ASEN 3200

Orbital Mechanics, Attitude Dynamics and Control

Fall 2019

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Instructor (2nd Half): Dr. Marcus Holzinger
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Lectures: MW 4:00–5:15 pm, AERO 120
Lab: Tuesday 12:30–2:20 or Thursday 12:30–2:20, AERO 141

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Text: Howard D. Curtis, *Orbital Mechanics for Engineering Students*, 3rd Edition, Elsevier Aerospace Engineering Series 2013. Electronic edition available for free through CU Libraries.

Prerequisites: Requires prerequisite courses of ASEN2003 and ASEN2004 and APPM2360 and APPM 2350 or MATH 2400 (all with minimum grade of C)

Course Web Page: http://canvas.colorado.edu

Overview and Goals: Students will learn the basics of spacecraft orbital and attitude motion.

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 Satellite 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 the 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 attendant 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 to make the student comfortable with a small subset 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 the students how simple open-loop and closed-loop flow diagrams can be created, and how to sue 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 of the course will focus on orbital mechanics, led by Professor Nerem. The second half is devoted to attitude dynamics and is led by Professor Holzinger. Each section has a similar format:

• Twice-weekly lectures on Monday and Wednesday

• Two laboratory sections on Tuesday or Thursday. Lab experiments will be conducted on these days and written group reports will generally be due two weeks later. Students will be assigned to a new group for each lab exercise. 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, or copying from a previous year's report 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.

• In <u>each</u> of the two sections of the course there is a midterm and final exam (a total of 4 exams for the course). These exams will generally be scheduled in the evenings (see the class schedule). The final exam for the attitude section will be given on during the scheduled final exam period, but will only cover the attitude part of the class. All exams must be completed individually. Any type of collaboration or copying on an exam constitutes cheating and will result in an F for the course. If you have exam grading issues, you must see the instructor within 2 weeks of having the exam returned to you.

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.
- If you must miss class for an excused absence, you may submit your homework early. 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 attach a cover page describing what you think the error in grading was, and hand it in with your complete homework package from that problem set to a course CA or instructor.

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 class mates and get the notes from them. Campus policy regarding religious observances requires that faculty make every effort to reasonably and fairly deal with 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 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, he/she will not pass the class overall. Keeping this in mind, the final grades will be determined as shown in Tables 1 and 2.

All Homework 15%
Orbit Quiz 10%
Orbital Final Exam 15%
Attitude Quiz 10%
Attitude Final Exam 15%
Lab Experiments 30%
Research Reports 5%

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

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

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

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 or injury, see Temporary Medical Conditions under the Students tab on the Disability Services website and discuss your needs with your professor.

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 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. Class rosters are provided to the instructor with the student's legal name. I

will gladly honor your request to address you by an alternate name or gender pronoun. Please advise me of this preference early in the semester so that I may make appropriate changes to my records. For more information, see the policies on classroom behavior and the Student Code of Conduct.

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 (including sexual assault, exploitation, harassment, dating or domestic violence, and stalking), discrimination, and 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, http://honorcode.colorado.edu.