ASEN 3200
Orbital Mechanics / Attitude Dynamics and Control
Spring 2020

Instructor (1st half): Dr. Natasha Bosanac
Office: AERO 459
Phone: (303) 492-7061
Email: natasha.bosanac@colorado.edu
Office Hours: Monday 11:00am-12:00pm, Wednesday 11:00am-12:00pm, during Friday labs

Instructor (2nd half): Dr. Daniel Scheeres
Office: AERO 454
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Email: scheeres@colorado.edu
Office Hours: TBD

Lectures: MW 2:00 – 3:15pm, AERO 120
Labs: F 8:30-10:20am (AERO 141), F 1:30-3:20pm (AERO N100)

Exam Dates:
Orbital Mechanics: 02/10 (in class), 03/04 (in class)
Attitude Dynamics and Control: Date for quiz is TBD (likely either 4/6 or 4/8 in the evening); final will be scheduled during regular final exam period

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Course Assistants:
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TA Office Hours:
Monday: 4pm-5pm in AERO 302
Tuesday: 1pm-2pm in AERO 302; 4pm-5pm in AERO 302
Wednesday: 4pm-5pm in AERO 403 (except on 2/12 in AERO N353)
Thursday: 1pm-2pm in AERO 302; 4pm-5pm in AERO 302

Required Text: Howard D. Curtis, Orbital Mechanics for Engineering Students, 3rd Edition, Elsevier Aerospace Engineering Series 2014. Errata for this textbook is available on the course website.
If preferred, an electronic version of this textbook is available via CU Libraries.

Supplementary Text:

- Bedford and W. Fowler, Engineering Mechanics: Dynamics, 5th Edition Pearson Prentice Hall, Upper Saddle River, NJ, 2008.
  See Chapter 20 and Appendix C for an alternate and compressed version of the material in the first half of the course.
- H. Schaub and J. L. Junkins, Analytical Mechanics of Space Systems, 3rd Edition AIAA Education Series, Reston, VA, 2014.
  Provides an advanced introduction to the material given in this course.
- Larson and Wetz, Space Mission Analysis and Design.
  Provides useful hardware information.

Note: These three textbooks are not required for use in this course.

Prerequisites: ASEN 2003, ASEN 2004, APPM 2360 and either APPM 2350 or MATH 2400 (all with a minimum grade of C)
Course Webpage: canvas.colorado.edu

Overview and Goals:

In the first half of the course, students will learn the characteristics of the motion of a system of particles with emphasis on the two-body problem, a model that offers a good preliminary approximation for the dynamics governing the motion of a planetary orbiter or interplanetary transfer vehicle. We will study the motion of a spacecraft under the influence of gravitational perturbing forces and n-body perturbations from additional celestial bodies. Also, the perturbations caused by atmospheric drag, and solar radiation pressure will be considered. In addition to studying the motion, we will look at ways to determine the ephemeris or trajectory of a satellite from observations. Finally, we will study aspects of designing an Earth orbiting and/or interplanetary mission.

The lab will involve a combination of Matlab and Systems Tool Kit (STK), e.g. students will be asked to solve a problem with STK, verify the solution, and/or use data generated by STK in a follow-on application. The objective here is to teach students how to determine if a result from ‘off the shelf software’ is reasonable. A primary complaint of employers is that recent graduates often believe whatever comes out of ‘blackbox software’ even when results are obviously unreasonable. When completed with the orbit portion of the class the student should be somewhat proficient with STK and more skilled in the use of Matlab. They will understand the basics of orbital motion and significant perturbations as well as mission design and preliminary orbit determination techniques. They will be able to solve problems on these subjects using both their analytical and computer skills.

The second half of the course focuses on dynamics and control of the pointing attitude of spacecraft. Nearly all spacecraft must be accurately pointed to accomplish their mission, yet the natural behavior in orbit is typically uncontrolled tumbling. We will develop a fundamental

understanding of these natural 3D rigid body kinematics and dynamics, using this to discuss common methods of passive and active attitude control. Attitude sensor and actuator technology will be investigated, as well as common ways of representing and determining attitude. On the topic of rigid body kinematics, the goal is for the student to be comfortable with a small sub-set of attitude representations such as the DCM and the 3-2-1 Euler angles, and make them at least aware of other set of coordinates such as other Euler angle sequences and the Euler parameters (quaternions). On the topic of rigid body dynamics, the goal is to expose the students to repeated uses of Euler's equation and the angular momentum vector to develop the system equations of motion. On the topic of control, the goal is to show students how simple open-loop and closed-loop flow diagrams can be created, and how to use the frequency space modeling methods to develop single-input-single-output linear controls. This is applied to 1-D constrained rotational motion only.

Lab experiments will be conducted to measure spacecraft mass properties, understand the operation of gyroscopic instruments, and design feedback control to achieve precise spacecraft pointing. In these labs, the goal is for students to receive hands-on opportunities to see the complex dynamic interactions that can occur with spinning rigid bodies, or even gyroscopic systems.

