PURDUE UNIVERSITY | School of Aeronautics and Astronautics

Memorandum

To: The Faculty of the College of Engineering

From: The School of Aeronautics and Astronautics

Date: January 29, 2025

Re: New Graduate Course, **AAE 52900 Nonequilibrium Hypersonic Flow**

The faculty of the School of Aeronautics and Astronautics have approved the following new course. This action is now submitted to the Engineering Faculty with a recommendation for approval.

Course no. **AAE 52900 Nonequilibrium Hypersonic Flow**
Spring (offered alternate years), Lecture, Cr. 3

Description: The objective of this course is to introduce students with a background in fundamental fluid mechanics and thermodynamics to hypersonic flow with thermochemical nonequilibrium.

Reason: This introductory 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 are covered evenly.

The course is complementary to other courses offered in the COE, such as AAE 51900 Hypersonic Aerothermodynamics and AAE 59000 Molecular Gasdynamics. The proposed course fills a gap between the AAE 51900 and AAE 59000 MGD, focusing on continuum flows with strong thermochemical nonequilibrium.

This course has been taken by both undergraduate and graduate students in Aeronautics and Astronautics, graduate students in Mechanical Engineering, with additional students from Materials Engineering and Interdisciplinary Engineering.

William A. Crossley
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Date: 2025.01.29 14:58:01 -05'00'

William A. Crossley
Uhrig & Vournas Head of Aeronautics and Astronautics
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SCHOOL OF AERONAUTICS AND ASTRONAUTICS
Neil Armstrong Hall of Engineering
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Enrollment History – Previously taught as AAE 590 Nonequilibrium Hypersonic Flow

	Enrollment		**Spring 2019**	**Spring 2021**
AAE59000 - Nonequilibrium Hypersonic Flows PWL Enrollment	GR - Graduate School	MECH - Mechanical Engineering		5
		AAEN - Aeronautics & Astronautics	6	7
		MSE - Materials Engineering		1
	AE - School of Aero and Astro Engr Undergraduates	AAE - Aero & Astro Engineering	9	4
AAE59000 - NonEquilibrium Hypersonic Flow Pro Ed (CEC) Enrollment	GR - Graduate School	MECH - Mechanical Engineering		1
		IDE - Interdisciplinary Engineering		1
		AAEN - Aeronautics & Astronautics		5
	Totals		**15**	**24**

	Spring 2019	**Spring 2021**
Undergraduate	9	4
Graduate	6	13
Prod Ed		7
Grand Total	**15**	**24**

Course Information

- **AAE 52900 Nonequilibrium Hypersonic Flow,**
- **CRN:** 28596 (on campus lectures), 28623 (distance section)
- **Meeting day(s) and time**: Lectures recorded MWF 10:30-11:20 AM in WANG 2555
- **Instructional Modality:** Hybrid; in-person lectures optional; videos posted on Brightspace
- **Course credit hours:** 3.0
- **Prerequisites:** Undergraduate fluid mechanics (AAE 33300 and AAE 33400, or equivalent), vector calculus, partial differential equations, basic programming skills, introductory chemistry and physics

Instructor(s) Contact Information

- **Name of the instructor:** Jonathan Poggie
- **Office Location:** ARMS 3315
- **Office Phone Number:** (765) 496-0614
- **Purdue Email Address:** jpoggie@purdue.edu

- **Consultation hours, times, and location**: Thursdays, 7:00-8:00 PM eastern time (time subject to change) at https://purdue.webex.com/meet/jpoggie, and Brightspace discussion board. Use the discussion board for class questions and email for private issues.

Course Description

This introductory course provides engineering students with an overview of statistical physics, physical chemistry, and the modeling of nonequilibrium 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.

Learning Resources, Technology & Texts

The class will primarily follow Prof. Poggie's course notes, which will be provided. Suggested references include:

- J. D. Anderson, *Hypersonic and High Temperature Gas Dynamics*, 3rd ed., AIAA, 2019 [recommended textbook]
- I. D. Boyd and T. E. Schwartzentruber, *Nonequilibrium Gas Dynamics and Molecular Simulation*, Cambridge University Press, 2017
- D. A. McQuarrie and J. D. Simon, *Physical Chemistry: A Molecular Approach*, University Science Books, 1997
- R. Shankar, "Principles of Quantum Mechanics," Springer, 2nd ed., 1994
- W. G. Vincenti and C. H. Kruger, *Introduction to Physical Gas Dynamics*, Krieger Publishing, 1965

Class notes and additional materials will be posted on Brightspace.

