MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS

DESCRIPTION OF COURSE 16-ENG DEGREE REQUIREMENTS

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, etc).

Additional questions on the degree program can be directed towards Marie Stuppard (Course 16-ENG Coordinator and Academic Programs Administrator), mas@mit.edu.

Description of Course 16-ENG

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 & Astronautics (the department will be seeking accreditation by the Accreditation Board for Engineering and Technology as an engineering degree). 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.

The core of the 16-ENG degree is similar to the core of the 16 degree, specifically including: Unified Engineering (16.001-004); Differential Equations (18.03); a programming subject (6.00); and either feedback control (16.06) or dynamics (16.07).

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 are able to 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 16 degree program (also see the Course 16 degree requirements for additional details on the laboratory and capstone sequences).

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

Description of Course 16-ENG

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 6.00; 18.03 or 18.032; and 16.001 in the Departmental Program]	2
Laboratory Requirement [can be satisfied by 16.405J, 16.622, 16.821, or 16.831J in the Departmental Program]	1
Total GIR Subjects Required for SB Degree	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.

PLUS Departmental Program	Units

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

Departmental Core	84

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)*
6.00 Introduction to Computer Science & Programming, 12, 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; 16.003 or 16.004
or
16.07 Dynamics, 12; 16.001 or 16.002; 16.003 or 16.004

Concentration Subjects	72

These electives define a concentrated area of study and must be chosen with the written approval of the AeroAstro Undergraduate Office. 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.

Laboratory and Capstone Subjects	24-30

One of the following two subjects:
16.82 Flight Vehicle Engineering, 12, CI-M; a minimum of two concentration subjects
16.83J Space Systems Engineering, 12, CI-M; a minimum of two concentration subjects
Plus one of the following four options:

Robotics
16.405J Robotics: Science & Systems, 12, 1.00 or 6.0001; 2.003, 6.005, 6.006, 6.009, or 16.06; or permission of instructor
or
Experimental Projects
16.621 Experimental Projects I, 6; *16.06 or 16.07; and*
16.622 Experimental Projects II, 12, LAB, CI-M; 16.621
or
Flight Vehicle Development
16.821 Flight Vehicle Development, 18, LAB, CI-M; permission of department
or
Space Systems Development
16.831J Space Systems Development I, 18, LAB, CI-M; permission of department

Description of Course 16-ENG

Departmental Program Units That Also Satisfy the GIRS	(-36)
Unrestricted Electives	48
Total Units Beyond the GIRs Required for SB Degree	**192-198**

Notes:
No subject can be counted both as part of the 17-subject GIRs and as part of the 192-198 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. 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 Experimental and Capstone Subjects.*

Description of Course 16-ENG

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 Documentations".

All concentrations need to be approved by a Concentration Advisor and by the Course 16 Undergraduate Office.

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, e.g. 16.00, may not be included.
- UROPs may not be included.
- Concentration subjects must be letter graded.
- Subjects graded PDF 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 from Unified, one from 6.00, 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 should 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: N.G. Leveson, B.C. Williams

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.

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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 are as follows. Note that 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:
• 6.042J/18.062J: Mathematics for Computer Science [M/S].
• 6.045J/18.400J: Automata, Computability, and Complexity [M/S].
• 6.046J/18.410J): Design and Analysis of Algorithms [M/S].

2. Algorithm Design and Analysis:

Pick two courses from the following list:
• 6.031 Software Construction [E]
• 6.006: 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:
• 6.033: Computer System 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, B.C. Williams

Concentration advisors: L. Carlone, S.R. Hall, 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:
• 6.042J/18.062J: Mathematics for Computer Science [M/S]
or one of:
• 6.041A-B: Introduction to Probability I-II [M/S].
• 16.09: Statistics and Probability [M/S].
2 Foundations
Pick three courses from the following list:
• 6.006: 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]
• 6.141J/16.405J: Robotics Science and Systems I [E] ???
• 6.801: Machine Vision [E]
• 16.35: Real-time Systems and Software [E].

