

Department of Aeronautics and Astronautics
School of Engineering
Massachusetts Institute of Technology

Graduate Program (S.M., Ph.D., Sc.D.)

Field: Aerospace, Energy, and the Environment

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1. Introduction and Purpose

The graduate program in the Department of Aeronautics and Astronautics at MIT provides educational opportunities in a wide variety of aerospace-related topics through academic subjects and research. The purpose of this document is to provide incoming masters and doctoral level students guidance in planning the subjects they will take during their graduate program, with particular relevance to the field of aerospace, Energy, and the environment. The suggestions outlined here are to be understood as guidance and not as a mandatory, rigid framework. The final decision as to which subjects are taken and in what sequence is to be decided between each student and their academic advisor and/or doctoral committee. We further emphasize that in addition to these guides the official SM and doctoral degree completion requirements must be followed in the design of any graduate program.

2. Motivation for studying Aerospace, Energy, and the Environment

A defining challenge for aerospace in the 21st century is understanding and reducing air travel's environmental impacts. With air travel demand forecast to double or triple by mid-century, meeting this will require major advances in aerospace vehicle technologies, changes to the air transportation system, reimagining the energy sources and carriers used in aviation, and reshaping of our regulatory and policy frameworks. For example, if aviation is to halve its climate impacts by mid-century while growing at projected rates, there will need to be an approximately 80% reduction in the climate intensity of flying.

Aviation is a unique sector in terms of its environmental challenges because it is the only human made source of pollution emitted at altitude. These emissions give rise to phenomena that are currently thought to double (or more) their climate impact relative to the same emissions at ground level. To know what changes to make to the aviation system, we need to better understand how aviation impacts the environment. This applies not only for aircraft that are in or entering service, but for potential new aircraft – perhaps even supersonic aircraft at high altitudes that may give rise to stratospheric ozone depletion. Beyond commercial aviation, the growth in satellite and manned launches also raises the potential for environmental challenges associated with rocket emissions.

The aviation sector is a significant and growing user of oil, and there are energy security challenges as well as the environmental consequences of using fossil fuels. Biofuels are a potential way to address both these issues, but it is far from clear what would be the overall impact of this transition. Beyond fuels that serve as a drop-in replacement for jet fuel, there are other potential energy carriers – cryogenic fuels such as liquefied natural gas or hydrogen, or

even electrochemical storage (batteries). Such alternatives have major barriers to overcome if they are to become viable.

Aerospace technologies offer great potential for understanding and protecting our environment. Space-based earth observation is important for measuring our changing climate and aviation's impact on it. The rise of small satellites enables new capabilities in distributed environmental monitoring from space, and drone-based environmental sensing combined with advanced atmospheric modeling offers new ways to manage air pollution, monitor emissions, and observe our planet's ecosystem. Finally, the potential to use aerospace technologies to engineer the earth system to offset adverse effects of climate change – known as geoengineering or climate engineering – may be the ultimate backup plan if global measures to curb carbon dioxide emissions are not successful. But the potential for unintended consequences at large scale means that the risks need careful evaluation.

With an education in Aerospace, Energy, and the Environment you will be prepared to tackle major multidisciplinary energy and environmental problems facing aviation, and to seek opportunities for aerospace to be part of the solution to environmental problems. MIT offers a wide range of subjects related to the topic, as well as a core subject that educates aerospace engineers in the relevant environmental and energy science.

3. What is Aerospace, Energy, and the Environment?

The field is defined by the intersection of aerospace, energy, and environmental systems, with the goal of understanding (creating knowledge) and using this knowledge to reduce the impact of aerospace systems on the environment.

Core topics include:

- Air Transportation
- Energy and Fuels
- Aircraft Design
- Environmental Science
- Aerospace Propulsion
- Energy and Environmental Policy

At MIT, the Laboratory for Aviation and the Environment is a focal point in research at the intersection of aerospace, energy, and the environment. Research efforts include improving scientific understanding of the environmental impacts of aviation, and developing technological, fuel-based, and regulatory strategies to mitigate these impacts. In addition, the International Center for Air Transportation conducts research to improve the environmental performance of aircraft operations, the Gas Turbine Lab works to improve both the efficiency of aircraft propulsion systems and also their integration with aircraft for lowered environmental impact, and the research at the Aerospace Computational Design Lab includes energy and environmental problems and ultra-efficient aircraft design.

