ASTE 475: Rocket Propulsion

Units: 2
Fall 2024—Mon/Wed—5:00-5:50pm
Location: SOS B2

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Course Description

This course aims to provide a comprehensive introduction to the fundamentals of rocketry and spacecraft propulsion. Both the design and performance of rocket propulsion systems are covered and discussed in the context of mission requirements and recent industry trends. Students will gain exposure to both chemical and electric propulsion techniques, as well as current state-of-the-art propulsion technologies. Special emphasis is placed on the interplay of thermodynamics, compressible gas dynamics, and propellant chemistry in the thrust chamber and nozzle of conventional chemical propulsion systems. A primary goal of this course is to give students the tools and working knowledge necessary to transition immediately into a career as a propulsion engineer, though students with career aspirations in any aspect of the space industry will greatly benefit from this introduction to the field of propulsion.

Learning Objectives

By the end of this course, students will be able to:
- Be conversant in the nomenclature, components, and high-level design and operation of different spacecraft propulsion types
- Evaluate propulsion subsystems based on mission requirements and perform simple system sizing calculations
- Apply principles of compressible gas dynamics and heat transfer to rocket thrust chamber design
- Analyze propellant combustion/decomposition using chemical equilibrium models
- Characterize performance of thruster components in liquid, solid, and electric propulsion systems

Prerequisite(s): (ASTE 305 or AME 309) and PHYS 152

Recommended Preparation: A strong background in compressible gas dynamics is assumed.

Course Notes

All lectures will also be webcast via Zoom and recordings will be posted after class ends on Brightspace. I plan to use Piazza for online Q&A and discussion of the material.

Technological Proficiency and Hardware/Software Required

Basic proficiency in a high-level programming language (e.g. Matlab or Python) is assumed. If you're an ASTE or AME major, you have what you need. The Engineering Computing Center provides both short-term and long-term loaner laptops to Viterbi students. The USC Computing Center Laptop Loaner Program through ITS is also available for short-term laptop rentals.

Additional USC Technology Support Links: Zoom information for students, Brightspace help for students, Software available to USC Campus

Required Readings and Supplementary Materials

Required Textbook:

No textbook is "required" as the course notes draw from a number of resources. However, obtaining at least one of the recommended textbooks is highly suggested (all are available through USC Libraries). Relevant readings for each lecture will be posted or mentioned in class, but keep in mind that the notation or units used may be slightly different from what we use in class. Supplementary material will be posted on Brightspace from time to time, including more detailed derivations, historical perspectives, or online resources that may be of use.

Recommended Textbook:

Mechanics and Thermodynamics of Propulsion 2nd ed., P. Hill and C. Peterson, Pearson, 1991.

Rocket Propulsion, S.D. Heister, W.E. Anderson, T.L. Pourpoint and R. J. Cassady, Cambridge, 2019.

Rocket Propulsion Elements 9th ed., G.P. Sutton and O. Biblarz, Wiley, 2016.

Additional References:

Modern Compressible Flow: With Historical Perspective 4th ed., J.D. Anderson, McGraw-Hill, 2021.

Modern Engineering for Design of Liquid-Propellant Rocket Engines, D. K. Huzel and D. H. Huang, AIAA, 1992.

Combustion Physics, C.K. Law, Cambridge, 2006.

Physics of Electric Propulsion, R.G. Jahn, Dover, 2006.

Grading Scale/Breakdown

Course final letter grades will be assigned from an applied curve over the weighted semester grade, subject to the breakdown tabulated below. The curve is applied only to the total grade at the end of the semester and not on a per-assignment basis. Consequently, no absolute grading scale will be applicable in advance, but I will post the curved scale when I assign the final letter grades. I also reserve the right to adjust this letter grade as I deem appropriate, and I will communicate my rationale to the student in any such case.

Assignment	% of Grade
Homework	35
Nozzle Project	25
Final	40
TOTAL	**100**

Description and Assessment of Assignments

The grade for this course is broadly broken down into two categories: out of class work (60%) and exams (40%). Out of class work consists of weekly homework and one project. The project is an individual coding assignment to determine nozzle flow characteristics throughout the nozzle given certain input conditions. It can be viewed essentially as an extended homework assignment and will be due in Week 7. The final exam will be comprehensive.

The final exam will be conducted *in person* and will be open note and open book. The use of electronic devices will be allowed to access course content and compute numerical results (for instance, using Matlab functions written *by the student*). In general, use of the Internet is prohibited during exams and will be monitored by the exam proctor. A whitelist of approved websites will be provided in advance of the exam.

Assignment Submission Policy

Homework will be assigned approximately biweekly and is **due on Wednesday at 12pm PT** unless specified otherwise. All homework must be submitted electronically to the assignment Dropbox folder on Brightspace **as a single PDF** which includes all written work and source code used. Late homework will receive a 20% grade deduction if submitted after the deadline unless prior approval was given. Homework submitted after the solutions are posted will receive zero credit, without exception. Solutions will typically be posted within a week after the due date. The score for one homework assignment will be dropped at the end of the semester, but *only if all assignments* have been submitted by the final exam (whether on-time or late).