2. Embedded Systems
• 6.002: Circuits and Electronics [E].
• 6.111: Introductory Digital Systems Lab [E].
• 6.115: 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 Systems Modeling [E]
• 6.804J/9.66J: Computational Cognitive Science [E].
• 6.813: User Interface Design and Implementation [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: 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:

<u>All students must take one subject in each of the following areas:</u>

1. Probability and Discrete Mathematics
Select one class from the following list.
16.09 Statistics and Probability [M/S].
6.041A-B Introduction to Probability I-II [M/S].
6.042J 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:
2.110J Information, Entropy, and Computation [E]
6.006 Introduction to Algorithms [E]
6.011 Signals, Systems and Inference [E]
6.033 Computer System Engineering [E]
6.046J Design and Analysis of Algorithms [E]
6.111 Introduction to Digital Systems Lab [E]
6.207J Networks [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 points of contact: Y.M. Marzouk

Concentration advisors: D.L. Darmofal, J. Peraire, R. Radovitzky, Q. Wang, B.C. Williams

Description of Course 16-ENG

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 6.041A-B (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: 6.042 (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

Concentration advisors: S. Barrett, Y.M. Marzouk, B.C.Williams

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 SB Eng 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.

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. 6.041A-B Introduction to Probability I-II
   b. 6.042J Mathematics for Computer Science
   c. 16.09 Statistics and Probability
   d. 18.06 Linear Algebra

Part B. Sustainability problem area

Description of Course 16-ENG

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.
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Concentration in Energy

Faculty points of contact: S. Barrett, Z.S. Spakovszky

Concentration advisors: Y.M. Marzouk, J. Peraire, B.L. Wardle, B.C. Williams,

The 16-ENG Energy Concentration is 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 the conversion of energy from different fossil, renewable and nuclear sources, energy utilization in land, sea and air transportation, residential and industrial applications, and the integration and operation of 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. With the exception of the specification of 2.006 (Thermal-Fluids Engineering) and 12.300J (Global Change Science) as required subjects and the addition of operations and control, it is similar to the Course 2-A Energy Track.

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. The latter requirement is satisfied by 12.300J. The (Mi) annotation indicates classes that are on the approved list of courses for a Minor in Energy Studies (http://web.mit.edu/mitei/education/minor.html#foundations). Note that the suggested subjects for the 16-ENG Energy Concentration and the Minor in Energy Studies are different. Students who wish to satisfy both may need to take additional subjects and should consult also with the MITEI Education Office.

Subject suggestions for the Energy Concentration

Foundational Content (3 subjects)
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) *or* 12.340 Global Warming Science (MS) (Mi)

Plus 1 subject from the following list:
2.51 Intermediate Heat and Mass Transfer (MS)
2.60J/10.390J Fundamentals of Advanced Energy Conversion (E) (Mi)
2.650J/10.291J/22.081J Introduction to Sustainable Energy (E) (Mi)
5.60 Thermodynamics and Kinetics (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
6.007 Electromagnetic Energy: From Motors to Solar Cells (E) (Mi)
6.061 Introduction to Electrical Power Systems (E) (Mi)

6.131 Power Electronics Laboratory (E) (Mi)
10.426 Electrochemical Energy Systems (E)

Resources
2.813 Energy, Materials, and Manufacturing (E) (Mi)

Solar
2.627 Fundamentals of Photovoltaics (E) (Mi)

Nuclear
22.05 Neutron Science and Reactor Physics (MS)
22.06 Engineering of Nuclear Systems (E) (Mi)

Residential and Industrial Applications
2.66J/1.044J/4.42J Fundamentals of Energy in Buildings (E) (Mi)
4.401 Environmental Technologies in 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 (0-1 subject)
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)
11.161J Energy Decisions, Markets, and Policies (Mi)
11.162 Politics of Energy and the Environment (Mi)
11.165 Urban Energy Systems and Policy (Mi)
12.348J/15.026J Global Climate Change: Economics, Science, and Policy (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: Energy (SP.775) (Mi)

Concentration in Engineering Management

Faculty point of contact: E.M. Greitzer

Concentration advisors: H. Balakrishnan, S. Barrett, P. Lagace

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.

