Policy

Concentration in Space Exploration

Faculty Point of Contact: J.A. Hoffman

Concentration Advisors: K. Cahoy, J.A. Hoffman, O. L. de Weck, C. Guerra Garcia, D.E. Hastings, R. Linares, P. C. Lozano, L. Petersen, J.A. Shah, B.C. Williams (on leave AY25-26)

The 16-ENG Concentration in Space Exploration is designed for students with an interest in space exploration. Because space exploration combines science and engineering, at least one science subject

is required, together with three engineering subjects. Candidate science subjects include those that provide background in i) remote sensing for areas such as astronomy and astrophysics, ii) search and maintenance of life outside Earth, such as astrobiology and exobiology, iii) in-situ exploration, for areas such as geology and planetary physics and iv) topics that serve as a scientific foundation for technology development, such as advanced physics. The engineering subjects require a selection from foundational subjects in areas essential to

the engineering of current and future space exploration systems. In addition, two subjects are required that synthesize engineering and scientific knowledge in the context of actual space exploration projects or systems. Note that several of the subjects have more or fewer than 12 units. The total concentration requirement is
72 units; 42 units must be engineeri ng subjects (subjects with at least a joint listing in an engineering department); and 12 units must be from math/science content areas. It is important for students interested in Space Exploration to have the experience of working on a design project that is space related, allowing them to integrate and apply their classroom learning in the space exploration context. In order to fulfill this requirement, all students pursuing the Space Exploration concentration should select the 16.83J space-
related capstone.

Subject Requirements for the Space Exploration Concentration

At least one subject from among the following (School of Science):

Space Exploration combines science and engineering. Therefore, an engineering degree with concentration in Space Exploration requires at least one science class. Potential selections are grouped below:

Observational Exploration – Astronomy/Astrophysics
•8.03 Physics III (S)
•8.224 Exploring Black Holes: General Relativity and Astrophysics (S)
•8.282J/12.402J Introduction to Astronomy (S – 9 units)
•8.284 Modern Astrophysics (S)
•8.286 The Early Universe (S)
•8.287J/12.410J Observational Techniques of Optical Astronomy (S - 15 units) •12.425 Extrasolar Planets: Physics and Detection Techniques (S)

In-Situ Exploration
•7.30AJ Fundamentals of Ecology I (S)

•12.002 Intro to Geophysics and Planetary Sci (S)
•12.007 Geobiology: History of Life on Earth (S)
•12.104 Geochemistry of Natural Waters (S)
•12.201 Essentials of Global Geophysics (S)
•12.400 Our Space Odyssey (S)
•12.420 Essentials of Planetary Sci (S)

Science for Technology Foundation
•8.07 Electromagnetism II (S)
•8.21 Physics of Energy (S)

At least three subjects from among the following (School of Engineering):

The engineering classes listed below all have applicability to Space Exploration.

•2.017J/1.015J Design of Electromechanical Robotic Systems (E)
•2.12 Introduction to Robotics (E)
•2.627 Fundamentals of Photovoltaics (E)
•2.71 Optics (E)
•6.2370 Modern Optics Project Laboratory (E)
•10.426 Electrochemical Energy Systems (E)
•16.07 Dynamics (E)
•16.20 Structural Mechanics (E)
•16.30 Feedback Control Systems (E)
•16.35 Real-Time Systems and Software (E)
•16.36 Communication Systems and Networks (E)
•16.400 Human Systems Engineering (E)
•16.405J/6.4200 Robotics: Science and Systems I (E) [If used here, 16.405J cannot Coursealso be used to satisfy the Course 16 Lab requirement]
•16.410 Principles of Autonomy and Decision Making (E)
•16.50 Aerospace Propulsion (E)

Two more space-related subjects (SoE or SoS):
The Space Exploration concentration requires two more classes, at least one of which has to be an engineering class (i.e. one science and one engineering class or two engineering classes). The studz`ent can select from the subject listings above.

Note that for all Course 16 degrees, undergraduates may petition the Undergraduate Office to have an undergraduate course substituted with an equivalent graduate subject. Graduate subjects relevant to the space exploration concentration include:
School of Science courses related to space exploration

Astrobiology and Exobiology
•22.55J/HST560J Radiation Biophysics (E)*

School of Engineering courses related to Space Exploration
•16.32 Principles of Optimal Control and Estimation (E)*
•16.343 Spacecraft and Aircraft Sensors and Instrumentation (E)*
•16.423J/HST.515J/IDS.337J Aerospace Biomedical and Life Support Engineering (E)*
•16.522 Space Propulsion (E)*
•16.851 Intro to Satellite Engineering (E, 6 units)* - 16.853 Advanced Satellite Engineering (E, 6 units)
•16.895J/STS.471J) Engineering Apollo: The Moon Project as a Complex System (E)*

* Graduate-level subjects.

Concentration in Transportation

Faculty Points of Contact: H. Balakrishnan, R.J. Hansman

The 16-ENG Transportation Concentration is available for students who wish to combine a foundation in aerospace engineering with a greater depth in either air transportation or transportation generally. The concentration typically builds from a core in either vehicle technologies or information technologies and expands to specific focus areas of interest to the student. These can include Airline Operations and Management, Air Transportation Infrastructure (Air Traffic Control and Airports), Transportation Systems, Multi-Modal Transportation, Environment and Transportation or other topics of interest. The faculty will work with students interested in this concentration to craft a coherent curriculum, which not only allows exploration based on a student's individual interests and goals but also meets the 16-ENG degree requirements.

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