School of Aeronautics and Astronautics

Memorandum

To: The Faculty of the College of Engineering

From: The School of Aeronautics and Astronautics

Date: December 11, 2024

Re: New Graduate Course, **AAE 53000 Computational Combustion and Propulsion**

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

Course no. **AAE 53000 Computational Combustion and Propulsion**
Spring, Lecture, Cr. 3

Description: The objective of this course is to provide students with theories and hands-on experience on advanced combustion models for turbulent reactive flow problems relevant to propulsion applications.

Reason: This course is unique in its introduction of advanced turbulent combustion models and the relevant computational approaches to students at Purdue. The course combines theories and hands-on experience on advanced combustion models, providing essential knowledge for students to conduct computational studies of combustion related problems found in transportation, power plants, and propulsion systems. It is complementary to other courses offered in the COE, such as AAE 41200 Introduction to Computational Fluid Dynamics, AAE 51200 Computational Aerodynamics, ME 61100 Principles of Turbulence, AAE 62600 Turbulence and Turbulence Modeling, ME 52500 Combustion.

In addition to AAE graduate and undergraduate students, this course has been taken by students in the Purdue Online Master program and in Mechanical Engineering.

William A. Crossley
Uhrig & Vournas Head of Aeronautics and Astronautics
Professor of Aeronautics and Astronautics

SCHOOL OF AERONAUTICS AND ASTRONAUTICS
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Enrollment History – Previously taught as AAE 690 Computational Combustion, AAE 690 Turbulent Combustion Modeling, AAE 590 Computational Combustion, and AAE 590 Computational Combustion and Propulsion

	Level	Major	2013 Spring	2014 Spring	2019 Spring	2021 Spring	2022 Spring	2023 Spring	2024 Spring
AAE59000 - Computational Combustion	GR - Graduate	MECH - Mechanical Engineering					2		
		AAEN - Aeronautics & Astronautics				6	3		
	AE - School of Aero and Astro Engr	AAE - Aero & Astro Engineering				2	4		
AAE59000 - Computational Combustion and Propulsion PWL Enrollment	GR - Graduate	AAEN - Aeronautics & Astronautics						7	12
		MECH - Mechanical Engineering						1	2
	AE - School of Aero and Astro Engr	AAE - Aero & Astro Engineering						10	35
AAE59000 - Computational Combustion and Propulsion Purdue Online(CEC) Enrollment	GR - Graduate	AAEN - Aeronautics & Astronautics							2
		MECH - Mechanical Engineering							1
AAE690 - Computational Combustion	GR - Graduate	AAEN - Aeronautics & Astronautics	3						
		MECH - Mechanical Engineering	3						
AAE 69000 - Turbulent Combustion Modeling	GR - Graduate	AAEN - Aeronautics & Astronautics		7	5				
		MECH - Mechanical Engineering		3					
	Totals		**6**	**10**	**5**	**8**	**9**	**18**	**52**

	2013 Spring	2014 Spring	2019 Spring	2021 Spring	2022 Spring	2023 Spring	2024 Spring	Totals
Undergraduate				2	4	10	35	51
Graduate	6	10	5	6	5	8	14	54
Prod Ed							3	3
Grand Total	**6**	**10**	5	8	**9**	**18**	**52**	108

AAE 53000 COMPUTATIONAL COMBUSTION AND PROPULSION

(Sample syllabus)

Pre-req: AAE 33800 or 33900 C+ or better, or instructor permission

PROFESSOR HAIFENG WANG

Office: ARMS 3313
Email: haifeng@purdue.edu

Office Hours: by email appointment only.

Teaching Assistants

- Jie Tao, tao7@purdue.edu
  - Questions/issues related to computer projects should be directed to Jie.
  - Office hours (in-person and online), 12:00pm-1:00pm, T/Th, ARMS 2106 (Click here to join the meeting online during the office hour time)
- Andrej Damjanov, adamjan@purdue.edu
  - Questions/issues related to the grading of computer projects should be directed to Andrej.
  - Piazza coordinator.