Learning Outcomes

The course will introduce students with a background in fundamental fluid mechanics and thermodynamics to hypersonic flow with thermochemical nonequilibrium. By the end of the course, students will be able to implement a simple computational fluid dynamics code that includes models of thermochemical nonequilibrium.

Assignments

There will be about 6 homework assignments, approximately every other week except for exam weeks. The assignments will involve writing computer programs (your choice of language) and short reports. Homework must be submitted through Brightspace by the due date and must be prepared in a professional manner. Late homework may be penalized.

Grading

There will be one midterm exam and one final exam. The weight of grading will be: Midterm 40%, Final 40%, Homework 20%.

Attendance Policy

For the present semester, this course is designed in a hybrid model. Students may attend the lectures either in-person or watch the recorded lectures online. The recorded lectures will be posted on Brightspace and will be available to all students.

Course Schedule

The course schedule will be posted on Brightspace. It is subject to change; please check frequently on Brightspace for announcements and updates. A rough outline of the course is provided below. Again, this is subject to change.

	Topic	Title	Anderson	Vincenti & Kruger	Shankar	McQuarrie & Simon	Boyd & Schwarzentruber	Approx. Lectures
1.0	**Introduction**	Overview	Ch. 9					1
1.1		Kinetic Theory	Ch. 10, 12	Ch. I		Ch. 27	Ch. 1	2
1.2		Quantum Mechanics			Ch. 1, 4-7	Ch. 1-6	Ch. 1	3
2.1	**Equilibrium**	Equilibrium Kinetic Theory	Ch. 10, 12	Ch. II				1
2.2		Equilibrium Statistical Mechanics	Ch. 11	Ch. IV				2
2.3		Equilibrium Chemistry	Ch. 10-12	Ch. III-IV		Ch. 26		2
3.1	**Nonequilibrium**	Boltzmann Equation		Ch. IX-X			Ch. 1, 5	2
3.2		Moment Equations		Ch. IX-X				2
3.3		Closure Models		Ch. IX-X				2
4.1	**Translational Nonequilibrium**	Translational Nonequilibrium		Ch. X				2
4.2		Rarefield Slip Flow		Ch. X				2
5.1	**Vibrational and Chemical Rate Processes**	Vibrational Relaxation	Ch. 13	Ch. VII			Ch. 4	1
5.2		Chemical Kinetics	Ch. 13	Ch. VII				1
5.3		Nonequilibrium Air	Ch. 13	Ch. VII				1
6.1	**Inviscid Flow**	Inviscid Equilibrium Flow	Ch. 14	Ch. VI				1.5
6.2		Inviscid Frozen Flow	Ch. 14	Ch. VI, VIII				0.5
6.3		Invsicid Equilibrium Flow Example	Ch. 14					1
6.4		Inviscid Nonequilibrium Flow	Ch. 15	Ch. VIII				2
6.5		Inviscid Nonequilibrium Flow Example	Ch. 15	Ch. VIII				1
7.1	**Viscous Flow**	Transport Properties	Ch. 16	Ch. X				1
7.2		Viscous Nonequilibrium Flow	Ch. 17	Ch. X				2
7.3		Viscous Nonequilibrium Flow Example						2
8.1		Introduction to Radiation	Ch. 18	Ch. XI-XII				2
8.2	**Radiative Transfer**	Radiative Transfer	Ch. 18	Ch. XI-XII				2
8.3		Radiative Nonequilibrium	Ch. 18	Ch. XI-XII				2

8.4		Radiative Shocks	Ch. 18	Ch. XI-XII				1
							Total Lectures	42

Academic Integrity

Academic integrity is one of the highest values that Purdue University holds. Individuals are encouraged to alert university officials to potential breaches of this value by either emailing integrity@purdue.edu or by calling 765-494-8778. While information may be submitted anonymously, the more information is submitted the greater the opportunity for the university to investigate the concern. More details are available on our course Brightspace under University Policies and Statements.

See the University Policies and Statements section of Brightspace for guidance on Use of Copyrighted Materials. Effective learning environments provide opportunities for students to reflect, explore new ideas, post opinions openly, and have the freedom to change those opinions over time. Students and instructors are the authors of the works they create in the learning environment. As authors, they own the copyright in their works subject only to the university's right to use those works for educational purposes Students may not copy, reproduce, or post to any other outlet (e.g., YouTube, Facebook, or other open media sources or websites) any work in which they are not the sole or joint author or have not obtained the permission of the author(s).

