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

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

Field: Aerospace Computational Engineering (ACE)
Date: *October, 2020*

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 considered during the design of a graduate program[1].

Motivation for studying Aerospace Computational Engineering (ACE)

Intensive computation for simulation and optimization has become an essential activity in the design and operation of complex systems in engineering. While computational science is a discipline in itself, it serves to advance all of science and engineering. Despite the already considerable level of development, it is expected that the next decades will experience an explosive growth in the demand for accurate and reliable numerical simulation and optimization of complex systems. It is important to realize the difference between computer science and computational science, the former referring to the science and technology pertinent to the computer, whereas the latter addresses the development of modeling and optimization technology and software for specific systems applications.

What is Aerospace Computational Engineering?

Since the early days of computational mechanics, the aerospace community has been at the forefront of computational science and engineering driven by a need for high accuracy models in the design of aerospace vehicles and systems. Not surprisingly, NASA has played a major role in the development of the early finite element codes for structural mechanics (e.g. NASTRAN) as well in the development of Computational Fluid Dynamics. Traditionally, the aerospace industry with companies such as, Boeing. Lockheed, Rolls Royce, Dassault, etc. has pioneered the use of the latest computational tools and in many cases they have developed highly sophisticated in-house capabilities through alliances with universities and research institutions. The origin of the more recent paradigms on multidisciplinary design and optimization (MDO) can also be traced back to the same community. The need for accurate and reliable prediction tools for complex engineering systems will continue within aerospace.

The department has had a strong presence in computational engineering, in particular but not exclusively in the areas of computational fluid dynamics and computational mechanics of materials, uncertainty quantification and optimization. Currently, our department has several faculty and staff focused principally on research in computational engineering. These faculty are affiliated with the MIT Center for Computational Science & Enginnering https://cse.mit.edu which is hosed in the newly created Schwarzman School of Computing.

Educational Goals of the Graduate Program in Aerospace Computational Engineering

Simply stated, at the SM level the ACE focus area aims to educate the engineers and scientists in advance computational methods who will computationally model, optimize, control, and operate the important aerospace engineering systems of the next decade, as well as contribute to our own increasingly computationally intensive research programs within the Department. The PhD in ACE program allows students to further specialize at the doctoral level in a computation-related field of their choice through focused coursework and a doctoral thesis. The graduate program is designed with a common core that serves all disciplines, and an elective component to concentrate on particular applications. The educational program is designed to emphasize: breadth through introductory courses in the areas of numerical linear algebra, discretization of partial differential equations and optimization methods; depth in the areas of materials and structures, fluid mechanics, propulsion and control; integration and multidisciplinary aspects; hands-on experience through a research-based thesis.

7. Courses related to Aerospace Computational Engineering Core Computational Subjects

This courses provide the foundation/core material that provides the basis for study of more advanced elective topics. Students pursuing SM and PhD are recommended to take at least two of the following subjects:

- 2.097J/6.339J/16.920J Numerical Methods for Partial Differential Equations*
- 2.098J/6.255J/15.093J Optimization Methods
- 6.337J/18.335J Introduction to Numerical Methods*

Core Disciplinary Subjects

Students pursuing SM/PhD are recommended to take two/four of the following subjects:

- 1.138J/2.062J/18.376J Wave Propagation
- 2.071 Mechanics of Solid Materials*
- 2.072 Mechanics of Continuous Media
- 2.073 Solid Mechanics: Plasticity and Inelastic Deformation
- 2.25 Advanced Fluid Mechanics*
- 16.110 Flight Vehicles Aerodynamics*
- 16.120 Compressible Flow
- 16.31 Feedback Control Systems

- 16.511 Aircraft Engines and Gas Turbines
- 16.512 Rocket Propulsion
- ENGSCI 241 Advanced Elasticity

Advanced Computational and Disciplinary Subjects

Students pursuing SM and PhD are recommended to take one or more of the following subjects:

- 16.13 Aerodynamics of Viscous Fluids*
- 2.099/16.225J Computational Mechanics of Materials*
- 16.540 Internal Flows in Turbomachines*
- 16.888J/ESD.77J Multidisciplinary System Design Optimization
- 16.930 Advanced Topics in Numerical Methods for Partial Differential Equations
- 16.940: Numerical Methods for Stochastic Modeling and Inference*

Other Recommended Subjects

The following subjects provide breadth in computation or in other aerospace-related disciplines:

- 1.128J/2.089J Computational Geometry
- 2.036J/18.385J Nonlinear Dynamics and Chaos
- 2.096J/6.336J/16.910J Introduction to Numerical Simulation
- 2.798J/3.971J/6.524J/10.537J/20.410J Molecular, Cellular, and Tissue Biomechanics
- 3.320 Atomistic Computer Modeling of Materials
- 6.231 Dynamic Programming and Reinforcement Learning
- 6.251/15.081J Introduction to Mathematical Programming
- 6.252/15.084J Nonlinear Programming*
- 6.255/15.093/IDS.200J: Optimization Methods*
- 6.338J/18.337J Parallel Computing and Scientific Machine Learning
- 6.431 Intro to Probability
- 6.436: Fundamentals of Probability*
- 6.434/16.391J Statistics for Engineers and Scientists
- 18.306 Advanced Partial Differential Equations with Applications
- 6.335/18.336J Fast Methods for Partial Differential and Integral Equations
- 1.203/15.073/IDS.700J Applied Probability and Stochastic Models

(*) Can be used to satisfy the ACE Qualifying Field Exam

8. Faculty and Staff with Interests in Aerospace Computational Engineering

Please consult MIT Aero & Astro web-page for detailed faculty and staff interests:

http://web.mit.edu/aeroastro/faculty/faculty.html

Name: Mark Drela
Title: T. J. Kohler Professor
Office: 37-475
Phone: (617) 2530067
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Research area: Computational algorithms for aerodynamics flows, boundary layer formulations, optimization and design.

Name: David Darmofal
Title: J. C. Hunsaker Professor
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Research area: Computational fluid dynamics, numerical analysis, probabilistic design, engineering education.

Name: Robert Haimes
Title: Principal Research Engineer
Office: 37-447
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Email: haimes@mit.edu
Research area: Computational fluid dynamics, scientific visualization, computational geometry and CAD interfaces, parallel and distributed computing.

Name: Adrian Lozano-Duran (Starting January 2021)
Title: Assistant Professor
Office: TBA
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Research area: Fluid dynamics theory and modeling by artificial intelligence, numerical simulation, turbulence flows.

Name: Youssef Marzouk
Title: Professor
Office: 37-451
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Research area: Uncertainty quantification, Bayesian modeling and computation, data assimilation, experimental design, and machine learning in complex physical systems.

Name: Ngoc C. Nguyen
Title: Principal Research Scientist
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Research area: Multiscale and multi-physics simulation, discontinuous Galerkin methods,

multiscale finite element methods, deterministic and probabilistic inverse methods, high performance computing.

Name: Jaime Peraire
Title: H.N. Slater Professor
Office: 33-213
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Research area: Numerical simulation, computational mechanics and aerodynamics, finite elements, high performance computing.

Name: Raul Radovitzky
Title: Professor
Office: 33-406
Phone: (617) 2521518
Email: rapa@mit.edu
Research area: Computational solid mechanics and fluid, structure interaction, mecahncis of materials, multiscale modeling and simulation, high performance computing anf massively parallel computing.

Name: Qiqi Wang
Title: Associate Professor
Office: 33-412a
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Email: qiqi@mit.edu
Research area: Engineering design of chaotic dynamics systems, unsteady aerodynamics and turbulence, numerical methods for exascale computation, design optimization under uncertainty.