COURSE DESCRIPTION:

The course covers the following topics:

- Fundamentals of thermochemistry
- Chemical equilibrium and its calculation
- Chemical kinetics and auto-ignition.
- Laminar non-premixed flames and computation of an opposed jet flame.
- Laminar premixed flames and calculation of the laminar flame speed.
- Models for turbulent combustion (the flamelet model and the transported probability density function model).
- Turbulent non-premixed combustion and the modeling and simulation of a turbulent free jet flame.
- Turbulent partial premixed combustion and the modeling and simulation of a turbulent lifted jet flame.
- Computational propulsion and the modeling of a model rocket combustor
- [optional] Advanced topics on data-driven modeling and machine learning.

The course consists of lectures and computer projects.

PREREQUISITES:

Students who have taken AAE338 or AAE339 at Purdue and received a grade of C+ or better can take this course. All other students who do not meet the prerequisite should obtain the instructor's permission to enroll, including graduate students who had undergrad studies in a different institution.

Although not required, some prior knowledge can significantly enhance the learning of this course such as the fundamentals of combustion theory (e.g., ME525 or equivalent), turbulence and its modeling (e.g., ME611, AAE626, or equivalent), computational fluid dynamics (e.g., AAE412, AAE512, or equivalent), a modern computer programming language (e.g., MATLAB, FORTRAN, C/C++).

COURSE GOALS:

Students are expected to learn the fundamentals and skills for performing combustion modeling and simulations, as well as the status of the frontier turbulent combustion research.

LEARNING OBJECTIVES:

- Calculate chemical equilibrium.
- Calculate rate of chemical reaction and compute auto-ignition process.
- Compute opposed jet flames and understand characteristics of non-premixed combustion;
- Compute laminar flame speed and understand characteristics of premixed combustion.
- Acquire basic understanding of turbulent combustion problems and the advanced modeling approaches.
- Choose appropriate models for turbulent combustion problems and perform turbulent combustion simulations.

TEXTBOOKS AND OHER RESOURCES

It is recommended that you buy a modern text on combustion (e.g., Turns) and turbulence (e.g., Pope). All books are "recommended".

Combustion

S.R. Turns, *An Introduction to Combustion*, McGraw Hill
J. Warnatz, U. Maas and R.W. Dibble, *Combustion*, Springer

More Specialized

R.J. Kee, M.E. Coltrin and P. Glarborg, *Chemically Reacting Flow*, Wiley
T. Poinsot and D. Veynante, *Theoretical and Numerical Combustion*, Edwards
R.O. Fox, *Computational Models for Turbulent Reacting Flows*, Cambridge
S.B. Pope, *Turbulent Flows*, Cambridge

Computational Fluid Dynamics

John Anderson, *Computational Fluid Dynamics: The Basics with Applications*, McGraw-Hill
Joel H. Ferziger, Milovan Perić, *Computational Methods for Fluid Dynamics*, Springer

Numerical Methods

W.H. Press, S.A. Teukolsky, W.T. Vetterling and B. P. Flannery, *Numerical Recipes in Fortran*, Cambridge

K.E. Brenan, S.L. Campbell and L.R. Petzold, *Numerical Solution of Initial-Value Problems in Differential-Algebraic Equations*, SIAM

TOPICS AND PROJECTS

There are in total 8 topics, each being covered in approximately 2-3 weeks and having a project for it.

- Topic 1. Thermochemistry
- Topic 2. Chemical kinetics
- Topic 3. Premixed laminar flames
- Topic 4. Nonpremixed laminar flames
- Topic 5. Turbulence modeling of jet flames
- Topic 6. Simple models of non-premixed jet flames
- Topic 7. Transported PDF methods
- Topic 8. Computational propulsion

There are 24 lectures and 8 computer projects. The computer projects will be done mostly in ANSYS FLUENT. There are two learning pathways that can be followed as shown below to fulfil the course requirements. Learning Path 1 focuses more on advanced combustion modeling and Learning Path 2 includes a project that is closely related to computational propulsion. Every student must pick one path to proceed.

