

Multiphase Combustion and Energetic Materials

EML 6934

Class Periods: MWF 12:50 – 1:40 MWF

Location: CSE E122

Academic Term: Spring 2023

Instructor:

Ryan Houim

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(352)-392-7164

Office Hours: TBD or by confirmed appointment

Course Description

Study of combustion related to multiphase flows and energetic materials. Topics include propellant combustion, detonation theory, combustion of particles and particle clouds, and deflagration-to-detonation transition. (Credits 3)

Teaching Assistants

NA

Course Pre-Requisites / Co-Requisites

None

Course Objectives

This course considers reactive multiphase flows where reactive droplets, particles, and energetic materials are important. The concepts learned in this class serve as a basis for understanding and computing multiphase reactive flow systems, detonation theory and detonation-shock-dynamics, propellant combustion, energetic material reaction pathways, and the combustion of particles and particle clouds.

Materials and Supply Fees

None

Required Textbooks and Software

No textbook is required. Some homework and computer project will require the use of Cantera, which is a freely-available Python-based software package for solving chemical reaction systems.

Recommended Materials

Energetic Materials and Applications

- Kuo and Acharya (2012), *Applications of Turbulent and Multiphase Combustion*, Wiley
- Kuo and Acharya (2012), *Fundamentals of Turbulent and Multiphase Combustion*, Wiley
- Kubota (2015), *Propellants and Explosives Thermochemical Aspects of Combustion, 3rd Ed.*, Wiley
- Cooper (1996), *Explosives Engineering*, Wiley
- Zukas and Walters (1998), *Explosive Effects and Applications*
- Carlucci and Jacobson (2018), *Ballistics Theory and Design of Guns and Ammunition, 3rd Ed.*, CRC Press

Detonation Theory

- Lee (2008), *The Detonation Phenomenon*, Cambridge
- Fickett and Davis (2011), *Detonation: Theory and Experiment*, Dover

Multiphase Combustion

- Sirignano (1999), *Fluid Dynamics and Transport of Droplets and Sprays*, Cambridge
- Yarin and Hetsroni (2004), *Combustion of Two-Phase Reactive Media*, Springer

General Combustion

- Kuo (2005), *Principles of Combustion*, 2nd Ed., Wiley
- Turns (2011), *Introduction to Combustion: Concepts and Applications*, 3rd Ed., Wiley
- Poiset and Veynante (2020), *Theoretical and Numerical Combustion*, 3rd Ed.
- Law (2006), *Combustion Physics*, Cambridge

Thermodynamics

- Callen (1985), *Thermodynamics and an Introduction to Thermostatistics*, 2nd Ed., Wiley
- Poling, Prausnitz, and O'Connell (2001), *The Properties of Gases and Liquids*, 5th Ed., McGraw Hill

Course Schedule (Subject to change based on timing and student interest)

1. Review of basic combustion.
 - a. Thermochemistry and chemical equilibrium
 - b. Energetic materials, oxygen balance, etc.
 - c. Chemical kinetics
2. Governing Equations
 - a. Reactive Navier-Stokes for single phase flows
 - b. Balance and boundary conditions at material interfaces
 - c. Governing equations for multiphase flow systems
3. Deflagration of Energetic Materials
 - a. Review of simple flame theory and flame structure
 - b. Homogeneous propellant combustion, flame structure, and reaction pathways
 - c. Heterogenous Propellant combustion
 - d. Flame spread and erosive burning.
4. Multiphase Combustion
 - a. Single-droplet combustion
 - b. Combustion of solid particles, diffusion-limited and kinetic-limited limits, and applications to coal, carbon, and Al
 - c. Liquid breakup in high-speed and flows with shocks
 - d. Combustion of particle/droplet clouds
 - e. Aspects of solid fuel combustion
5. Detonation of energetic materials and multiphase suspensions
 - a. Rankine-Hugoniot conditions for reactive flows
 - b. Planar Detonations: Chapman-Jouguet (CJ) and Zeldovich-von Neumann, Doring (ZND) Theory
 - c. Curved Detonations: Detonation Shock Dynamics (DSD)
 - d. Spray and dust detonations
6. Explosions and their initiation
 - a. Frank-Kamenetskii and Semenov ignition theories
 - b. Zeldovich reactivity gradient theory and SWACER
 - c. Flame acceleration and deflagration-to-detonation transition
 - d. Dust explosions
 - e. Air blasts

