

ASEN 5053

ROCKET AND SPACECRAFT PROPULSION

Tuesdays and Thursdays 11:40 AM – 12:55 PM

Course Description:

This course is designed to teach you the theory, analysis and design of modern rocket and spacecraft propulsion systems. We start from the basics of rocket propulsion, including some orbital mechanics to delineate the requirements. We will then discuss thermodynamics of rocket propulsion and nozzle flow theory, followed by in-depth study of various types of rocket and spacecraft propulsion: cold gas, monopropellant and bipropellant liquid rockets, solid and hybrid rockets, electric propulsion, nuclear rockets, and solar sails. If time permits, other exotic propulsion technologies will be dealt with. The goal is to provide you with a broad overview of this fast-changing field, including latest developments at NASA, ULA and SpaceX, as well as in-depth knowledge of rocket and spacecraft propulsion systems. The course is designed to be self-sufficient so that students who may not have taken the prerequisite undergraduate course on propulsion can successfully navigate it, albeit with some more effort, and benefit from it. ULA-sponsored graduate projects in the department, such as HySOR (Hybrid Sounding Rocket) and currently on-going AMARCS (Additively Manufactured Aerospike Reaction Control System), have built upon the knowledge my students gain in this course. Many of my students have ended up working for major corporations such as ULA, SpaceX, Orbital ATK, Boeing and Lockheed Martin.

Instructor:

Dr. Lakshmi Kantha

Professor, Department of Smead Aerospace Engineering Sciences

Office: Aerospace Building Room 463. Cell phone: 720-891-1775 (Please note that because of Covid-19 impact, I will be teaching from home. So it is best to e-mail me. Call me only if you need to contact me on an urgent matter).

E-mail: kantha@colorado.edu.

Office Hours: Tuesdays 3:00 PM to 5:00 PM

In addition, you can e-mail me any time for an appointment at a mutually convenient time. You are also welcome to call me to chat about latest events in the field or on any relevant issue or topic of your interest, but first notify me by e-mail to make sure I am free and available.

Office hours will be conducted remotely and not in the office as per CU regulations. The same applies to office hours with the TA.

Course Assistant (Teaching Fellow):

TBD

Email: TBD

Office Hours: TBD

Prerequisites: ASEN 4013 Undergraduate Course on Propulsion or Instructor's consent

Grading: Homework (8) – 40%, Quizzes (5) – 10%, Mid-Term Exam (1) – 20%, Final Project (or Exam) – 30%

Course Outline:

1. Introduction – History, Classification – Chemical, Electric, Nuclear. Examples
2. Principles of Jet and Rocket Propulsion, Ideal Rocket Equation, Single and Multi-Stage Rockets.
3. Basics of Orbital Mechanics, Space Flight, Orbit Perturbations, Orbit Maneuvers
4. Thermodynamics of Rocket Propulsion, Nozzle Theory, Over and Under-expanded Nozzles. Cold Gas Rockets
5. Heat Transfer, Regenerative and Radiative Cooling
6. Solid Propellant Rocket Motors, Burning Rate, Performance Analysis and Design. Examples.
7. Liquid Propellant Rockets - Monopropellant and Bipropellant. Combustion Thermodynamics. Pressure-fed and Pump-fed Systems. Analysis and Design. Examples.
8. Electric Propulsion Systems, Electrothermal, Electrostatic and Electromagnetic. Analysis and Design. Emerging and Exotic Systems.
9. Hybrid Rockets, Analysis.
10. Nuclear Propulsion, Principles and Analysis

Over the past 17 years of teaching this course, I have prepared an extensive set of notes I will be following. I will post each set of notes on Canvas, well before we discuss the topics in the class. However, the following books are useful. The first of them is required.

