PURDUE UNIVERSITY | School of Aeronautics and Astronautics

Engineering Faculty Document No. EFD 100-22
April 14, 2022

Memorandum

To: The College of Engineering Faculty

From: The School of Aeronautics and Astronautics

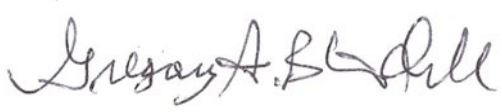
Re: new Hypersonics Graduate Certificate

The faculty of the School of Aeronautics and Astronautics has approved the following new graduate certificate from the College of Engineering. This action is now submitted to the Engineering faculty with a recommendation for approval.

Description: The Hypersonics Graduate Certificate provides courses related to hypersonic flows and includes foundational subjects needed for students to be successful in the more specialized courses. Students take one course in mathematics (if needed); one foundational course (if needed) to provide the necessary background in fundamental fluid mechanics, compressible flow, aerospace propulsion or aerospace materials, depending on the background and goals of the student; and two-four hypersonics relevant courses. The specialized courses related to hypersonics include courses on transition from laminar to turbulent flow, computational fluid dynamics, hypersonic propulsion systems, hypersonic external aerodynamics, nonequilibrium aerothermodynamics and materials for hypersonics.

Changes to the list of courses included in the certificate may be made upon approval by the AAE Graduate Committee. Relevant courses from Schools other than AAE will be considered and are encouraged. Courses from within AAE must also be approved by the appropriate AAE discipline area committee (e.g., Propulsion).

Reasons: Because of national security needs, there is a strong interest in industry and government agencies for engineers and managers to gain understanding of issues related to hypersonic flows and the methods used to analyze them. Development of systems operating at hypersonic speeds (greater than Mach 5) is challenging because of the intense heat transfer rates generated. The design of efficient propulsion systems is also challenging. The ability of engineers to accurately predict hypersonic flows and to choose appropriate materials is critical to the successful development of hypersonic flight vehicles.



Gregory A. Blaisdell
Professor and Associate Head for the Gambaro Graduate Program of Aeronautics and Astronautics

PURDUE UNIVERSITY | Purdue Online

Hypersonics Graduate Online Certificate Program

Overview

Hypersonics Graduate Certificate (proposed graduate certificate; approval anticipated in mid-to-late 2022) is designed to document successful participation in a set of graduate-level courses. The four course (12-credit) program is designed to support industry in achieving several goals, including:

- Upskill working engineers with a number of courses/programs that support areas related to hypersonics
- Develop a strong foundation in the fundamentals of fluid dynamics or materials engineering
- Expand knowledge and analysis capabilities for hypersonic propulsion, hypersonic external aerodynamics and materials selection

Curriculum

This is structured such that students will participate in four online graduate-level courses including three courses from the College of Engineering, and one related math course.

- Successful completion of these courses will result in 12 graduate credits with grades on a Purdue transcript
- Each course within the program is three credits
- Credits earned in this program with a grade of B- or better can be applied towards a Master of Science in Interdisciplinary Engineering, MS in Aeronautics and Astronautics or MS in another engineering program according to program policy
- Changes to the list of courses included in the certificate may be made upon approval by the AAE Graduate Committee. Relevant courses from Schools other than AAE will be considered and are encouraged. Courses from within AAE must also be approved by the appropriate AAE discipline area committee (e.g., Propulsion).