Nondiscrimination Statement

Purdue University is committed to maintaining a community that recognizes and values the inherent worth and dignity of every person; fosters tolerance, sensitivity, understanding, and mutual respect among its members; and encourages each individual to strive to reach his or her potential. In pursuit of its goal of academic excellence, the University seeks to develop and nurture diversity. The University believes that diversity among its many members strengthens the institution, stimulates creativity, promotes the exchange of ideas, and enriches campus life. A hyperlink to Purdue's full Nondiscrimination Policy Statement is included in our course Brightspace under University Policies and Statements.

Accessibility

Purdue University strives to make learning experiences accessible to all participants. If you anticipate or experience physical or academic barriers based on disability, you are encouraged to contact the Disability Resource Center at: drc@purdue.edu or by phone: 765-494-1247, as soon as possible.

If the Disability Resource Center (DRC) has determined reasonable accommodations that you would like to utilize in my class, you must send me your Course Accommodation Letter. Instructions on sharing your Course Accommodation Letter can be found by visiting: https://www.purdue.edu/drc/students/course-accommodation-letter.php Additionally, you are strongly encouraged to contact me as soon as possible to discuss implementation of your accommodations.

Students with disabilities whose DRC Course Accommodation Letter (CAL) includes test accommodations must first release their CAL to me and then schedule to take their exams with Purdue Testing Services at https://www.purdue.edu/studentsuccess/testing-services/accommodated-testing/student.php. You must schedule at least four days (96 hours) before the exam date listed on the syllabus.

In the case of finals week, you must schedule by the Friday before quiet week. I will provide Purdue Testing Services with your exam and they will proctor it and provide the result to me for grading. Students must inform me immediately of cases when Purdue Testing Services is at capacity or otherwise unable to proctor the exam so that I can make other arrangements. Students who fail to follow this process and meet stated deadlines risk not being able to have their accommodations for that exam.

Mental Health/Wellness Statement

If you find yourself beginning to feel some stress, anxiety and/or feeling slightly overwhelmed, try Therapy Assistance Online (TAO), a web and app-based mental health resource available courtesy of Purdue Counseling and Psychological Services (CAPS). TAO is available to all students at any time by creating an account on the TAO Connect website, or downloading the app from the App Store or Google Play. It offers free, confidential well-being resources through a self-guided program informed by psychotherapy research and strategies that may aid in overcoming anxiety, depression and

other concerns. It provides accessible and effective resources including short videos, brief exercises, and self-reflection tools.
If you need support and information about options and resources, please contact or see the Office of the Dean of Students. Call 765-494-1747. Hours of operation are M-F, 8 a.m.- 5 p.m.
If you find yourself struggling to find a healthy balance between academics, social life, stress, etc., sign up for free one-on-one virtual or in-person sessions in West Lafayette with a Purdue Wellness Coach at RecWell. Student coaches can help you navigate through barriers and challenges toward your goals throughout the semester. Sign up is free and can be done on BoilerConnect. Students in Indianapolis will find support services curated on the Vice Provost for Student Life website.
If you're struggling and need mental health services: Purdue University is committed to advancing the mental health and well-being of its students. If you or someone you know is feeling overwhelmed, depressed, and/or in need of mental health support, services are available. For help, such individuals should contact Counseling and Psychological Services (CAPS) at 765-494-6995 during and after hours, on weekends and holidays, or by going to the CAPS offices in West Lafayette or Indianapolis.

Emergency Preparedness

In the event of a major campus emergency, course requirements, deadlines and grading percentages are subject to changes that may be necessitated by a revised semester calendar or other circumstances beyond the instructor's control. Relevant changes to this course will be posted onto the course website or can be obtained by contacting the instructors or TAs via email or phone. You are expected to read your @purdue.edu email on a frequent basis.

A link to Purdue's Information on Emergency Preparation and Planning is located on our Brightspace under "University Policies and Statements." This website covers topics such as Severe Weather Guidance, Emergency Plans, and a place to sign up for the Emergency Warning Notification System. I encourage you to download and review the *Emergency Preparedness for Classrooms document*.

The first day of class, I will review the **Emergency Preparedness plan for our specific classroom**, following Purdue's required Emergency Preparedness Briefing. Please make note of items like:

- The location to where we will proceed after evacuating the building if we hear a fire alarm.
- The location of our Shelter in Place in the event of a tornado warning.
- The location of our Shelter in Place in the event of an active threat such as a shooting.