ASEN 6008 Interplanetary Mission Design

Lectures: Monday 5:30 – 6:45 pm, AERO N250
Lab: Wednesday 6:00 - 7:15 pm, AERO N100
Office Hours: See Canvas website for details

Zoom Information:

Passcode:
This link will be used for lectures, labs, and office hours.

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 5:30-6:45 pm in AERO N250. 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 5:30-6:45 pm in AERO N100. There may be a few cases where a lecture will be given on Wednesday in place of the lab session and will be conducted in a classroom. The information for the lecture location will be clearly communicated to students via email and an announcement on the Canvas website.

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 50500/ASEN 5052 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***. This book is referenced 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. CU Boulder currently requires COVID-19 vaccination and boosters for all faculty, staff and students. Students, faculty

and staff must upload proof of vaccination and boosters or file for an exemption based on medical, ethical or moral grounds through the MyCUHealth portal.

The CU Boulder campus is currently mask-optional. However, if public health conditions change and masks are again required in classrooms, students who fail to adhere to masking 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.
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). {Faculty: insert your procedure here for students to alert you about absence due to illness or quarantine. Because of FERPA student privacy laws, do not require students to state the nature of their illness when alerting you. Do not require "doctor's notes" for classes missed due to illness; campus health services no longer provide "doctor's notes" or appointment verifications.}

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. 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 Student Conduct & Conflict Resolution (honor@colorado.edu); 303-492-5550). Students found responsible for violating the Honor Code will be assigned resolution outcomes from the Student Conduct & Conflict Resolution as well as be subject to 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. University policy prohibits sexual misconduct (harassment, exploitation, and assault), intimate partner violence (dating or domestic violence), stalking, protected-class discrimination and harassment, and related retaliation by or against members of our community on- and off-campus. These behaviors harm individuals and our community. The Office of Institutional Equity and Compliance (OIEC) addresses these concerns, and individuals who believe they have been subjected to misconduct can contact OIEC at 303-492-2127 or email cureport@colorado.edu. Information about university policies, reporting options, and 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 any issues related to these policies regardless of when or where they occurred to ensure that individuals impacted receive information about their rights, support resources, and resolution 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.