Books:

1. ***Rocket Propulsion Elements*** by G. P. Sutton and O. Biblarz, 9th Edition, John Wiley and Sons, 2001 (ISBN 0-471-32642-9) (**Required Text**. *This version is extensively updated - an excellent reference on the subject. Contains some topics I do not cover in my notes*). Eighth edition is also acceptable.
2. ***Rocket Propulsion*** by S. D. Heister, W. E. Anderson, T. L. Pourpoint and R. J. Cassady, Cambridge, 2019 (ISBN 978-1-108-42227-7). *The latest book on the topic, quite well-written but more appropriate to an undergraduate class.*
3. ***Space Propulsion Analysis and Design***, Revised Edition, by R. W. Humble, G. N. Henry and W. J. Larson, McGraw Hill, 1995 (ISBN 0-07-031320-2). **Call # TL782.S62 1995** (**Recommended**, *more details on elementary aspects than can be found in Sutton's book*).
4. ***Spacecraft Propulsion*** by C. D. Brown, AIAA Education Series, 1996 (ISBN 1-56347-128-0). **Call # TL782.B68 1996** (*compact, concentrating mostly on spacecraft propulsion systems, unfortunately uses British units*).
5. ***Mechanics and Thermodynamics of Propulsion*** by P. Hill and C. Peterson, Second Edition, 1992, Addison-Wesley (ISBN 0-2011-46592). **Call # TL709.H5 1992** (**Classic text on propulsion**, *one third dealing with rockets – an excellent reference*).
6. ***Rocket and Spacecraft Propulsion: Principles, Practice and New Developments*** by M. J. L. Turner, Third Edition, Springer, 2009 (ISBN 978-3-540-69202-7) **Call # TL782.T87 2009** (**Recommended**, *written for the non-specialist - very readable, nice chapter on nuclear rockets*)
7. ***Elements of Spacecraft design*** by C. D. Brown, AIAA Education Series, 2002 (ISBN 1-56347-5243). **Call # TL875.B76 2002** (*Good discussion of orbital mechanics*).

8. ***Introduction to Rocket Science and Engineering*** by T. S. Taylor, CRC Press, 2009 (ISBN 978-1-4200-7528-1) **Call # TL782.T395 2009** (Rather elementary book but has a good chapter on rocket testing).
9. ***Astronautics*** by U. Walter, Wiley-VCH Press, 2008 (ISBN 978-3-527-40685-2) **Call # TL791.W35 2008** (Excellent treatment of astronautical aspects of rocket propulsion).
10. ***Fundamentals of Electric Propulsion (Ion and Hall Thrusters)*** by D. M. Gobel and I. Katz, John Wiley, 2008 (ISBN 978-0-470-42927-3) **Call # TL783.63.G64 2008** (detailed discussion of electric thrusters)
11. ***Solar Sailing*** by C. R. McInnes, Springer 1999 (ISBN 1-85233-102-X) **Call # TL783.9.M39 1999** (Good discussion of solar sails)
12. ***Propellants and Explosives*** by N. Kubota, Second Edition, Wiley-VCH, 2007 (ISBN 978-3-527-31424-9) (*very good book on thermochemistry of propellants*)
13. ***International Launch Site Guide*** by S. R. Strom, Aerospace Press, 2005 (ISBN 1-884989-16-0) **Call # TL4020.I58 2005** (Good description of launch sites, their history and facilities available as well as contact information)

Journals:

AIAA Journal of Spacecraft and Rockets
AIAA Journal of Propulsion and Power

Logistics:

We will make use of Canvas, to which I will upload my lecture notes for you to download if you like, post homework, homework solutions, quizzes and grades. We will be using Canvas for all matters related to the course, including e-mail. Please try not to use my regular e-mail for class business, since it may get lost in other e-mails I receive, including junk mail. For access to Canvas, please contact OIT at help@colorado.edu or 303-735-help. Obviously, you need to be registered for the course and you will need your identikey. All homework and assignments should be submitted in electronic form (.pdf, .docx, .ppt, .xlsx formats) with following naming convention: HW#_LastName.pdf . The same goes for other assignments with HW replaced by QZ, Exam or Finals.

The preferred programming language in this course is MatLab. We will be using MatLab at various stages during this course and therefore you need to know how to use it. Please brush up, if you are rusty.

Campus-mandated Syllabus Statements

Classroom Behavior

Both students and faculty are responsible for maintaining an appropriate learning environment in all instructional settings, whether in person, remote or online. Those who fail to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation or political philosophy. For more information, see the policies on [classroom behavior](#) and the [Student Code of Conduct](#).