Lecture Videos (LecV)	Computer Projects (CP)	Learning Path 1	Learning Path 2
Lecture 1: Introduction		◆	◆
Lecture 2: In compressible assumption		◆	◆
Lecture 3: Flame examples		◆	◆
Lecture 4: Thermodynamic properties		◆	◆
Lecture 5: Chemical equilibrium	Project 1 (finish Lecture 5)	◆	◆
Lecture 6: Chemical kinetics-I		◆	◆
Lecture 7: Chemical kinetics-II		◆	◆
Lecture 8: Chemical kinetics-III	Project 2 (finish Lecture 8)	◆	◆
Lecture 9: Laminar premixed flame I		◆	◆
Lecture 10: Laminar premixed flame II	Project 3 (finish Lecture 10)	◆	◆
Lecture 11: Laminar non-premixed flame I		◆	◆
Lecture 12: Laminar non-premixed flame II	Project 4 (finish Lecture 12)	◆	◆
Lecture 13: Turbulence modeling I		◆	◆
Lecture 14: Turbulence modeling II		◆	◆
Lecture 15: Turbulence modeling III	Project 5 (finish Lecture 15)	◆	◆
Lecture 16: Turbulent combustion with equilibrium chemistry model		◆	◆
Lecture 17: Turbulent combustion with flamelet model	Project 6 (finish Lecture 17)	◆	
Lecture 18: Turbulent combustion with PDF methods (composition space)		◆	
Lecture 19: Turbulent combustion with PDF methods (PDF transport equations)		◆	
Lecture 20: Turbulent combustion with PDF methods (model implementation)	Project 7 (finish Lecture 20)	◆	
Lecture 21: Turbulent combustion with PDF methods (efficient chemistry implementation)		◆	
Lecture 22*: Computational propulsion			◆
Lecture 23*: Computational propulsion	Project 8 (finish Lecture 23)		◆
Lecture 24*: Computational propulsion			◆

COURSE WEBSITE AND TOOLS

Purdue Brightspace (https://purdue.brightspace.com) is used to organize the course contents such as announcements, course notes, assignments, report submission, and grades. Please check Brightspace frequently to get the latest update. ***Piazza*** (link in Brightspace) is used for questions and student collaboration.

MISCELLANEOUS

General Course Policies

Students are required to take all the lectures following their Learning Path choice. For questions or concerns arising from the course, students are encouraged to communicate with the instructor.

Absence

Attendance is strongly recommended. Most lectures are recorded.

Computer projects

The computer projects will be assigned approximately every two weeks. They may be assigned early if the relevant topic has been completed. Plenty of time will be given to finish the project. You are encouraged to form groups to work on the project together and get help from each other. Your report, however, should be your own. Copying or duplicating other's work in your report is not allowed. Your reports need to be submitted before the due date. In general, no late reports will be accepted, so plan early and make sure that you will be able to hand in your report in time. All project reports should be submitted in Brightspace.

Software tools

The computer projects require MATLAB and ANSYS FLUENT. Please manage to get both. The AAE computer lab (ARMS2106) has all the required software for this course. Both MATLAB and FLUENT (https://www.ansys.com/academic/students) are free to Purdue students for doing course work on their own computers. For distance learning students, you can also check and try AppsAnywhere, Software Remote, and Purdue Virtual Desktop:

- AppsAnywhere is a remote desktop service that is only available to engineering undergraduate students. Graduate students unfortunately do not have access to the service. FLUENT is available in AppsAnywhere. See this link for more details: https://engineering.purdue.edu/ECN/Support/KB/Docs/UsingAppsAnywhere.1
- Software Remote is an old service that will be phased out but is currently still available with the required software installed. See this link for details: https://it.purdue.edu/facilities/software/goremote.php
- Purdue Virtual Desktop is a new service that will be rolling out in Spring 2024 (to replace Software Remote). FLUENT is not there yet but hopefully will soon. (https://service.purdue.edu/TDClient/32/Purdue/KB/ArticleDet?ID=554&utm_source=delivra&utm_medium=email&utm_campaign=Purdue%20Virtual%20Desktop&utm_id=45619540)

Exams and Grades

There will be no exams. There are computer projects in this course. Students are required to do these projects and submit written reports. The final grades are based on the submitted project reports.

Office Hours

The TA office hours are provided at the beginning of the syllabus. If a private meeting is needed, please email us. It is recommended to use the class time and Piazza to ask questions.

Integrity and Code of Conduct

Students in this course are expected to abide by the Purdue University Statement of Integrity and Code of Conduct. Any work submitted by a student in this course for academic credit will be the student's own work. Purdue's student guide on Academic Integrity is available at http://www.purdue.edu/odos/aboutodos/academicintegrity.php.

