ASEN 5053: Space Propulsion

Image Credit: NASA

CLASSROOM: N/A

Mid-term Exams:
TBD

Project Report:
TBD

INSTRUCTOR: Prof. James Nabity
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ASSISTANTS:
none

WEB SITE: https://canvas.colorado.edu/

TEXTBOOK:
Required: George P. Sutton and Oscar Biblarz (2016), Rocket Propulsion Elements 9th Edition, ISBN-13 978-1118753651

<u>Other Useful References</u>:

1. Textbooks
   a. Dieter K Huzel, David H Huang and Harry Arbit (1992), Modern Engineering for Design of Liquid Propellant Rocket Engines (Progress in Astronautics and Aeronautics) Revised, Subsequent Edition, ISBN 978-1563470134
   b. Hill P., and C. Peterson (1992). Mechanics and Thermodynamics of Propulsion, 2nd Ed., Addison---Wesley (an excellent, albeit dated, reference on the subject)
2. Journal articles, Conference papers and Technical reports
3. Personal notes

PREREQUISITES: ASEN 4013 Foundations of Propulsion or equivalent or permission of the instructor

REQUIRED EQUIPMENT: As needed for access to Canvas, the required textbook, CEARUN, lectures and completion of assignments

COURSE OBJECTIVES: This course teaches the theory, analysis and design of modern rocket and spacecraft propulsion systems. Lectures begin with 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, electric propulsion, nuclear rockets, and solar sails. If time permits, other exotic propulsion technologies will be dealt with. Specific emphasis will be placed on fundamental cycle analyses, component level understanding, and challenges with propulsion integration. The goal is to provide you with a broad overview of this fast-changing field, including latest developments and in-depth knowledge of rocket and spacecraft propulsion systems. Students are expected to have taken courses in thermodynamics, fluid mechanics and/or aerodynamics, heat transfer, and chemistry. Even so, 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 and benefit from it, albeit with greater effort.

TOPICAL OUTLINE:

1. Introduction & Overview – Chemical, Electric, Nuclear. Examples.
2. Fundamentals - Principles of Rocket Propulsion, Ideal Rocket Equation, Single and Multi-Stage Rockets.
3. Thermodynamics of Rocket Propulsion, Nozzle Theory, Over and Under-expanded Nozzles.
4. Heat Transfer, Regenerative and Radiative Cooling.
5. Flight Performance - Basics of Orbital Mechanics, Space Flight, Orbit Perturbations, Orbit Maneuvers.
6. Non-reacting Rockets – Cold gas & warm gas thrusters. Nuclear Propulsion.

7. Liquid Propellant Rockets - Monopropellant and Bipropellant. Combustion Thermodynamics. Pressure-fed and Pump-fed Systems. Design and Analysis. Examples.
8. Electric Propulsion Systems, Electrothermal, Electrostatic and Electromagnetic. Design and Analysis.
9. Emerging and Exotic Systems, Solar Sails, Directed Laser, Rail Launch.

COURSE ASSIGNMENTS:

- Readings
- Lectures
- Homework
- Quizzes
- Term Exams
- Project Final Report

ACADEMIC INTEGRITY AND GRADE SCHEDULE:

Evaluated Outcomes: The Department of Aerospace Engineering Sciences has adopted a policy of assigning grades according to "evaluated outcomes" in each course:

O1 Professional context and expectations (ethics, economics, business environment, etc.)
O2 Current and historical perspective
O3 Multidisciplinary, systems perspective
O4 Written, oral, graphical communication ability
O5 Knowledge of key scientific/engineering concepts
O6 Ability to define and conduct experiments, use instrumentation
O7 Ability to learn independently, find information
O8 Ability to work in teams
O9 Ability to design
O10 Ability to formulate and solve problems
O11 Ability to use and program computers

Evaluation of these outcomes allows an assessment of your performance and provides a major portion of the process we (the Faculty) use for continuous assessment and improvement of the entire AES curriculum. The model for these outcomes derives from several sources including the "Desired Attributes of an Engineer" as defined by The Boeing Company, and "curriculum reviews" from major aerospace corporations including The Boeing Co., Lockheed Martin Corp., and Ball Aerospace Corp. These inputs were combined with the AES faculty vision of the desired attributes of an aerospace engineer and the requirements of the Accreditation Board for Engineering and Technology (ABET) to produce this list of evaluated outcomes. Each assignment is designed and graded to assess some combination of several or a few of the outcomes.

Grade Breakdown: Your final grade is determined according to the following percentage breakdown (see below for additional information regarding assignments and individual grade assessment).