Requirements for COVID-19

As a matter of public health and safety due to the pandemic, all members of the CU Boulder community and all visitors to campus must follow university, department and building requirements, and public health orders in place to reduce the risk of spreading infectious disease. Required safety measures at CU Boulder relevant to the classroom setting include:

- maintain 6-foot distancing when possible,
- wear a face covering in public indoor spaces and outdoors while on campus consistent with state and county health orders,
- clean local work area,
- practice hand hygiene,
- follow public health orders, and
- if sick and you live off campus, do not come onto campus (unless instructed by a CU Healthcare professional), or if you live on-campus, please alert [CU Boulder Medical Services](#).

Students who fail to adhere to these requirements will be asked to leave class, and students who do not leave class when asked or who refuse to comply with these requirements will be referred to [Student Conduct and Conflict Resolution](#). For more information, see the policies on [COVID-19 Health and Safety](#) and [classroom behavior](#) and the [Student Code of Conduct](#). If you require accommodation because a disability prevents you from fulfilling these safety measures, please see the “Accommodation for Disabilities” statement on this syllabus.

Before returning to campus, all students must complete the [COVID-19 Student Health and Expectations Course](#). Before coming on to campus each day, all students are required to complete a [Daily Health Form](#).

Classes for this course will be taught completely on-line, with lectures, homework, quizzes, exams and discussions conducted via Canvas, and so there is no need for students taking this course to be on campus. The only exception (TBD) may be Final Projects that may require access to Departmental facilities such as the Machine Shop and Rocket Testing Bunker, in which case above protocols must be obeyed.

Students who have tested positive for COVID-19, have symptoms of COVID-19, or have had close contact with someone who has tested positive for or had symptoms of COVID-19 must stay home and complete the [Health Questionnaire and Illness Reporting Form](#) remotely.

In this class, if you are sick or quarantined, please let me know about your absence by e-mail. Because of FERPA student privacy laws, students are not required to state the nature of their illness when alerting me.

Accommodation for Disabilities

If you qualify for accommodations because of a disability, please submit your accommodation letter from Disability Services to your faculty member in a timely manner so that your needs can be addressed. Disability Services determines accommodations based on documented disabilities in the academic environment. Information on requesting accommodations is located on the [Disability Services website](#). Contact Disability Services at 303-492-8671 or dsinfo@colorado.edu for further assistance. If you have a temporary medical condition, see [Temporary Medical Conditions](#) on the Disability Services website.

Preferred Student Names and Pronouns

CU Boulder recognizes that students' legal information doesn't always align with how they identify. Students may update their preferred names and pronouns via the student portal; those preferred names and pronouns are listed on instructors' class rosters. In the absence of such updates, the name that appears on the class roster is the student's legal name.

Honor Code

All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the Honor Code. Violations of the policy may include: plagiarism, cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, submitting the same or similar work in more than one course without permission from all course instructors involved, and aiding academic dishonesty. All incidents of academic misconduct will be reported to the Honor Code (honor@colorado.edu); 303-492-5550). Students found responsible for violating the academic integrity policy will be subject to nonacademic sanctions from the Honor Code as well as academic sanctions from the faculty member. Additional information regarding the Honor Code academic integrity policy can be found at the [Honor Code Office website](#).

Sexual Misconduct, Discrimination, Harassment and/or Related Retaliation

The University of Colorado Boulder (CU Boulder) is committed to fostering an inclusive and welcoming learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct (harassment, exploitation, and assault), intimate partner violence (dating or domestic violence), stalking, or protected-class discrimination or harassment by members of our community. Individuals who believe they have been subject to misconduct or retaliatory actions for reporting a concern should contact the Office of Institutional Equity and Compliance (OIEC) at 303-492-2127 or cureport@colorado.edu. Information about the OIEC, university policies, [anonymous reporting](#), and the campus resources can be found on the [OIEC website](#).

Please know that faculty and instructors have a responsibility to inform OIEC when made aware of incidents of sexual misconduct, dating and domestic violence, stalking, discrimination, harassment and/or related retaliation, to ensure that individuals impacted receive information about options for reporting and support resources.

Religious Holidays

Campus policy regarding religious observances requires that faculty make every effort to deal reasonably and fairly with all students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. ***In this class, just let me know so that we can avoid any conflicts.*** See the [campus policy regarding religious observances](#) for full details.