ASEN 6060: Advanced Astrodynamics Spring 2024

Course description:

This course focuses on studying motion within multi-body gravitational systems via the circular restricted three-body problem. We will derive this dynamical model in detail. Then, we will explore the complex solution space through the numerical computation, characterization, and analysis of fundamental dynamical structures and the application of dynamical systems theory. We will use these solutions to construct a transfer and generate similar motions in higher-fidelity models using commercial software. This course will involve a significant amount of numerical computation using code/scripts that students write on their own.

Prerequisites: ASEN 5050/5052 or equivalent, or instructor permission required.

Instructional Team Information

Instructor: Prof. Natasha Bosanac

Teaching Assistant: Kevin Bonnet

Course Information

Assigned Lecture Periods: T,Th: 10am-11.15am in AERO N250

Course webpage: canvas.colorado.edu (Please check that your settings in Canvas enable you to receive regular notifications, announcements, and emails)

Course format:

- Selected lecture periods will be used for lectures and others will be used for small-group activities and discussions. The designated days for lectures and discussions appear on the course schedule.
- All lectures are recorded whereas only selected parts of the discussion sessions will be recorded. Recordings are available in Canvas so that you can watch them later if you are unable to attend or are registered for the -002 section.
- I will not monitor or mandate in-person attendance for students registered in the -001 section, but strongly encourage you to attend class and actively participate.

- During some small-group activities and discussions, each group may need to have at least one laptop available in class if in the -001 section and participating in class. Please contact the instructor during the first week of class if this will be infeasible for you so that we can coordinate alternative options.
- Students registered in the -002 section are expected to stay up-to-date with the course material by watching the lecture video recordings in a timely manner and asynchronously completing the activities and discussions on their own or with other students enrolled in the course this semester.

Restrictions on use of course materials:

- Lecture recordings may not be downloaded or used for any other purpose, consistent with FERPA restrictions.
- Course materials (including but not limited to lecture notes, homework, instructions, videos, etc) may not be distributed publicly or shared with individuals who are not registered in the course this semester without prior instructor consent.

Student Learning Objectives

By the end of this course, students should be able to:

1. Describe the formulation of the circular restricted three-body problem and derive the equations of motion
2. Compute, characterize, and analyze equilibrium points and periodic orbits as well as their hyperbolic invariant manifolds
3. Implement a numerical corrections procedure and examine the validity of the results
4. Construct a Poincaré map to visualize and analyze an array of trajectories
5. Design foundational transfers between libration point orbits in the circular restricted three-body problem
6. Formulate technically precise and clear discussions of a solution to a problem and critically assess the corresponding results and observations
7. Approximately recover solutions in STK or GMAT

Textbooks

There is no required textbook for this course. Any recommendations to useful, but optional, references will be provided on the course webpage for anyone who is interested.

Software

At this point in your aerospace education at CU Boulder, you are expected to have sufficient coding skills to be able to implement the numerical computations required to generate, analyze, and visualize trajectories in this course. To implement numerical computations, please use either MATLAB (preferred), Python, or C++. If you choose to use an alternative language or software, the instructional team might not be able to provide you with any useful feedback on your scripts or suggestions for addressing any problems.

To recover trajectories in higher-fidelity environments using commercial software, you may use either GMAT or STK. Neither of these software may be accessible to users of assistive technology. If you use assistive technology to access the course material, please contact me as soon as possible to discuss. These software may have usage restrictions that must be followed by all students.

To participate in virtual or hybrid office hours, we will use Zoom.

To optionally discuss technical concepts and general questions as well as connect with other members of the class, we will use Slack. A Slack invitation link is available on Canvas.

Course Grading Policy

Homework: 75%

Final Project: 25%

There are no exams in this course.

Assessment Policies

Homework Assignments:

Throughout the semester, homework assignments will feature a combination of analytical derivations and implementing numerical procedures. Homework submissions will be graded on 1) the accuracy of the answers and 2) the accuracy and completeness of the accompanying working/discussion. Homework submissions – including those that require implementing numerical procedures – require a clear and technically precise discussion that may consist of the following elements: discussion of relevant theory and technical details, description of the solution to a problem, working or a derivation to solve the problem, listing intermediate steps

and quantities, description of the results, analysis of the results, and justification of the results. Where appropriate, the text of any computational scripts must be appended to the end of your homework submission; a script alone is not considered a sufficient homework submission unless specifically noted in a homework problem. For any writeups, you are welcome to either hand-write or type your responses; please ensure they are clear and legible. Code comments are not an acceptable writeup method and will not be graded.

You are welcome to collaborate with your peers to discuss solution approaches, compare results and debug numerical procedures. However, you must write your own scripts, implement your own scenarios in STK or GMAT, and write up your own responses.