Table 1. Grade Breakdown

Type	Description	Percentage
Individual	Quizzes	10%
Individual	Term Exams	50% (25% each)
Group	Project Final Report	30%
Group	Homework*	10%
Total		**100%**

** Homework will earn a participation grade if submitted on time. Although homework must be submitted individually, it can be discussed and therefore, counts as a 'group' grade.*

Table 2. Letter Grade Assignment for Final Student Grading

Letter Grade	Percent Grade	4.0 Scale
A	93-100	4.0
A-	90-92	3.7
B+	87-89	3.3
B	83-86	3.0
B-	80-82	2.7
C+	77-79	2.3
C	73-76	2.0
C-	70-72	1.7
D	60-69	1.0
F	Below 60	0.0

IMPORTANT NOTES AND CLASS POLICIES:

1. Homework and quizzes are due by the submission deadline! **Late homework or quiz submittals are not accepted**.
2. **In the case of homework, report, presentation, or exam conflicts, you must make arrangements with the professor at least two weeks in advance. There are no unexcused make-up assignments or exams.**
3. Each homework assignment will include a set of problems, which you are expected to completely solve using the Engineering Solution Approach. This approach entails the following elements:
    - **Problem statement** (*this will be given*)
    - **Sketch the system**: *diagram the problem* with given information
    - **Governing principles**: *state the governing principles applicable to this problem*
    - **Governing equations**: a mathematical formulation of physics (*describe the governing equation(s), e.g. the Navier-Stokes equations*)
    - **State Assumptions**: implications and influence on governing equations (*declare all simplifying assumptions*)
    - **Solve** using the simplified equation set and tools (*show your work!*)

- **Critically assess** your solution. *Is the answer reasonable? Are the simplifying assumptions sound? Use the text, class notes, literature or other engineering rationale to defend your results.*

<u>All homework</u> must be completed on 8.5×11-inch paper. Submit via Canvas. You may use both sides of ruled notebook paper. However, use only the front side of engineering paper. Your name (last, first), assignment number, and due date should be visible on the outside in the upper portion of each page, to the right of the fold. Written work must be neat and readable with adequate spacing and margins. You are responsible for legibility – no reevaluation will be granted. Homework grading will only be for completeness (30 pts). Students are encouraged to review the posted solution and self-grade each assignment.

Always submit work with a professional appearance. Neatness, clarity, and completeness count in the work world! Unacceptably messy work will earn a score of zero. Messy work will be docked points. **Final answers must be indicated with an arrow or box, or underlined.**

Group collaboration is permitted on homework, but efforts are individual. This means you may discuss the means and methods for solving problems and even compare answers, but you are not free to copy someone's work or the solutions manual. **The homework you submit must be your own.** ***Copying material from any resource (including solutions manuals) and submitting it as one's own work is considered plagiarism and is an Honor Code violation. Keep in mind that the more you think about the problems yourself, the more you will learn, and the easier it will be to succeed on exams.***

Homework solutions must demonstrate an understanding of the principles involved by including diagrams, using correct notation and terminology, explaining the approach, showing the key steps to obtaining the solution, and outlining the answer with proper units. These problem---solving steps are critical for developing problem formulation skills.

4. **Collaboration on quizzes or exams, using another student's work as your own, or allowing another student to use your work as their own, is considered academic misconduct and will not be tolerated. If you are caught in any of these activities, you may receive a grade of "F" for the course and a report may be made to the Dean's office for further punitive action.**
5. Use of MATLAB is permitted, but not always desirable. MATLAB code will not suffice for homework solutions without prior permission, please write out your work in "human" readable format (we will not try to decipher your code). MATLAB figures should be legible, and have meaningful axes and legends.
6. Lectures are an important part of your training as an engineer and is expected. Some of the material covered in class is not in the textbook. **Quizzes and exams can cover any material in the course including information from the textbook, lecture/discussions, homework, and supplemental handouts.**
7. Rationale for course assignments:

- Reading assignments are to be completed *before* the lecture/discussion since this material will be on the quizzes. The lecture/discussions should help to clarify and supplement what you have read.
- Homework reinforces classroom instruction such that you may become proficient in the field of propulsion. In addition to the assigned homework, I encourage you to work additional problems for

practice. Before beginning any homework assignment, you should read the text and review the examples in the text.

- Exams and quizzes provide a gauge to determine what *you* have learned.
- The project helps you to learn how to synthesize and communicate the basic concepts, methods, and tools presented in the course curriculum.

GRADING PHILOSOPHY

Assignments are graded to an absolute standard designed to indicate your level of competency in the course material. Minor adjustments may be made in the assignment of final grades, but there is a limited amount of "curving" in the course. The final grade indicates your readiness to continue to the next level in the curriculum. The AES faculty have set these standards based on our education, experience, interactions with industry, government laboratories, others in academe, and according to the criteria established by the ABET accreditation board.

The course grade is primarily dependent on individual measures of competency, i.e. quizzes, exams and final project. The other course assignments are designed to enrich the learning experience and to enhance individual performance, not to substitute for sub-standard individual competency. Accordingly, group assignment grades are only incorporated into the final grade when the individual grade is a C or better. **In other words, if your individual average is below a C, the group-based grade fraction will not be averaged into your final grade, which will then be based solely on your individual score.** This policy makes it important to use the group assignments to enhance your own learning. If the work in the assignment is split up among group members, be sure that the learning is not also split up, but is shared among the whole group. For these purposes, quizzes and exams (60%), the final project (30%) and homework (10%) are considered 'individual' grades for this Library version of the course.

SYLLABUS STATEMENTS

See https://www.colorado.edu/academicaffairs/about/policies-customs-guidelines/required-syllabus-statements