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- 3.080: Strategic Materials Selection ([E], 12 units).
- 6.041A-6.041B: Intro to Probability I-II ([M/S], 12 units).
- 15.053: Optimization Methods in Business Analytics ([E], 12 units
- 15.075: Statistical Thinking and Data Analysis ([E], 12 units).
- 15.871: Introduction to System Dynamics ([E], 6 units)
- 15.872: System Dynamics II ([E], 6 units).
- 16.09: Statistics and Probability ([E], 12 units).
- 16.653: Management in Engineering ([E], 12 units).

Other subjects of interest with less engineering units include:

- 14.01 Principles of Microeconomics, 12 units (no engineering units)
- 15.501: Corporate Financial Accounting ([E], 12 units)
- 15.668: People and Organizations ([E], 9 units)
- 15.812: Marketing Management ([E], 9 units)

Concentration in Environment

Faculty points of contact: H. Balakrishnan, Y.M. Marzouk

Concentration advisors: H. Balakrishnan, S. Barrett, E.F. Crawley, R.J. Hansman, Y.M. Marzouk, D. Newman, B.C. Williams

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 identifed 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 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.

Subject guidelines for the Environment concentration:

Choose at least one technology-focused subject:

• 2.60J/10.390J	Fundamentals of Advanced Energy Conversion (E)
• 2.650J/10.291J/22.081J	Introduction to Sustainable Energy (E)
• 2.66J/1.044J/4.42J	Fundamentals of Energy in Buildings (E)
• 2.813	Energy, Materials, and Manufacturing (E)
• 3.080	Economic and Environmental Materials Selection (E)
• 4.021	Introduction to Architecture Design (E)
• 4.473	Design Workshop for a Sustainable Future (E)
• 6.141J/16.405J ???	Robotics: Science and Systems I (E)
• 15.053	Optimization Methods in Management Science (E)
• 16.410	Principles of Autonomy and Decision Making (E)
• 16.50	Aerospace Propulsion (E)

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Choose at least one science-focused subject:

- 1.018AJ/7.30AJ/12.031AJ Fundamentals of Ecology I (M/S), ½ term, and
- 1.018BJ/7.30BJ/12.031BJ Fundamentals of Ecology II (M/S), ½ term
- 1.020 Principles of Energy and Water Sustainability
- 1.061A Transport Processes in the Environment I (M/S), ½ term, and
- 1.061B Transport Processes in the Environment II (M/S), ½ term
- 1.070AJ/12.320AJ Introduction to Hydrology and Water Resources (M/S), ½ term, and
- 1.070BJ/12.320BJ Introduction to Hydrology and Water Resources (M/S); ½ term
- 1.071J/12.300J Global Change Science (M/S)
- 1.080A Environmental Chemistry I (M/S), ½ term, and
- 1.080B Environmental Chemistry II (M/S), ½ term
- 1.083A Environmental Health Engineering and Biology I (M/S), ½ term, and
- 1.083B Environmental Health Engineering and Biology II (M/S), ½ term
- 12.009 Theoretical Environmental Analysis (M/S)
- 12.021 Earth Science, Energy, and the Environment (M/S)
- 12.086 Modeling Environmental Complexity (M/S)
- 12.102 Environmental Earth Science (M/S)
- 12.301 Past and Present Climate (M/S)
- 12.306J/10.571J Atmospheric Physics and Chemistry (M/S)
- 12.333 Atmospheric Dynamics (M/S)
- 12.335 Experimental Atmospheric Chemistry (M/S)
- 12.340 Global Warming Science (M/S)

Choose at least one policy-focused subject:

- 1.801J/11.021J/17.393J Environmental Law, Policy, and Economics: Pollution Prevention and Control
- 1.802J/11.022J Regulation of Chemicals, Radiation, and Biotechnology (E)
- 11.162 Politics of Energy and the Environment
- 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

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Concentration in Space Exploration

Faculty point of contact: J.A. Hoffman

Concentration advisors: K. Cahoy, J.A. Hoffman, O. de Weck (on leave), Carmen Guerra Garcia, D.E. Hastings (on leave), R. Linares, P. C. Lozano, D.W. Miller, D. Newman, J.A. Shah, B.C. Williams

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 engineering 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):

Description of Course 16-ENG

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)

Astrobiology and Exobiology
•12.158 Molecular Biogeochemistry (S – 9 units)