No extensions will be granted for the nozzle project. Late project submissions will receive zero credit, without exception.

Additional Policies

Any technology or other learning tools may be used during lectures so long as they do not disrupt the class—students are encouraged to utilize whatever resources help them learn best. Attendance is not required, but I will be taking attendance to collect statistics for my own use in evaluating teaching effectiveness. Feel free to speak up in class when something is unclear. I prefer my lectures to be interactive with student participation guiding the pace.

Please copy the TA on all email correspondence unless the email contains personal or private information. In general, you can expect a response within 48 hours; otherwise, *please* follow up and I will respond ASAP.

Academic Integrity

The University of Southern California is foremost a learning community committed to fostering successful scholars and researchers dedicated to the pursuit of knowledge and the transmission of ideas. Academic misconduct is in contrast to the university's mission to educate students through a broad array of first-rank academic, professional, and extracurricular programs and includes any act of dishonesty in the submission of academic work (either in draft or final form).

This course will follow the expectations for academic integrity as stated in the USC Student Handbook. All students are expected to submit assignments that are original work and prepared specifically for the course/section in this academic term. You may not submit work written by others or "recycle" work prepared for other courses without obtaining written permission from the instructor(s). Students suspected of engaging in academic misconduct will be reported to the Office of Academic Integrity.

Other violations of academic misconduct include, but are not limited to, cheating, plagiarism, fabrication (e.g., falsifying data), knowingly assisting others in acts of academic dishonesty, and any act that gains or is intended to gain an unfair academic advantage. Plagiarism includes the submission of code written by, or otherwise obtained from someone else.

Academic dishonesty has a far-reaching impact and is considered a serious offense against the university. Violations will result in a grade penalty, such as a failing grade on the assignment or in the course, and disciplinary action from the university itself, such as suspension or even expulsion.

For more information about academic integrity see the student handbook or the Office of Academic Integrity's website, and university policies on Research and Scholarship Misconduct.

Please ask me if you are unsure what constitutes unauthorized assistance on an exam or assignment or what information requires citation and/or attribution.

Collaboration:

Students are encouraged to collaborate on homework and programming assignments, but ultimately my expectation is that your submissions reflect your own individual understanding and effort. Please indicate any collaboration on your submissions. List the people you worked with for each problem/section of an assignment on both hand-written submissions and as comments in any source code submitted.

Use of Generative AI and Large Language Models (e.g. ChatGPT):

In this course, you may use artificial intelligence (AI)-powered programs to help you with assignments that indicate the permitted use of AI. **You should also be aware that AI text generation tools may present incorrect information, biased responses, and incomplete analyses**; thus they are not prepared to produce text that meets the standards of this course. To adhere to our university values, you must cite any AI-generated material (e.g., text, images, etc.) included or referenced in your work and provide the prompts used to generate the content. Using an AI tool to generate content without proper attribution will be treated as plagiarism and reported to the Office of Academic Integrity. Please review the instructions in each assignment for more details on how and when to use AI Generators for your submissions.

Course Content Distribution and Synchronous Session Recordings Policies

USC has policies that prohibit recording and distribution of any synchronous and asynchronous course content outside of the learning environment.

Recording a university class without the express permission of the instructor and announcement to the class, or unless conducted pursuant to an Office of Student Accessibility Services (OSAS) accommodation. Recording can inhibit free discussion in the future, and thus infringe on the academic freedom of other students as well as the instructor. (Living our Unifying Values: The USC Student Handbook, page 13).

Distribution or use of notes, recordings, exams, or other intellectual property, based on university classes or lectures without the express permission of the instructor for purposes other than individual or group study. This includes but is not limited to providing materials for distribution by services publishing course materials. This restriction on unauthorized use also applies to all information, which had been distributed to students or in any way had been displayed for use in relation to the class, whether obtained in class, via email, on the internet, or via any other media. Distributing course material without the instructor's permission will be presumed to be an intentional act to facilitate or enable academic dishonestly and is strictly prohibited. (Living our Unifying Values: The USC Student Handbook, page 13).

Course Schedule: A Weekly Breakdown (SUBJECT TO CHANGE)