Incidents of academic misconduct in this course will be addressed by the course instructor and referred to the Office of Student Rights and Responsibilities (OSRR) for review at the university level. Any violation of course policies as it relates to academic integrity will result minimally in a failing or zero grade for that particular assignment, and at the instructor's discretion may result in a failing grade for the course. In addition, all incidents of academic misconduct will be forwarded to OSRR, where university penalties, including removal from the university, may be considered.

Nondiscrimination Statement

Purdue University is committed to maintaining a community which 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 own 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. More details are available on our course Brightspace table of contents, under University Policies.

The School of Aeronautics and Astronautics is also committed to a climate of inclusion; if you need to report an issue of hate or bias, you may use the link at the top right of our page here: https://engineering.purdue.edu/AAE/aboutus/Diversity/index_html.

Mental Health/Wellness Statement

If you find yourself beginning to feel some stress, anxiety and/or feeling slightly overwhelmed, try WellTrack**.** Sign in and find information and tools at your fingertips, available to you at any time.

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 am- 5 pm.

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 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.

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 office on the second floor of the Purdue University Student Health Center (PUSH) during business hours. The CAPS website also offers resources specific to situations such as COVID-19.

Basic Needs Security

Any student who faces challenges securing their food or housing and believes this may affect their performance in the course is urged to contact the Dean of Students for support. There is no appointment needed and Student Support Services is available to serve students 8 a.m.-5 p.m. Monday through Friday. Considering the significant disruptions caused by the current global crisis as it relates to COVID-19, students may submit requests for emergency assistance from the Critical Need Fund

Emergency

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. Here are ways to get information about changes in this course when an emergency occurs: Brightspace web page, my email address: haifeng@purdue.edu, and my office phone: 765-494-4093.

The course syllabus is subject to change at the discretion of the instructor.

	Mon	Tues	Wed	Thur	Fri
Week 1	January 8	January 9	January 10	January 11	January 12
	Lecture 1 (intro.) LecV2 (incompress.)		LecV3 (flame examples)		LecV4 (thermodynamic properties)
Week 2	January 15	January 16	January 17	January 18	January 19
	MLK day (no class)		LecV5 (Chem. Equil.) CP1 demo		LecV6 (chem. kinetics-I)
Week 3	January 22	January 23	January 24	January 25	January 26
			LecV7 (chem. kinetics-II)		LecV8 (chem. kinetics-III)
Week 4	January 29	January 30	January 31	February 1	February 2
			LecV9 (Lam. premixed I) CP2 demo/CP1 due		LecV10 (Lam. premixed II)
Week 5	February 5	February 6	February 7	February 8	February 9
			LecV11 (Lam. non-premixed I) CP3 demo		LecV12 (Lam. non-premixed II)
Week 6	February 12	February 13	February 14	February 15	February 16
			CP4 demo/CP2 due		LecV13 (Turbul. Model I)
Week 7	February 19	February 20	February 21	February 22	February 23
			CP3 due		LecV14 (Turbul. Model II)
Week 8	February 26	February 27	February 28	February 29	March 1
			LecV15 (Turbul. Model III) CP5 demo/CP4 due		LecV16 (Equil. Chem. Model)
Week 9	March 4	March 5	March 6	March 7	March 8
			LecV17 (Flamelet)/ LecV22* (Comp. Prop.)		
Week 10	March 11	March 12	March 13	March 14	March 15
	SP VAC	SP VAC	SP VAC	SP VAC	SP VAC
Week 11	March 18	March 19	March 20	March 21	March 22
			CP6 demo/CP5 due		LecV18 (PDF-Comp. Space)/ LecV23* (Comp. Prop.)
Week 12	March 25	March 26	March 27	March 28	March 29
			LecV19 (PDF – Equations) CP8* demo		LecV20 (PDF-Imple.)/ LecV24* (Comp. Prop.)
Week 13	April 1	April 2	April 3	April 4	April 5
			CP7 demo/CP6 due		LecV21 (Efficient Chem.)
Week 14	April 8	April 9	April 10	April 11	April 12
			CP8* due		
Week 15	April 15	April 16	April 17	April 18	April 19
			CP7 due		
Week 16	April 22	April 23	April 24	April 25	April 26
		Quiet Week		Quiet Week	
Week 17	April 29	April 30	May 1	May 2	May 3
Final Exam Week (no Final Exam)					

LecV=Lecture

CP Demo=Computer Project demonstration

CP Due=Computer Project deadline

Q&A/Review=Q&A or Project Review (in-class time)