ASEN 6015: SPACE VEHICLE GUIDANCE AND CONTROL FALL 2022

Instructor: Jay McMahon, Office: AERO 461, email: jay.mcmahon@colorado.edu

Lectures: T-Th 8:30 - 9:45 AM, AERO N240

Course Web Site: Canvas (https://canvas.colorado.edu)

Office Hours: By appointment

Text: "Required" text: Kabamba, P. T., and Girard, A. R., *Fundamentals of Aerospace Navigation and Guidance*, Cambridge, 2014

References: There are a number of books that are good references on a variety of subjects covered in this course:

- Stengel, R. F., *Optimal Control and Estimation*, Dover, 1994
- Bryson, A. E., and Ho, Y. C., *Applied Optimal Contro*, Taylor & Francis, 1975
- Zarchan, P., *Tactical and Strategic Missile Guidance*, Fourth Edition, Progress in Astronautics and Aeronautics, 2002
- Wie, B., *Space Vehicle Guidance, Controls, and Astrodynamics*, AIAA, 2015
- Ben-Asher, J. Z., *Optimal Control Theory with Aerospace Applications*, AIAA Education Series, 2010
- Longuski, J. M., Guzmán, J. J., and Prussing, J. E., *Optimal Control with Aerospace Applications*, Springer, 2014
- Lawden, D. F., *Analytical Methods of Optimization*, Dover, 2003
- Lawden, D. F., *Optimal Trajectories for Space Navigation*, Butterworths, 1963
- Kirk, D. E.,*Optimal Control Theory*, Prentice-Hall, 1970
- Battin, R. H., *An Introduction to the Mathematics and Methods of Astrodynamics, Revised Edition*, AIAA Education Series, 1999
- Noton, M, *Spacecraft Navigation and Guidance*, Advances in Industrial Control, Springer, 1998
- Battin, R. H., *Astronautical Guidance*, McGraw-Hill, 1964

Goal: To introduce the concept of guidance, derive commonly used guidance laws for aerospace vehicles, and learn how to analyze the performance of guidance systems.

Overview: The course gives a comprehensive view of guidance systems used in space vehicles, and methods for analyzing the performance of these systems. The types of guidance systems that will be covered are launch vehicle ascent, intercept/rendezvous, interplanetary, orbit station-keeping, atmospheric re-entry, lander, and low-thrust. The mathematical foundation of these systems will be derived and discussed. Real world applications will be presented by reviewing selections from published literature. Course work will emphasize the analysis of the guidance system performance to achieve stated goals.

Grading: I use the standard 100 point system for grading. I reserve the right to define the final numeric ranges for each letter grade, although they typically match the standard scale (and won't

be higher than) where an A is 90-100, a B is 80-89, etc. I will assign ±'s to the letter grades at the end of the course as I find appropriate. The grade breakdown for this course is:
Homework - 50%
Midterm - 20%
Project - 30%

Homework Policy: I plan to have 6 homework sets in this course. Typically 2 weeks will be given for each assignment to be completed. Homework sets will generally involve simulations to be created. Any programming language can be used to create these programs. All assignments, including any code written, will be submitted through the course web site.
There may also be some journal papers assigned as pre-class readings so we can discuss the papers in class. These papers will be posted on the course web page or will be available through the library.

Exams: There will be a take-home midterm exam and no final exam. If you have exam grading issues, you must see me within 2 weeks of having the exam returned to you. See policies below for issues with schedule, although given the take-home nature I don't think there will be issues.

Project: There will be one **significant** semester project for the course. This project will involve more detailed simulation and analysis than a typical homework assignment. The details will be discussed during the semester. A professionally formatted technical report will be required for the project, and there will be a presentation of results to the class at the end of the semester.

Web Page: We will be using Canvas for posting all class information (assignments, notes, slides); work will also be turned in and returned through this site. There will also be a discussion board that will be used (see next section).
To access Canvas, go to: https://canvas.colorado.edu. Log-in using your CU login name and IdentiKey password.
Once you log-in, click on ASEN6015 to go into our course.
Make the most out of Canvas by downloading the Canvas Student App to view your grades, view course materials, submit assignments, take quizzes, and more.
Subscribing to notifications to be reminded of due dates, receive announcements, and grades.
Browsing the Canvas Guides or help videos for information on how to use Canvas. If you run into any problems, click the Help Icon within Canvas to report a problem or chat 24x7 with Canvas Support.
For additional assistance, contact the IT Service Center at help@colorado.edu or 303-735-4357.

Outside of Class Communication
Outside of class discussion will be very important for cementing concepts and collaborating on homework. The primary way we will do this is through Slack. This should the primary forum for questions and discussion in the course. For questions or comments about class material, theory, homework etc, PLEASE post here first as opposed to emailing me. And please answer each other! After all, they say the best way to learn is to teach! I will chime in as soon as I'm able, but I can't keep up with Slack messages in real time at all so please don't expect that.
The slack invite link will be posted on Canvas.
The second method to start discussion is through a Google Form "Comment Box", which will be accessible via Canvas. This interface allows students to submit anonymous comments, which I can address in class or via Slack as necessary.
Finally, if there are any personal questions, either Direct Message me on Slack, or email me and put "ASEN 6015" at the start of the subject line so that I don't miss it!

CAMPUS SYLLABUS STATEMENTS

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 Code of Conduct.

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). In this class, if you are sick or quarantined, you can simply attend the course remotely as discussed above. If being sick affects your ability to complete your work according to class deadlines, please let me know via email so I can accommodate you.

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.

See the campus policy regarding religious observances for full details.

Planned List of Topics
(roughly in order; subject to change at the whim of Prof. McMahon)

- **Introduction of the GNC System**
- **Review**
  - Dynamics, linear control theory
- **Performance Analysis Methods**
  - Introduction to Stochastic Systems
  - Monte-Carlo simulations, sensitivity analysis, method of adjoints
- **Velocity-Correlated/Intercept Guidance**
  - Proportional navigation.
  - Lambert guidance and Q-guidance.
  - Applications to missiles, rendezvous and intercept problems
- **Interplanetary ΔV Guidance**
  - Mid-course corrections and B-plane targeting. Applications: Moon, Mars and any interplanetary missions
- **Optimal Control Theory**
  - Derivation of linear quadratic control and Hamiltonian optimal control from a calculus of variations perspective.
- **Launch Vehicle Ascent Guidance**
  - Optimal and near-optimal solutions. Applications: Space shuttle, Apollo, IUS, current launch vehicles
  - First stage launch vehicle control
- **Station-keeping**
  - GEO satellite orbit maintenance strategies
  - Asteroid hovering guidance
  - Low-thrust Lyapunov guidance
- **Entry Guidance**
  - Bank-angle control for guided reentry. Applications: space shuttle re-entry, Mars landing, Orion re-entry targeting.
- **Powered Descent Guidance**
  - Final approach guidance and targeting for landing vehicles. Applications: OSIRIS-REx, Mars landers, Apollo.
- **Low-thrust vehicle Guidance** (time permitting)
  - Guidance considerations for low-thrust systems using electric propulsion or solar sails
- **Advanced Topics** (time permitting)
  - Stochastic optimal control
  - Adaptive control