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

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

Field: Air-Breathing Propulsion
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Introduction and Purpose

The graduate program in the Department of Aeronautics and Astronautics at M.I.T. 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. 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. In addition to these recommendations, the official S.M. and doctoral degree completion requirements must be taken into account during the design of a graduate program[1].

What is Air-Breathing Propulsion all about?

In contrast to a rocket engine which, in addition to the fuel, carries along an oxidizer, an air-breathing propulsion system uses atmospheric air to oxidize the liquid fuel. Air-breathing propulsion systems include the jet engine, the ramjet and the scramjet. The field of air-breathing propulsion involves various disciplines in science and engineering such as fluid dynamics, turbomachinery aerodynamics, thermodynamics, and materials and structures.

At MIT, research and teaching in this field is conducted at the Gas Turbine Laboratory (GTL) which has had a worldwide reputation for research and teaching at the forefront of gas turbine technology for over 50 years. The concept of an MIT Gas Turbine Laboratory was formulated not long after the first jet engines were successfully run. Shortly after the end of the Second World War, Professor J.C. Hunsaker, who was one of the pioneers of aviation in this country and who was a member of the original National Advisory Committee on Aeronautics (the forerunner of NASA), brought together a group of American industries who donated funds for the construction of a laboratory devoted to jet propulsion. A plaque commemorating the 1947 dedication now hangs in the main laboratory.

The research at the GTL is focused on advanced propulsion systems and turbomachinery with activities in computational, theoretical and experimental study of (1) loss

[1] Refer to the S.M., Ph.D. and Sc.D. degree requirements in Aeronautics and Astronautics section of the MIT Bulletin, or to http://web.mit.edu/aeroastro/academics/grad/index.html

mechanisms and unsteady flows in turbomachines, (2) compression system stability and active control, (3) heat transfer in turbine blading, (4) gas turbine engine noise reduction and aero-acoustics, (5) pollutant emissions and community noise, and (5) MEMS based high-power density engines.

Examples of past research activities include the first implementation of a three-dimensional computation of the flow in a transonic compressor, and the concept of blow-down testing of transonic compressors and turbines (thereby enabling these machines to be used for university scale experiments). Current examples are the work on "smart engines", in particular active control of turbomachine instabilities, the research project on "micro engines" which involves extensive collaboration with the Department of Electrical Engineering and Computer Science, and the “Silent Aircraft Initiative” which is a collaborative project with Cambridge University, Boeing, Rolls Royce and other industrial partners, to dramatically reduce aircraft noise below the background noise level in a well populated area.

The Gas Turbine Laboratory maintains strong ties with industry and government research in the area of propulsion and turbomachinery technology, as well as with other academic institutions who are leaders in this field. For example there are collaborative projects with the gas turbine engine manufacturers connecting the work in the GTL with "real world" problems, and there are longstanding collaborative efforts with Caltech and with the Whittle Laboratory at Cambridge University in England. From an educational perspective, the close links to the outside world enable the exchange of knowledge and ideas, and gives the students an opportunity to present work directly to outside sponsors, to conferences, or to other individuals from academia, industry, or government.

Educational Goals of the SM Program in Air Breathing Propulsion

The proposed course of study is intended to introduce and expose the student to the latest technologies and techniques used in the development of the current and next generation air-breathing propulsion systems. The educational goal of the Masters program in air-breathing propulsion is to provide students with the foundational understanding of fluid mechanic principles and concepts which are required to (i) enable physical insight into the behavior of a broad class of propulsion devices, and (ii) to model and solve industrial strength fluid mechanics problems in a rigorous manner. The successful graduate of the program will have:

1. Acquired the fundamentals in internal flow, turbomachinery aerodynamics, and air-breathing propulsion system design
2. Developed physical insight into the phenomena which characterize the fluid dynamic behavior of air-breathing propulsion systems
3. Acquired the ability to rigorously define the levels of modeling required for a useful description of a number of air-breathing propulsion situations

4. Acquired the ability to interpret numerical simulations and experimental results in terms of first principles and underlying concepts
5. Generated research contributions to the current air-breathing propulsion body of knowledge

To achieve this goal each student should develop an educational plan in discussion with their academic advisor.

Educational Plan

After matriculation in the program, each student should develop a plan which meets their individual learning objectives and measurable outcomes, expectations of their advisor, financial aid requirements, schedule, and the departmental requirements. The measurable outcomes directly follow from the learning objectives and, as the name says, capture what can be explicitly measured. They define the actionable items and capabilities that the prospective student will be able to carry out.