Homework will be submitted electronically in Gradescope. It is your responsibility to familiarize yourself with Gradescope. In Gradescope, you must also manually identify the correct pages that are associated with each homework problem. Homework will generally be due in the early evening of the due date listed on the calendar to accommodate students who need a flexible schedule due to their current location, work, carer, or other commitments. You may consider submitting your homework before this deadline and during your preferred working hours to facilitate creating work/life boundaries during the semester. Once you submit your homework electronically, please double check that the file has uploaded correctly and is not corrupted. We will not grade or accept a homework if we cannot open the file; in that case, the unreadable homework will receive a score of zero. We will not accept additional submission files outside of Gradescope (except outside of extenuating circumstances).

Homework solutions will not be provided. However, you will be provided with feedback in Gradescope and can attend office hours to discuss how to address any issues once the homework has been returned to you.

If you need to request an extension on the homework due to extenuating circumstances, please send me an email by no later than 10am on the business day before the deadline so that I have an opportunity to respond during reasonable working hours. Extensions will only be granted where allowable and under extenuating circumstances. If unforeseen emergencies arise after that, then please notify me as soon as possible. I will do my best to accommodate these requests with a solution that is both flexible for you and feasible for me, where appropriate. Otherwise, late homework that does not have a prior approved extension will not be accepted and will receive a score of zero.

If you believe that your homework has been graded incorrectly, you will have one week from the date that the homework is returned to request a regrade. Regrade requests must be

submitted in writing using Gradescope and include an outline of the reason that you believe there may be an error and the relevant rubric item/s.

Final Project:

There will be one final project that is due towards the end of the semester. This project will focus on numerically generating a transfer in the circular restricted three-body problem. The format for this submission will follow the expectations for the homework. Except in the case of unforeseen emergencies or illness, no extensions will be provided for this due date. Late projects without a prior approved extension will not be accepted, receiving a score of zero.

Restrictions:

You are not allowed to use artificial intelligence (AI) or machine learning tools (e.g., ChatGPT or Dall-E 2) on any assignment or project for this course. Each student is expected to complete each assignment and project without assistance from AI. Use of AI will be treated as a form of academic dishonesty akin to plagiarism or cheating.

Classroom Behavior

Students and faculty are responsible for maintaining an appropriate learning environment in all instructional settings, whether in person, remote, or online. Failure 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 classroom behavior policy, the Student Code of Conduct, and the Office of Institutional Equity and Compliance.

Requirements for Infectious Disease

Members of the CU Boulder community and visitors to campus must follow university, department, and building health and safety requirements and all applicable campus policies and public health guidelines to reduce the risk of spreading infectious diseases. If public health conditions require, the university may also invoke related requirements for student conduct and disability accommodation that will apply to this class.

If you feel ill and think you might have COVID-19 or if you have tested positive for COVID-19, please stay home and follow the guidance of the Centers for Disease Control and Prevention

(CDC) for isolation and testing. If you have been in close contact with someone who has COVID-19 but do not have any symptoms and have not tested positive for COVID-19, you do not need to stay home but should follow the guidance of the CDC for masking and testing.

Accommodation for Disabilities, Temporary Medical Conditions, and Medical Isolation

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.

If you have a required medical isolation for which you require adjustment, please notify the instructor as soon as possible.

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 (including use of paper writing services or technology [such as essay bots]), 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. Visit Honor Code for more information on the academic integrity policy.

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 protected-class discrimination and harassment, sexual misconduct (harassment, exploitation, and assault), intimate partner violence (dating or domestic violence), stalking, 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 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 must inform OIEC when they are made aware of incidents related to these policies regardless of when or where something occurred. This is to ensure that individuals impacted receive outreach from OIEC about resolution options and support resources. To learn more about reporting and support for a variety of concerns, visit the Don't Ignore It page.

Religious Observances

Campus policy requires faculty to provide reasonable accommodations for students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. Please communicate the need for a religious accommodation in a timely manner. In this class, please provide the instructor with a list of these conflicts in the first week of classes.

See the campus policy regarding religious observances for full details.

Mental Health and Wellness

The University of Colorado Boulder is committed to the well-being of all students. If you are struggling with personal stressors, mental health or substance use concerns that are impacting academic or daily life, please contact Counseling and Psychiatric Services (CAPS) located in C4C or call (303) 492-2277, 24/7.

Free and unlimited telehealth is also available through Academic Live Care. The Academic Live Care site also provides information about additional wellness services on campus that are available to students.

Tentative List of Topics

*These topics may change throughout the semester

- Formulating the Circular Restricted Three-Body Problem
- Jacobi constant and zero velocity surfaces
- Equilibrium points
- Periodic orbits
- Orbital stability and the state transition matrix
- Numerical corrections and continuation
- Recreating trajectories in higher-fidelity environments in commercial software
- Manifolds
- Quasi-periodic orbits
- Poincaré mapping
- Designing transfers
- An overview of higher-fidelity models of multi-body systems