Proposed Graduate Certificate (comprised of 1 Foundational course*, 2-4 Hypersonic Relevant courses, plus 1 Math course**; total of 4 courses):

* Students with an undergraduate background or graduate degree including fluid dynamics, aerospace propulsion, compressible flows or material engineering may substitute a Hypersonic Relevant course for the foundational course with approval of the AAE Grad Chair

** Students with a background including graduate level courses in mathematics may substitute a Hypersonics Relevant course for the course in mathematics with approval of the AAE Grad Chair

Foundational Courses (to establish basis for advanced courses):

- AAE 51100 Introduction to Fluid Mechanics (or ME 50900 Intermediate Fluid Mechanics)
    - The basic conservation equations are derived for a compressible viscous fluid and then are specialized for applications in incompressible potential flow and viscous flow. (The courses contain similar material and are at the same level.)
- AAE 51400 Intermediate Aerodynamics (or ME 51000 Gas Dynamics)
    - The course objective is to increase student understanding of airfoil and wing aerodynamics and compressible flow beyond the undergraduate level. A deeper understanding of the analytical background in each topic is sought based on the

expectations of graduate level mathematical ability and a solid background in elementary fluid mechanics and thermodynamics.

- AAE 54800 Mechanical Behavior of Aerospace Materials
    - This course serves as an overview for materials behavior for students without a materials background, including seniors and entry-level graduate students. Materials are at the foundation for all of engineering, as evident by the latest products that we design, to the airplanes that we fly, to the latest smart phones. In this class, we focus on the structure of materials, the microstructure connection to mechanical properties, and ultimately failure mechanisms. Particular topics will also include: elastic deformation, dislocation mechanics, plastic deformation and strengthening mechanisms, creep, and failure mechanisms; design criteria; special topics.
- AAE 59000 Aerospace Propulsion
    - Overview of propulsion applications; review of mechanics and thermodynamics of fluid flow; 1D isentropic and non-isentropic flow; gas turbine engine cycles and inlets, combustors, and nozzles; the rocket equation; rocket performance parameters and rocket design; liquid rocket engines, solid rocket motors, and their components; rocket nozzle design, combustor heat transfer, and combustion instability.

Hypersonic Relevant Courses:

- AAE 51200 Computational Aerodynamics (CFD)
    - This course provides an introduction to finite-difference (FD) and finite volume (FV) methods in CFD. The course is divided into three parts. Part 1 reviews the building blocks needed to develop, analyze, and implement CFD algorithms. Part 2 presents FD and FV methods in a step-by-step manner, showing how the building blocks are assembled and their limitations. Part 3 shows how FD and FV methods are applied to the Euler and the Navier-Stokes equations for compressible and incompressible flows with focus on boundary conditions, verification and validation issues, and uncertainty quantification.
- AAE 51900 Hypersonic Aerothermodynamics
    - Aerodynamics of satellites and planetary re-entry. Continuum hypersonic flow. Inviscid and viscous effects, boundary layers, and heat transfer. Shock and boundary-layer interactions.
- AAE 53700 Hypersonic Propulsion
    - The main emphasis is on high-speed airbreathing systems with and without turbomachinery. High-speed inlets, isolators, combustors and exhaust systems are discussed in detail. A brief introduction to modern detonation-based approaches and thermal management is included. Students conduct a detailed analysis of a given system as a final project in the course.
- AAE 59000 Nonequilibrium Hypersonic Flows
    - Course provides engineering students with an overview of statistical physics, physical chemistry, and the modeling of nonequilbrium thermodynamic processes. It goes on to apply these tools to predicting flow at very high speeds, for example in atmospheric entry flight. Theory and application of hypersonic aerothermodynamics will be covered evenly.
- MSE 59700 Ceramics for Hypersonic Applications
    - This course will include a brief history of hypersonic flight and design, along with a description of the aerothermal environment, to provide motivation for the use of ceramic materials as thermal protection systems and window materials. The classroom

approach is to develop a fundamental understanding of materials structure, forming and sintering, and properties (mechanical and thermal), and then apply that knowledge to ceramics for hypersonic applications such as ultra-high temperature ceramics (UHTCs including ZrB_2), ceramic matrix composites (including C_f/SiC, SiC_f/SiC, and Carbon/Carbon), and silicon nitride for RF radomes.