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 the Earth and Planets (S)
•12.201 Essentials of Global Geophysics (S)
•12.400 The Solar System (S)
•12.420 Physics and Chemistry of the Solar System (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)
•2.372J/6.777J Design and Fabrication of Microelectromechanical Systems (E)
•2.627 Fundamentals of Photovoltaics (E)
•2.71 Optics (E)
•6.007 Electromagnetic Energy: From Motors to Solar Cells (E)
•6.161 Modern Optics Project Laboratory (E)
•6.801 Machine Vision (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 Engineering (E)
•16.400 Human Systems Engineering (E)
•16.405J/6.141J Robotics: Science and Systems I (E) [If used here, 16.405J cannot also 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 student can select from the subject listings above.

Note that for all 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
•16.323 Principles of Optimal Control (E)*
•16.343 Spacecraft and Aircraft Sensors and Instrumentation (E)*

Description of Course 16-ENG

- 16.423J/HST.515J/IDS.337J Aerospace Biomedical and Life Support Engineering (E)*
- 16.522 Space Propulsion (E)*
- 16.851 Satellite Engineering (E)*
- 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 the student to craft a coherent curriculum, which not only allows exploration based on the student's individual interests and goals but also meets the 16-ENG degree requirements.

Typical academic pathways for Course 16-ENG students entering the program in the fall of the sophomore year.

Units from departmental requirements that also fulfill the Lab and REST requirements (a total of 36 units) do not count in units beyond GIRs. A student will fill this unit gap in their departmental program by taking 36 additional elective units. Please check the current MIT Course Catalog for subject availability and prerequisites.

Subject & Units	Institute Requirement	Units Beyond GIRS
1. **First Year**		
Fall Term		
3.091-Intro to Solid-State Chemistry (12)	CHEM	
8.01-Physics I (12)	PHYS	
18.01-Calculus I (12)	CALC	
HASS (12)	HASS	
Term Units = 48		
Spring Term		
7.012-Introductory Biology (12)	BIO	
8.02-Physics II (12)	PHYS	
18.02-Calculus II (12)	CALC	
HASS (12), CI-H	HASS-A	
Term Units = 48		
2. **Sophomore Year**		
Fall Term		
16.001-Unified Engineering: Materials & Structures (12),	REST	
16.002-Unified Engineering: Signals & Systems (12)		12
18.03 Differential Equations (12)	REST	
HASS (12), CI-H	HASS	
Term Units = 48		
Spring Term		
16.003-Unified Engineering: Fluids Dynamics (12)		12
16.004-Unified Engineering: Thermodynamics (12)		12
6.00 Intro to Computer Science & Programming, 12		12
HASS (12)	HASS-H	
Term Units = 48		
3. **Junior Year**		
Fall Term		
16.06-Principles of Automatic Control (12), or 16.07-Dynamics (12)		12

Description of Course 16-ENG

Concentration Subject #1 (12)		12
Concentration Subject #2 (12)		12
Concentration Subject #3 (12)		12
Term Units = 48		
Independent Activities Period		
A six-unit elective, i.e. UROP-for-credit		6
Spring Term		
Concentration Subject #4 (12)		12
Concentration Subject #5 (12)		12
HASS (12)	HASS-SS	
HASS (12)	HASS	
Elective (6)		6
Term Units = 54		

4. Senior Year

Fall Term		
16.82 Flight Vehicle Engineering (12), CI-M, or		
16.83 Space Systems Engineering (12), CI-M		12
Elective (12)		12
Elective (12)		12
HASS (12)	HASS	
Term Units = 48		
Independent Activities Period		
A six-unit elective, i.e. UROP-for-credit		6
Spring Term		
16.405J Robotics: Science & Sys (12), CI-M, or	LAB	
16.62x Experimental Lab (18), CI-M, or	LAB	6
16.821 Flight Vehicle Development (18), CI-M, or	LAB	
16.831J Space Systems Development (18), CI-M, or	LAB	6
Concentration Subject #6 (12)		12
Elective (6)		6
HASS (12)	HASS	
Term Units = 42-48 units		

TOTAL UNITS BEYOND GIRS	**192-198**