	Topics/Daily Activities	Deliverables
Week 1 8/26-8/28	Syllabus, History of Rocketry, Introduction to Spacecraft Propulsion, Tsiolkovsky Rocket Equation	
Week 2 9/2-9/4	**LABOR DAY 9/2 – No Lecture**, Energy Transfer and Efficiencies	HW1
Week 3 9/9-9/11	Rocket Dynamics, Flight Performance, Mission Analysis, Duty Cycles, Multistaging, Low-Thrust Trajectories	
Week 4 9/16-9/18	Thermodynamics and Compressible Gas Dynamics Review, Shocks and Expansion Waves, Isentropic Nozzle Flow	HW2
Week 5 9/23-9/25	Ideal Rocket, Real Nozzles and Nozzle Design, Flow with Heat Addition/Friction, Plumes and Mach Diamonds	
Week 6 9/30-10/2	Propellant Chemistry, Chemical and Statistical Thermodynamics, Combustion, Equilibrium Gas Composition	HW3
Week 7 10/7-10/9	Adiabatic Flame Temperature, Chemical Kinetics, Frozen and Equilibrium Nozzle Flow	**Project Due**
Week 8 10/14-10/16	Boundary Layers, Rocket Heat Transfer	HW4
Week 9 10/21-10/23	Rocket Cooling Techniques, Regenerative Cooling Systems	HW5 (Fri)
Week 10 10/28-10/30	Liquid Rocket Engines I: Tanks, Feed Systems, Engine Cycles	
Week 11 11/4-11/6	Liquid Rocket Engines II: Valves, Lines, Injectors, Thrust Chamber Design	HW6
Week 12 11/11-11/13	**VETERAN'S DAY 11/11 – No Lecture**, Monopropellant Thrusters, Ignition, Combustion Instabilities	
Week 13 11/18-11/20	Solid Rocket Motors, Hybrid Rockets, Review of Electricity and Magnetism, Plasma Physics	HW7
Week 14 11/25-11/27	Electric Propulsion Systems, Ion Thrusters, Hall Thrusters, **THANKSGIVING BREAK 11/27 – No Lecture**	
Week 15 12/2-12/4	Nuclear Propulsion Systems, Advanced Propulsion Concepts, Final Review	HW8
FINAL 12/11	**FINAL EXAM WEDNESDAY, 12/11, 4:30-6:30pm**	

Statement on University Academic and Support Systems

Students and Disability Accommodations:
USC welcomes students with disabilities into all of the University's educational programs. The Office of Student Accessibility Services (OSAS) is responsible for the determination of appropriate accommodations for students who encounter disability-related barriers. Once a student has completed the OSAS process (registration, initial appointment, and submitted documentation) and accommodations are determined to be reasonable and appropriate, a Letter of Accommodation (LOA) will be available to generate for each course. The LOA must be given to each course instructor by the student and followed up with a discussion. This should be done as early in the semester as possible as accommodations are not retroactive. More information can be found at osas.usc.edu. You may contact OSAS at (213) 740-0776 or via email at osasfrontdesk@usc.edu.

Student Financial Aid and Satisfactory Academic Progress:
To be eligible for certain kinds of financial aid, students are required to maintain Satisfactory Academic Progress (SAP) toward their degree objectives. Visit the Financial Aid Office webpage for undergraduate- and graduate-level SAP eligibility requirements and the appeals process.

Support Systems:
Counseling and Mental Health - *(213) 740-9355 – 24/7 on call*
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.

988 Suicide and Crisis Lifeline - *988 for both calls and text messages – 24/7 on call*
The 988 Suicide and Crisis Lifeline (formerly known as the National Suicide Prevention Lifeline) provides free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week, across the United States. The Lifeline consists of a national network of over 200 local crisis centers, combining custom local care and resources with national standards and best practices. The new, shorter phone number makes it easier for people to remember and access mental health crisis services (though the previous 1 (800) 273-8255 number will continue to function indefinitely) and represents a continued commitment to those in crisis.

Relationship and Sexual Violence Prevention Services (RSVP) - *(213) 740-9355(WELL) – 24/7 on call*
Free and confidential therapy services, workshops, and training for situations related to gender- and power-based harm (including sexual assault, intimate partner violence, and stalking).

Office for Equity, Equal Opportunity, and Title IX (EEO-TIX) - *(213) 740-5086*
Information about how to get help or help someone affected by harassment or discrimination, rights of protected classes, reporting options, and additional resources for students, faculty, staff, visitors, and applicants.

Reporting Incidents of Bias or Harassment - *(213) 740-2500*
Avenue to report incidents of bias, hate crimes, and microaggressions to the Office for Equity, Equal Opportunity, and Title for appropriate investigation, supportive measures, and response.

The Office of Student Accessibility Services (OSAS) - *(213) 740-0776*
OSAS ensures equal access for students with disabilities through providing academic accommodations and auxiliary aids in accordance with federal laws and university policy.

USC Campus Support and Intervention - *(213) 740-0411*
Assists students and families in resolving complex personal, financial, and academic issues adversely affecting their success as a student.

Diversity, Equity and Inclusion - (213) 740-2101
Information on events, programs and training, the Provost's Diversity and Inclusion Council, Diversity Liaisons for each academic school, chronology, participation, and various resources for students.

USC Emergency - UPC: (213) 740-4321, HSC: (323) 442-1000 – 24/7 on call
Emergency assistance and avenue to report a crime. Latest updates regarding safety, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible.

USC Department of Public Safety - UPC: (213) 740-6000, HSC: (323) 442-1200 – 24/7 on call
Non-emergency assistance or information.

Office of the Ombuds - (213) 821-9556 (UPC) / (323-442-0382 (HSC)
A safe and confidential place to share your USC-related issues with a University Ombuds who will work with you to explore options or paths to manage your concern.

Occupational Therapy Faculty Practice - (323) 442-2850 or otfp@med.usc.edu
Confidential Lifestyle Redesign services for USC students to support health promoting habits and routines that enhance quality of life and academic performance.