ASEN 6008 Interplanetary Mission Design

Lectures: Monday 6:00 - 7:15 pm, SEEC N125
Lab: Wednesday 6:00 - 7:15 pm, AERO N100
Office Hours: See Canvas website for details

Interplanetary Mission Design covers many topics in the field of astrodynamics that are useful when constructing conventional interplanetary mission designs. The course focuses on simple ballistic mission designs, such as the interplanetary trajectories of Galileo, Cassini, New Horizons, and the various missions to Venus and Mars. Other types of interplanetary missions will also be briefly explored, such as SOHO's libration point trajectory design. Students will learn techniques to design interplanetary trajectories theoretically using simplified models and to take these theoretical trajectories and transition them into more robust trajectories in the ephemeris. Students will also gain experience using mission design software.

Course Logistics: In Campus section:
The course has a lecture component and a lab component. Lectures will be held on Mondays from 6:00-7:15 pm in SEEC N125. The majority of course content will be presented during lecture sessions. We will engage in small group discussions, exercises, and examples. The lectures will be recorded and posted to the Canvas website. Lab sessions will be conducted Wednesdays from 6:00-7:15 pm in AERO N100. *The campus will remotely from January 10-23. All lectures and labs will be conducted remotely using the course Zoom link.*

Course Logistics: Distance Students:
Students enrolled in the distance section (ASEN 6008-001B) are encouraged to attend lecture synchronously via Zoom if your schedule allows. This will enable you to ask questions and participate in breakout discussions. If you cannot attend a lecture synchronously, it is fine to watch the recordings afterwards. Zoom sessions will be run concurrently during lab so distance students who wish to participate remotely can do so. If new material is presented during lab, that portion of the lab session will be recorded and posted to Canvas. In general, the entirety of lab sessions will NOT be recorded.

Pre-requisites:
Courses: ASEN 5050 or equivalent, or the instructor's consent.
Material: We expect you to know the following (or to learn about these very quickly): Particle dynamics and orbital mechanics, Keplerian orbital elements, Conic orbits.
Access to GMAT software: This can be through a lab on campus, or GMAT can be downloaded to personal computers.

There are no required textbooks for this class. However, these are some suggested texts that are good additions to an astrodynamicist's library:

- **Vallado, *Fundamentals of Astrodynamics and Applications***. We will probably reference this frequently.
- Bate, Roger R., D.D. Mueller, and J.E. White, *Fundamentals of Astrodynamics*, New Dover Publications, New York, 1971.

- Brown, Charles D., *Spacecraft Mission Design*, AIAA Education Series, Reston, VA, 1998.
- Curtis, H., *Orbital Mechanics for Engineering Students*, Elsevier, Butlington, MA., 2005.
- Meeus, J., *Astronomical Algorithms*, Willmann-Bell, Inc., 1991.
- Murray, C.D. and S.F. Dermott, *Solar System Dynamics*, Cambridge University Press, 1999.
- Prussing, J. and B. Conway, *Orbital Mechanics*, Oxford University Press, 1993.

Computing:
Coding software of choice (MATLAB, C, Python, etc). GMAT software.

Grading:
- Homework: 30%. There are 9 assignments in the class.
- Labs: 30%. There are 6 labs and 1 midterm project. The midterm project is weighted as 2 labs.
- Final Project: 40%. There are several separate submissions for the final project. Due dates and point values will be clearly denoted on the assignment. The Final Project will be announced in March.
- There are no exams in this class and there are no dropped assignments. If you do not submit an assignment, it is counted as a zero.

Assignment submission
- Collaboration is permitted on assignments. However, each student must submit a **unique** assignment write-up.
- Many assignments in the class will require coding. You may use the coding language or software package of your choice. It is not necessary to include code as part of your submission. **Code may not be submitted solely as your solution.**
- Partial credit will be given based on intermediate steps and explanations provided in the assignment.
- Assignment due dates will be denoted on the Canvas/Gradescope webpages. Students are responsible to ensure that submitted documents are uploaded correctly, readable, and in the correct location. Corrupt files will not be graded.