4. Educational Goals in Aerospace, Energy, and the Environment

The goal of the Aerospace, Energy, and the Environment field is to prepare students to address the major environmental and energy challenges facing aerospace. Specific objectives will be decided between advisor and advisee, but a typical graduate of the program will aim to have:

- A foundational understanding of the relevant environmental and energy science as it relates to aviation, including climate science, air pollution, fuels, combustion, energy conversion in gas turbines and other propulsion devices, and alternative fuels and energy carriers;
- A foundational understanding of the air transportation system, aircraft design, and aerospace propulsion as it relates to energy use and environmental impacts;
- An awareness of the interaction of energy and environmental policy with aerospace; and
- A more developed (deeper) understanding of an area in technology, operations, fuels, or policy that can provide the capability to mitigate the environmental impacts of aviation, space launches, or an area in which aerospace technologies contribute to environmental solutions.

5. Educational Plan in Aerospace, Energy, and the Environment

For the SM students take six subjects: the core subject (category A below), one mathematics subject (category H below), and four elective subjects (categories below B-G). For students taking the PhD qualifying exam the core subject covers the material relevant to the exam. Elective subjects need not be taken from the same category.

A. Core Subject

- 16.715 Aerospace, Energy, and the Environment

B. Air Transportation

- 16.71J The Airline Industry
- 16.72 Air Traffic Control
- 16.75/1.234 Airline Management
- 16.781 Planning and Design of Airport Systems

C. Energy and Fuels

- 2.28 Fundamentals and Applications of Combustion
- 2.42 General Thermodynamics
- 2.55 Advanced Heat and Mass Transfer
- 2.62 Fundamentals of Advanced Energy Conversion
- 2.61 Internal Combustion Engines
- 2.625 Electrochemical Energy Conversion and Storage: Fundamentals, Materials and Applications
- 2.65 Sustainable Energy

- 10.626 Electrochemical Energy Systems
- 10.652 Kinetics of Chemical Reactions

D. Aircraft Design

- 16.110 Flight Vehicle Aerodynamics

E. Environmental Science

- 12.806 Atmospheric Physics and Chemistry
- 1.84/10.817/12.807 Atmospheric Chemistry
- 12.814 Aerosol and Cloud Microphysics and Chemistry
- 12.842 Climate Science
- 1.841/12.817J Atmospheric Composition in the Changing Earth System

F. Propulsion

- 16.13 Aerodynamics of Viscous Fluids
- 16.511 Aircraft Engines and Gas Turbines
- 16.540 Internal Flows in Turbomachines
- 16.S198 Compressible Internal Flow
- 2.25 Advanced Fluid Mechanics

G. Energy and Environmental Policy

- IDS.410 Modeling and Assessment for Policy
- IDS.525 Global Environmental Negotiations
- 1.153 Transportation Policy, the Environment, and Livable Communities
- 12.885 Science, Politics, and Environmental Policy
- 15.038 Energy Economics and Policy
- 15.663 Environmental Law, Policy, and Economics
- 10.579 Energy Technology and Policy: From Principles to Practice
- 12.848J Global Climate Change: Economics, Science, and Policy
- 14.003 Microeconomic Theory and Public Policy
- 14.444 Energy economics and policy

H. Mathematics

- 1.151 Probability and Statistics in Engineering
- 6.431A Introduction to Probability I
- 6.431B Introduction to Probability II
- 16.391J Statistics for Engineers and Scientists

- 16.470 Statistical Methods in Experimental Design
- 16.76J Logistical and Transportation Planning Methods
- 16.910J Introduction to Numerical Simulation
- 16.920J Numerical Methods for Partial Differential Equations
- 18.0851 Computational Science and Engineering I
- 18.0861 Computational Science and Engineering II
- 18.305 Advanced Analytic Methods in Science and Engineering
- 18.306 Advanced Partial Differential Equations with Applications

6. Faculty and Staff with Interests in Aerospace, Energy, and the Environment

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