The Master of Science program at the Department of Aeronautics and Astronautics is a two year program (approximately) with the following requirements:

- 66 subject units, not including thesis units, in graduate subjects in the candidate's area of technical interest
    - Minimum of 42 H-level units with at least 21 units from Aero-Astro subjects
    - Non-H-level subjects must carry a grade of B or better to count toward degree requirements
    - Classes taken on a pass/fail basis do not count towards degree requirements
- Math requirement
- Technical writing requirement

Math Requirement. The purpose of the graduate math requirement is to give Master of Science students exposure to advanced mathematical concepts at the graduate level. There are a number of subjects in the Math department that count towards this requirement. Selected subjects offered by departments other than Mathematics can also be used toward the math requirement. Suggested subjects for students focusing on air-breathing propulsion are given below.

Technical Writing Requirement. The department of Aeronautics and Astronautics requires that all entering graduate students, including those who completed their bachelor's degree at MIT, demonstrate satisfactory English writing ability by taking the Technical Writing Examination administered by the Program in Writing and Humanistic Studies. The exam is administered once each year during the first week of fall term. Students matriculating in the spring or summer terms take the exam the first fall term of their studies. Students who score less than 80 percent on the examination must complete remedial training by the end of the first Independent Activities Period following graduate program registration.

English Evaluation Test. The English Evaluation Test is required of all new graduate students whose language of primary school instruction was not English.

Suggested Choice of Subjects

The above requirements can be fulfilled by taking six subjects, two of which are math subjects. On average the Master of Science program is a two year program and it is suggested that the prospective student take one core and one math subject the first two terms and one or two elective subjects the third and fourth term. In addition to the subjects, the prospective student is expected to attend the weekly GTL seminar series which is held by inside and outside speakers from industry, government and academia. It is also expected that, during the course of the SM program, the student holds at least one seminar.

The student is encouraged to register in the two core subjects listed in category A and to chose two math subjects (subjects listed under categories B, C and D count towards the math requirement) and two elective subjects from categories E through H.

A. Core Subjects

2.25	Advanced Fluid Mechanics
16.511	Aircraft Engines and Gas Turbines

B. Advanced Mathematical Methods (count toward math requirement)

18.085	Mathematical Methods for Engineers I
18.086	Mathematical Methods for Engineers II
18.305	Advanced Analytic Methods in Science and Engineering
18.306	Advanced Partial Differential Equations with Applications
18.307	Integral Equations
18.308	Wave Motion

C. Probability and Statistics (count towards math requirement)

1.151	Probability and Statistics in Engineering
6.262	Discrete Stochastic Processes
6.431	Applied Probability
16.391J	Statistics with Engineering Applications
16.470	Statistical Methods in Experimental Design

D. Numerical Methods (count towards math requirement)

16.910J	Introduction to Numerical Simulation
16.920J	Numerical Methods for Partial Differential Equations

16.930[2]	Advanced Numerical Methods for PDEs
16.940J	Computational Geometry

E. Fluid Mechanics and Aerodynamics

2.28	Fundamentals and Applications of Combustion
16.13	Aerodynamics of Viscous Fluids
16.120	Compressible Flow
2.27	Turbulent and Separated Flows
16.540	Internal Flows in Turbomachines
16.543	An Introduction to Acoustics of Fluid Flow

F. Propulsion

16.512	Rocket Propulsion

G. Material and Structures

16.58	Aircraft Gas Turbine Structures

H. Control Theory

16.322	Stochastic Estimation and Control
16.323	Principles of Optimal Control

The following sample schedules illustrate possible combinations of subjects, with focus for example on (1) turbomachinery or (2) aero-acoustics.

1. Sample Schedule with Focus on Turbomachinery

Core:	2.25	Advanced Fluid Mechanics
	16.511	Aircraft Engines and Gas Turbines
Electives:	16.540	Internal Flow in Turbomachines
	16.120	Compressible Flow
Math Req.:	18.305	Advanced Analytic Methods in Science and Engineering
	16.910J	Introduction to Numerical Simulation

2. Sample Schedule with Focus on Aero-acoustics

Core:	2.25	Advanced Fluid Mechanics
	16.511	Aircraft Engines and Gas Turbines
Electives:	2.27	Turbulent Flow and Transport
	16.543	An Introduction to Acoustics of Fluid Flow
Math Req.:	18.308	Wave Motion
	16.920J	Numerical Methods for Partial Differential Equations

[2] Currently not counting towards math requirement.

Appendix

Aero-Astro Faculty Affiliated with Air Breathing Propulsion:

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Microengine Project

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