Late Policy
- 10% deduction per day.
- I'll grant exceptions for good reasons, of course! Please notify me IN ADVANCE if you will be turning something in late (Conference, illness, etc)

Topics:

I. Review
   a. History of Interplanetary Missions
   b. The Two-body problem
   c. The N-body problem
   d. Perturbations
   e. Patched conics
   f. Reference frames
   g. Sphere of Influence
   h. Hohmann transfers

II. Lambert's Problem
   a. Lambert's general theorem
   b. Type I vs Type 2 orbits
   c. Discussion of Geometry of Lambert's problem
   d. Universal Variables Algorithm
   e. Revisit f and g functions
   f. TOF equations for elliptical, parabolic, and hyperbolic transfers
   g. Multi-Revolution solutions (Type 3, Type 4, etc)
   h. Algorithm for multi-rev solutions

III. Ephemeris
   a. Meeus Coefficients
   b. Discussion of JPL Ephemerides

IV. Pork Chop Plots
   a. Construction and Analysis

V. Gravity Assists
   a. History
   b. Vector Diagrams
   c. Leading vs Trailing
   d. Geometry
   e. Computation of parameters (periapsis radius, turn angles, etc)

VI. B-Plane
   a. Motivation
   b. Geometry and axes derivation
   c. Computing nominal B-Plane parameters
   d. Targeting desired B-Plane parameters
   e. Various targeting algorithms

VII. Resonant Orbits
   a. History (Galileo)
   b. Motivation
   c. Construction

VIII. Mission Development
   a. Using tools to construct end-to-end mission
   b. How to develop an initial itinerary?

IX. Introduction to Trajectory Optimization
   a. How to define an optimal trajectory?
   b. Optimization Problem Setup

c. Performance index, constraints
d. Defining state vector
e. Pruning the search space
f. Algorithms for optimization
    i. Deterministic vs Stochastic
g. Examples of optimization algorithms

X. Tisserand Plots
XI. Three Body Problem
a. History
b. Simplified forms (Restricted, Elliptical Restricted, Circular Restricted)
XII. Circular Restricted Three Body Problem
a. Geometry of nondimensional, rotating frame
b. Derivation of Equations of Motion
c. Transformation from synodic to inertial frame
d. Libration Points
XIII. State Transition Matrix
a. Motivation
b. Derivation for CRTBP
XIV. Libration Point Orbits
a. History in Mission Design
b. Types of orbits (Halo, Lissajous, etc)
c. Construction of LPOs using Single Shooting Algorithm
d. Stability
XV. Invariant Manifolds
a. Definition
b. Stable/Unstable Eigenvalues and vectors
c. Computing Invariant Manifolds (general discussion)
d. Applications to Mission design
XVI. Differential Correction

Additional information regarding general CU classroom policies:

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 Conduct & Conflict Resolution policies.

Requirements for COVID-19
As a matter of public health and safety, all members of the CU Boulder community and all visitors to campus must follow university, department and building requirements and all public health orders in place to reduce the risk of spreading infectious disease. 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 policy on classroom behavior and the Student Code of Conduct. If you require accommodation because a disability prevents you from fulfilling these safety measures, please follow the steps in the "Accommodation for Disabilities" statement on this syllabus.

CU Boulder currently requires masks in classrooms and laboratories regardless of vaccination status. This requirement is a precaution to supplement CU Boulder's COVID-19 vaccine requirement. Exemptions include individuals who cannot medically tolerate a face covering, as well as those who are hearing-impaired or otherwise disabled or who are communicating with someone who is hearing-impaired or otherwise disabled and where the ability to see the mouth is essential to communication. If you qualify for a mask-related accommodation, please follow the steps in the "Accommodation for Disabilities" statement on this syllabus. In addition, vaccinated instructional faculty who are engaged in an indoor instructional activity and are separated by at least 6 feet from the nearest person are exempt from wearing masks if they so choose.
If you feel ill and think you might have COVID-19, if you have tested positive for COVID-19, or if you are unvaccinated or partially vaccinated and have been in close contact with someone who has COVID-19, you should stay home and follow the further guidance of the Public Health Office (contacttracing@colorado.edu). If you are fully vaccinated and have been in close contact with someone who has COVID-19, you do not need to stay home; rather, you should self-monitor for symptoms and follow the further guidance of the Public Health Office (contacttracing@colorado.edu).
If you will miss class due to a medical reason, email Professor Davis: Kate.Davis@colorado.edu. Assignment due dates can be modified as necessary.

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 academic integrity policy. Violations of the Honor Code may include, but are not limited to: 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 on the Honor Code website.

Sexual Misconduct, Discrimination, Harassment and/or Related Retaliation
CU Boulder is committed to fostering an inclusive and welcoming learning, working, and living environment. The university 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 or against 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 email cureport@colorado.edu. Information about university policies, reporting options, and the support resources can be found on the OIEC website.
Please know that faculty and graduate instructors have a responsibility to inform OIEC when they are 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 their rights, support resources, and reporting options. To learn more about reporting and support options for a variety of concerns, visit Don't Ignore It.

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, please provide me with a list of potential conflicts within the first two weeks of the semester.
See the campus policy regarding religious observances for full details.