Class format:

The first half covers orbital mechanics and is led by Professor Bosanac. The second half of the course will focus on attitude dynamics and control, led by Professor Scheeres. Each section has a similar format:

- Twice-weekly lectures on Monday and Wednesday.
- Two laboratory sections each Friday. Lab experiments will be conducted on Fridays and written reports will generally be due a week later. Any collaborations with other lab groups including shared diagrams or extensive discussion of results must be acknowledged at the end of your report. Copying text or answers from another group with or without their permission constitutes cheating and will result in a zero grade for the lab. A repeated instance of cheating will result in an F for the course.
- Reading assignments are given weekly.
- Half-way through each section a Quiz will be held, covering the lecture and reading material covered thus far. Quizzes are to be completed individually. Any type of collaboration or copying on a quiz constitutes cheating and will result in an F for the course. If you have quiz grading issues, you must see the appropriate instructor within 2 weeks of having the quiz returned to you.
- Homework will be assigned at weekly intervals and is due at the beginning of class on the due date. Collaboration with others on homework is acceptable, but line-by-line copying of someone else's homework is cheating and will result in a grade of zero for that assignment. A repeated instance of cheating will result in an F for the course.
- Final Exams are held at the end of each of the two sections of the course. Check with the orbital section instructor on the orbital final exam. The attitude exam is during the regular class final exam period. Any type of collaboration or copying on an exam constitutes cheating and will result in a zero grade for the exam. A repeated instance of cheating will result in an F for the course

Homework Policy:

Please note the following policies regarding completing and turning in your homework:

- For grading purposes, homework is considered part of the group grade and only contributes to the total grade when the individual work is C or better.
- Collaboration is permitted on homework. You may discuss the means and methods for formulating and solving problems and even compare answers, but you are not free to copy someone's assignment. Copying material from any resource (including solutions manuals) and submitting it as one's own is considered plagiarism and is an Honor Code violation. Remember, the less you think about the problems yourself, the less you actually learn, and the more difficult 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 and intermediate values used to obtain the solution, and outlining the answer with proper units. These problem solving steps are critical for developing problem formulation skills.
- Always submit work with a professional appearance. Neatness, clarity, and completeness count.
- Late assignments are not accepted without prior instructor approval. If you know in advance that you must miss a homework due date or lab, please make arrangements with your instructor via email.
- Although each homework assignment will have several problems, all problems may not be graded. However, solutions will be provided to you for all the problems.
- If you believe that your homework was graded incorrectly, you have 2 weeks from when it is handed back to ask for a regrade. To ask for a regrade, you must briefly outline via email what you think the error in grading was and submit it to a course teaching assistant.

Class Attendance:

You are expected to attend class. If you need to miss a lecture, it is your responsibility to catch up on the material. Don't go to the instructor to catch up on missed material, speak with your peers in the class and get the notes from them. Campus policy regarding religious observances requires that faculty make every effort to reasonably and fairly accommodate all students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. If you cannot attend a regularly scheduled class, it is up to the student to catch up on the missed material. If you cannot take an exam on a particular day, please let the instructor know at the time the exam is being scheduled.

Make-Up Assessment Policy:

There are no make-up homework assignments. If you miss the assignment, you get a zero for it. If you can't make a quiz or exam for a pressing reason, you need to contact the instructor at least one week prior to the exam date. If you can't take the exam for some emergency reason, you still need to notify the instructor prior to the exam. Without prior consent, there will be no make-up exams.

Grading Policy:

In an effort to ensure that each student leaves the class with a fundamental understanding of the topics covered in this course, the final grades will be heavily weighted on each student's individual performance. That is, if a student does not pass the individually graded aspects of the course, they will not pass the class overall. Keeping this in mind, the final grades will be determined as shown in Tables 1 and 2.

Table 1: Course Grade Percentages if the student achieves an overall grade of C or better on all exams.

All Homework: 15%
Orbital Quiz: 10%
Orbital Final Exam: 15%
Attitude Quiz: 10%
Attitude Final Exam: 15%
Lab Experiments: 30%
Research Projects: 5%

Table 2: Course Grade Percentages if the student achieves an overall grade less than a C on all exams.

Orbital Quiz: 20%
Orbital Final Exam: 30%
Attitude Quiz: 20%
Attitude Final Exam: 30%

Accommodations 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 or injury, see Temporary Medical Conditions under the Students tab on the Disability Services website.

Religious Observances:

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 alert the instructors about any possible conflicts you potentially foresee during the first week of class. Early knowledge of possible conflicts will enable us to plan appropriately with you. See the campus policy regarding religious observances for full details.

Classroom Behavior:

Students and faculty each have responsibility for maintaining an appropriate learning environment. 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.

Preferred 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.

Sexual Misconduct, Discrimination, Harassment and/or Related Retaliation:

The University of Colorado Boulder (CU Boulder) is committed to fostering a positive and welcoming learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct intimate partner abuse (including dating or domestic violence), stalking, protected-class discrimination or harassment by 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 cureport@colorado.edu. Information about the OIEC, university policies, anonymous reporting, and the campus resources can be found on the OIEC website.

Please know that faculty and instructors have a responsibility to inform OIEC when made aware of incidents of sexual misconduct, discrimination, harassment and/or related retaliation, to ensure that individuals impacted receive information about options for reporting and support resources.

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 policy may include: 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 who are 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 at the Honor Code Office website.