- AAE 62400 Laminar / Turbulent Transition
    - Instability mechanisms, such as: Kelvin-Helmholtz, Tollmien-Schlichting, Görtler, and crossflow. Secondary instabilities. Nonlinear and nonparallel effects. The Parabolized Stability Equations. Receptivity. Transition prediction. Effects of compressibility, heating, roughness, turbulence, noise, curvature, etc. Turbulent spots and the extent of transitional flow.

Math Courses:

- MA 51100 Linear Algebra with Applications
    - Linear spaces; linear systems; matrices; Gauss elimination; LU and PLU factorization; linear transformations; orthogonality; QR factorization; inner products, least squares and projections; determinants; eigenvalues and eigenvectors; condition number and ill conditioning; spectral theorems; quadratic forms, singular value decomposition and pseudo inverse of a matrix; linear systems of differential equations.
- MA 52700 Advanced Mathematics for Engineers and Physicists I
    - Linear algebra, systems of differential equations, stability, Laplace transforms, Fourier series, Fourier transforms, partial differential equations.
- MA 52800 Advanced Mathematics for Engineers and Physicists II
    - Vector calculus: line integrals, surface integrals, divergence and Stokes theorems. Complex variables: Cauchy theory, power series, residues, conformal mappings, potential theory.

Faculty/instructor course formatting and delivery may vary. For reference, each of the current AAE courses within the program are delivered asynchronously and 100% online in a lecture capture format.

Course syllabi will detail the list of required reference materials that will need to be acquired by the student. Faculty reserve the right to change the materials, such as text books, that are required for the class.

Recommended Course Paths:

- Students without Fluid Mechanics background:
    - Math Course: MA 52800
    - Foundational Course: AAE 51100
    - Hypersonic Relevant Courses: AAE 51200, AAE 62400
- Students without Compressible Flow background:
    - Math Course: MA 52700
    - Foundational Course: AAE 51400
    - Hypersonic Relevant Courses: AAE 51900, AAE 590 NEHF
- Students without Propulsion background:
    - Math Course: MA 52700
    - Foundational Course: AAE 59000 Aerospace Propulsion
    - Hypersonic Relevant Courses: AAE 53700, AAE 51900 or AAE 59000 NEHF

- Students without Materials background:
  - Math Course: MA 52700
  - Foundational Course: AAE 54800 Mechanical Behavior of Aerospace Materials
  - Hypersonic Relevant Courses: MSE 59700, other Hypersonic Relevant course depending on interests

Availability/Timing table: (see Courses By School | Purdue Online | College of Engineering)

COURSE	TERM(S) AVAILABLE (Next Start)
AAE 51100 Introduction to Fluid Mechanics	Fall (August 22, 2022)
AAE 51200 Computational Aerodynamics	Spring (January 10, 2024)
AAE 51400 Intermediate Aerodynamics	Spring (January 9, 2023)
AAE 51900 Hypersonic Aerothermodynamics	Spring (January 10, 2024)
AAE 53700 Hypersonic Propulsion	Fall (August 21, 2023)
AAE 54800 Mechanical Behavior of Aerospace Materials	Fall (August 22, 2022)
AAE 59000 Nonequilibrium Hypersonic Flows	Spring (January 9, 2023)
AAE 59000 Aerospace Propulsion	Fall (August 21, 2023)
AAE 62400 Laminar / Turbulent Transition	Spring (January 13, 2025)
MA 51100 Linear Algebra with Applications	Spring, Summer (June 13, 2022)
MA 52700 Advanced Mathematics for Engineers and Physicists I	Fall, Summer (June 13, 2022)
MA 52800 Advanced Mathematics for Engineers and Physicists II	Spring (January 9, 2023)
ME 50900 Intermediate Fluid Mechanics	Fall (August 21, 2023)
ME 51000 Gas Dynamics	Spring (January 9, 2023)
MSE 59700 Ceramics for Hypersonic Applications	Spring (January 9, 2023)