Online Course Recording

Our class sessions may be audio visually recorded for students in the class to refer back and for enrolled students who are unable to attend live. Students who participate with their camera engaged or utilize a profile image are agreeing to have their video or image recorded. If you are unwilling to consent to have your profile or video image recorded, be sure to keep your camera off and do not use a profile image. Likewise, students who un-mute during class and participate orally are agreeing to have their voices recorded. If you are not willing to consent to have your voice recorded during class, you will need to keep your mute button activated and communicate exclusively using the "chat" feature, which allows students to type questions and comments live. The chat will not be recorded or shared. As in all courses, unauthorized recording and unauthorized sharing of recorded materials is prohibited.

Attendance Policy, Class Expectations, and Make-Up Policy

On-campus students are expected to attend lectures. Excused absences must be in compliance with university policies in the Graduate Catalog (<http://gradcatalog.ufl.edu/content.php?catoid=10&navoid=2020#attendance>) and require appropriate documentation.

Evaluation of Grades

<i>Homework and Readings</i>	30%
<i>Computer Projects (2)</i>	50%
<i>Midterm (take home)</i>	10%
<i>Final Exam (take home)</i>	10%

Grading Policy

Percent	Grade	Grade Points
90.0 - 100.0	A	4.00
87.0 - 89.9	A-	3.67
84.0 - 86.9	B+	3.33
81.0 - 83.9	B	3.00
78.0 - 80.9	B-	2.67
75.0 - 79.9	C+	2.33
72.0 - 74.9	C	2.00
69.0 - 71.9	C-	1.67
66.0 - 68.9	D+	1.33
63.0 - 65.9	D	1.00
60.0 - 62.9	D-	0.67
0 - 59.9	E	0.00

More information on UF grading policy may be found at:

[UF Graduate Catalog](#)
[Grades and Grading Policies](#)

Students Requiring Accommodations

Students with disabilities who experience learning barriers and would like to request academic accommodations should connect with the disability Resource Center by visiting <https://disability.ufl.edu/students/get-started/>. It is important for students to share their accommodation letter with their instructor and discuss their access needs, as early as possible in the semester.

Course Evaluation

Students are expected to provide professional and respectful feedback on the quality of instruction in this course by completing course evaluations online via GatorEvals. Guidance on how to give feedback in a professional and

respectful manner is available at <https://gatorevals.aa.ufl.edu/students/>. Students will be notified when the evaluation period opens, and can complete evaluations through the email they receive from GatorEvals, in their Canvas course menu under GatorEvals, or via <https://ufl.bluera.com/ufl/>. Summaries of course evaluation results are available to students at <https://gatorevals.aa.ufl.edu/public-results/>.

In-Class Recording

Students are allowed to record video or audio of class lectures. However, the purposes for which these recordings may be used are strictly controlled. The only allowable purposes are (1) for personal educational use, (2) in connection with a complaint to the university, or (3) as evidence in, or in preparation for, a criminal or civil proceeding. All other purposes are prohibited. Specifically, students may not publish recorded lectures without the written consent of the instructor.

A “class lecture” is an educational presentation intended to inform or teach enrolled students about a particular subject, including any instructor-led discussions that form part of the presentation, and delivered by any instructor hired or appointed by the University, or by a guest instructor, as part of a University of Florida course. A class lecture does not include lab sessions, student presentations, clinical presentations such as patient history, academic exercises involving solely student participation, assessments (quizzes, tests, exams), field trips, private conversations between students in the class or between a student and the faculty or lecturer during a class session.

Publication without permission of the instructor is prohibited. To “publish” means to share, transmit, circulate, distribute, or provide access to a recording, regardless of format or medium, to another person (or persons), including but not limited to another student within the same class section. Additionally, a recording, or transcript of a recording, is considered published if it is posted on or uploaded to, in whole or in part, any media platform, including but not limited to social media, book, magazine, newspaper, leaflet, or third party note/tutoring services. A student who publishes a recording without written consent may be subject to a civil cause of action instituted by a person injured by the publication and/or discipline under UF Regulation 4.040 Student Honor Code and Student Conduct Code.

