

ASEN 6080: Statistical Orbit Determination Syllabus, Spring 2024

Lecture: Monday & Wednesdays, 3:00 pm-4:15 pm in AERO 114

Instructors

Dr. Jason Leonard

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Office Hours: In person + online (see Canvas for details)

Course Website

<https://canvas.colorado.edu>

This semester we will be using Canvas, CU Boulder's learning management system. 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.

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 ASEN 6080 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.

Subscribe 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.

Course Text

Required:

- *Statistical Orbit Determination*, Byron D. Tapley, Bob E. Schutz, and George H. Born, 2004.

Not required, but recommended and available for free through library (links on web site):

- *Optimal Estimation of Dynamic Systems*, John Crassidis and John Junkins, 2004.
- *Applied Optimal Estimation*, Edited by A. Gelb, 1974.

Cheap (in Dover) and worth buying for reference:

- *Factorization Methods for Discrete Sequential Estimation*, Gerald J. Bierman, 2006.
- *Stochastic Processes and Filtering Theory*, Andrew H. Jazwinski, 2007.

Course Description

ASEN 6080 is a course providing an in-depth discussion of advanced orbit determination techniques. The focus is on the fundamentals of these methods based on non-linear estimation theory and, critically, the ability to implement them in software. The course lectures are derived from experiences in industry and research.

Date	Lecture	Topic
January 17, 2024	1	Introduction and Review
January 22, 2024	2	Linearization, the STM, and Error Propagation
January 24, 2024	3	Orbits Review
January 29, 2024	4	Measurements, Time, and Coordinate Systems
January 31, 2024	5	Estimation Methods: Batch Least Squares, Kalman Filter, EKF
February 5, 2024	6	Residual Analysis
February 7, 2024	7	Stochastic Process: White Noise, Gauss-Markov, Continuous vs Discrete
February 12, 2024	8	Stochastic Process: Model Noise Compensation
February 14, 2024	9	Kalman Filter Smoother
February 19, 2024	10	Kalman Filter Smoother
February 21, 2024	11	Extended Kalman Filter Smoother
February 26, 2024	12	Numerical Issues in Filtering
February 28, 2024	13	Factorization Methods: UDU, Givens, Householder, etc.
March 4, 2024	14	UDU Filter
March 6, 2024	15	Square Root Information Filter
March 11, 2024	16	Square Root Information Filter
March 13, 2024	17	Consider Kalman Filter
March 18, 2024	18	Consider Kalman Filter
March 20, 2024	19	State Constrained Estimation Methods: Equality and Inequality
March 25, 2024	-	Spring Break
March 27, 2024	-	Spring Break
April 1, 2024	20	B-Plane Mapping for Interplanetary OD
April 3, 2024	21	Conducting Covariance Analysis, Error Budgets, Sub-optimal Filtering
April 8, 2024	22	Kalman Filter Sensitivity Analysis
April 10, 2024	23	UKF
April 15, 2024	24	Monte Carlo Methods, Linear Covariance Analysis (LINCOV)
April 17, 2024	25	Monte Carlo Methods, Linear Covariance Analysis (LINCOV)
April 22, 2024	26	Particle Filter
April 24, 2024	27	TBD
April 29, 2024	28	TBD
May 1, 2024	29	TBD

Course Format

The course will consist of two weekly lectures, homework, a mid-term project and a final project. Lecture attendance is highly recommended since many topics are not covered in the course textbook. The final project will be assigned mid-semester, and will be due at the end of the semester (exact date to be announced). Project presentations will be held the last week of class or during the finals week and will count toward the 10% participation grade of the final project.

Collaborative study and exploration of the course material is highly encouraged.

Course Grading

Project 1	25%
Project 2	35%
Homework	30%
Discussion	10%

Homework

Electronic submission of each homework is due by 2:00 pm before the beginning of lecture on the specified due date. Late assignments will not be accepted unless there are extenuating circumstances (at my judgement). All homework submissions must be in the form of a single pdf with code attached when asked for.

Homework grading is on a scale of 0 $\rightarrow$ “ $\checkmark$ -” $\rightarrow$ “ $\checkmark$ ” $\rightarrow$ “ $\checkmark$ +” scale as follows.

- 0 = assignment not turned in (0/10)
- “ $\checkmark$ -” = assignment turned in, but either not complete or with major errors (6/10)
- “ $\checkmark$ ” = assignment turned in complete (10/10)
- “ $\checkmark$ +” = assignment turned in complete with above average effort/analysis (14/10)

It is expected that students will generally get a “ $\checkmark$ ” or “ $\checkmark$ +” on all assignments. Averaging above a “ $\checkmark$ ” for the term will receive all homework points.

Projects

There are two projects in this course. They both require significant coding effort and analysis. The first project is the implementation of the basic estimation techniques for a LEO satellite. The final project is based on a deep space mission performing a targeted Earth flyby to go to its final destination. The details will be released later in the semester. See the class schedule for the timing of the projects.

Discussion

Discussion requirements can be satisfied through speaking out loud in class and/or by adding to online discussion. It is often the case that you can explain things better to one another than I will explain them to you - I want you to all take advantage of this. Furthermore, just because you think you understand something doesn't mean you should stop thinking about it - ask any professor and they will tell you that mastering material reaches a new level once you *teach* it.

Zoom Information for Distance Students

While this course contains a distance learning section, classrooms in the AERO building are not fully equipped for live concurrent discussions with distance students during lecture. Instead, lecture capture is used, providing recorded lectures.

1 University Policies

This class will be conducted in accordance with university policies:

1.1 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](#).

1.2 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](#).

1.3 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 for accommodations.

1.4 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.

1.5 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.

1.6 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](#).

1.7 Religious Accommodations

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.

See the [campus policy regarding religious observances](#) for full details.

1.8 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.