University Honesty Policy

UF students are bound by The Honor Pledge which states, “We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honor and integrity by abiding by the Honor Code. On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: “On my honor, I have neither given nor received unauthorized aid in doing this assignment.” The Honor Code (<https://sccr.dso.ufl.edu/policies/student-honor-code-student-conduct-code/>) specifies a number of behaviors that are in violation of this code and the possible sanctions. Furthermore, you are obligated to report any condition that facilitates academic misconduct to appropriate personnel. If you have any questions or concerns, please consult with the instructor or TAs in this class.

Commitment to a Safe and Inclusive Learning Environment

The Herbert Wertheim College of Engineering values broad diversity within our community and is committed to individual and group empowerment, inclusion, and the elimination of discrimination. It is expected that every person in this class will treat one another with dignity and respect regardless of gender, sexuality, disability, age, socioeconomic status, ethnicity, race, and culture.

If you feel like your performance in class is being impacted by discrimination or harassment of any kind, please contact your instructor or any of the following:

- Your academic advisor or Graduate Program Coordinator
- Jennifer Nappo, Director of Human Resources, 352-392-0904, jpennacc@ufl.edu
- Curtis Taylor, Associate Dean of Student Affairs, 352-392-2177, taylor@eng.ufl.edu
- Toshikazu Nishida, Associate Dean of Academic Affairs, 352-392-0943, nishida@eng.ufl.edu

Software Use

All faculty, staff, and students of the University are required and expected to obey the laws and legal agreements governing software use. Failure to do so can lead to monetary damages and/or criminal penalties for the individual violator. Because such violations are also against University policies and rules, disciplinary action will be taken as appropriate. We, the members of the University of Florida community, pledge to uphold ourselves and our peers to the highest standards of honesty and integrity.

Student Privacy

There are federal laws protecting your privacy with regards to grades earned in courses and on individual assignments. For more information, please see: <https://registrar.ufl.edu/ferpa.html>

Campus Resources:

Health and Wellness

U Matter, We Care:

Your well-being is important to the University of Florida. The U Matter, We Care initiative is committed to creating a culture of care on our campus by encouraging members of our community to look out for one another and to reach out for help if a member of our community is in need. If you or a friend is in distress, please contact umatter@ufl.edu so that the U Matter, We Care Team can reach out to the student in distress. A nighttime and weekend crisis counselor is available by phone at 352-392-1575. The U Matter, We Care Team can help connect students to the many other helping resources available including, but not limited to, Victim Advocates, Housing staff, and the Counseling and Wellness Center. Please remember that asking for help is a sign of strength. In case of emergency, call 9-1-1.

Counseling and Wellness Center: <http://www.counseling.ufl.edu/cwc>, and 392-1575; and the University Police Department: 392-1111 or 9-1-1 for emergencies.

Sexual Discrimination, Harassment, Assault, or Violence

If you or a friend has been subjected to sexual discrimination, sexual harassment, sexual assault, or violence contact the [Office of Title IX Compliance](mailto:title-ix@ufl.edu), located at Yon Hall Room 427, 1908 Stadium Road, (352) 273-1094, title-ix@ufl.edu

Sexual Assault Recovery Services (SARS)

Student Health Care Center, 392-1161.

University Police Department at 392-1111 (or 9-1-1 for emergencies), or <http://www.police.ufl.edu/>.

Academic Resources

E-learning technical support, 352-392-4357 (select option 2) or e-mail to Learning-support@ufl.edu.
<https://lss.at.ufl.edu/help.shtml>.

Career Resource Center, Reitz Union, 392-1601. Career assistance and counseling. <https://www.crc.ufl.edu/>.

Library Support, <http://cms.uflib.ufl.edu/ask>. Various ways to receive assistance with respect to using the libraries or finding resources.

Teaching Center, Broward Hall, 392-2010 or 392-6420. General study skills and tutoring.
<https://teachingcenter.ufl.edu/>.

Writing Studio, 302 Tigert Hall, 846-1138. Help brainstorming, formatting, and writing papers.
<https://writing.ufl.edu/writing-studio/>.

Student Complaints Campus: <https://care.dso.ufl.edu>.

On-Line Students Complaints: <http://www.distance.ufl.edu/student-complaint-process>.