ASEN 5519 Small Uncrewed Aircraft System Guidance, Navigation, and Control

Spring 2023 Syllabus

Lecture: AERO 114 Tuesday and Thursday, 11:30 am – 12:45 pm

Instructor

Prof. Eric Frew
Office: AERO 269 Email: eric.frew@colorado.edu
Hours: TBD

Text

Required: *Small Unmanned Aircraft: Theory and Practice*
by Randal W. Beard and Timothy W. McLain
https://github.com/randybeard/uavbook

Prerequisites

This class is open to advanced graduates from all departments with a background in dynamics and control equivalent to ASEN 5014 and/or a background in sensor fusion and estimation equivalent to ASEN 5044.

Overview

Uncrewed aircraft systems (UAS) are being heralded as the next revolution in the aerospace industry. The purpose of this course is to introduce students to advanced techniques for guidance, navigation, and control of the emerging class of small uncrewed aircraft systems (SUAS), which are informally defined as aircraft too small to carry a person as payload.

The first third of the course will focus on aircraft dynamics and control with emphasis on linearization techniques applicable to the computing and sensing resources available on SUAS. Automatic guidance and control are the foundations of unpiloted flight. Therefore the class will develop the full, nonlinear aircraft equations of motion, linearize these equations into simpler form, and learn how to use classical (e.g. successive loop closure) control techniques to stabilize the aircraft.

The middle third of the course will focus on estimation algorithms and sensor fusion architectures to derive aircraft state information from inexpensive sensors. Common sensors will be described in order to develop models of their drift and error performance. Particular emphasis will be placed on a navigation architecture that combines inertial sensors, air data sensors, and GPS position and velocity measurements.

The final third of the course will investigate the impact of wind on aircraft guidance and control. Aircraft dynamics and aerodynamics will be revisited in order to derive where spatial- and time-varying winds enter into the aircraft equations of motion. Gust sensitivity will be discussed as well as static and dynamic soaring concepts whereby the aircraft can gain energy under certain flight conditions.

Students will develop an aircraft simulation capability in order to demonstrate the topics covered during the course. By the completion of the course students will have a complete nonlinear simulation of an aircraft under closed-loop guidance and control in wind.

Topics covered in this course include:

1. Introduction
2. Coordinate Frames
3. Kinematics and Dynamics
4. Forces and Moments
5. Linear Design Models
6. Autopilot Design
7. Nonlinear Design Models
8. Waypoint and Orbit Following
9. Sensors
10. State Estimation
11. Wind Models
12. Equations of Motion in Wind
13. Soaring Concepts and Wind Energy Extraction
14. System Identification and Flight Test Model Verification

Course Grading

20% Homework
30% Exam 1
30% Exam 2
20% Final Project

Grades for the overall course are set based on the following criteria. **Grades do not correspond to pre-specified ranges of scores.**

A, A-	Demonstrates superior understanding of the material beyond the course requirements, excellent technical work
B+, B	Demonstrates comprehensive understanding of the material, very strong technical work
B-, C+	Demonstrates good understanding of the material, complete technical work
C	Demonstrates adequate understanding of the material to proceed to the next level; sufficient technical work
C-	Does not demonstrate adequate understanding of the material to proceed to the next level
D	Poor technical work
F	Unsatisfactory performance

Homework Policy

Homework will be assigned each Thursday and will be due the following Thursday in class. Students are allowed to collaborate with one another on the homework; however, each student must submit his own work.

Exams

Exams will be open note, open book take home exams. Exam 1 will cover the first half of the course (Topics 1 – 6). Exam 2 will focus on material from the second half of the course.

Final Project

This course will have a final project in place of a final exam. The project will require students to implement concepts or topics based on material presented in the course, and then submit a final paper describing the results. The main mechanism for disseminating research into the broader scientific community is through conference and journal publications. As researchers, technical writing is one of the most critical, yet overlooked, skills you can obtain. Details of this assignment will be provided during the second week of the course.

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, 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. Additional information regarding the Honor Code academic integrity policy can be found on the Honor Code website.

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 classroom behavior policy, the Student Code of Conduct, and the Office of Institutional Equity and Compliance.

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).

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.

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 sexual misconduct (harassment, exploitation, and assault), intimate partner violence (dating or domestic violence), stalking, protected-class discrimination and harassment, 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 believe they 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 have a responsibility to inform OIEC when they are made aware of any issues related to these policies regardless of when or where they occurred to ensure that individuals impacted receive information about their rights, support resources, and resolution 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.

Course Outline

Numbers in parenthesis indicate book chapters. '+' indicates material not covered in the textbook.

Week	Dates		Tuesaday		Thursday	
1	1/16 - 1/20	Equations of Motion; Aircraft Dynamics; Guidance and Control.	Introduction (1)		Coordinate Frames (2)	
2	1/23-1/27		Kinematics and Dynamics (3)		Forces and Moments 1 (4)	HW1 due
3	1/30-2/3		Forces and Moments 2 (4)		Linear Design Models 1 (5)	HW2 due
4	2/6-2/10		Linear Design Models 2 (5)		Linear Modes and Reduced-Order Models (5)	HW3 due
5	2/13-2/17		Autopilot Design - Lateral (6)		Autopilot Design - Longitudinal (6)	HW4 due
6	2/20-2/24		Advanced Control Methods (+)		Nonlinear Design Models (9)	HW5 due
7	2/27-3/3		Waypoint Guidance and Straight Line Following (10)		Guidance Vector Fields for Closed Curves (10+)	HW6 due
8	3/6-3/10	Sensors; Estimation; Navigation and Sensor Fusion.	Sensors - Proprioceptive (7)		Sensors - Exteroceptive/Navigation (7)	**EXAM 1 due**
9	3/13-3/17		Air Data Systems (7+)		Kalman Filter Estimation Review (8)	HW7 due
10	3/20-3/24		State Estimation 1 (8)		State Estimation 2 (8)	HW8 due
11	3/27-3/31	SPRING BREAK			SPRING BREAK	
12	4/3-4/7		Multi-Sensor Fusion 1 (+)		Multi-Sensor Fusion 2 (+)	HW9 due
13	4/10-4/14		Attitude-Heading Reference System (+)		Advanced Sensor Fusion Methods (+)	HW 10 due
14	4/17-4/21	Wind; Autonomous Soaring.	Wind Models (+)		Equations of Motion in Wind (+)	**EXAM 2 due**
15	4/24-4/28		Autonomous Soaring (+)		Optimal Trajectories for Soaring 1 (+)	HW11 due
16	5/1-5/5		Optimal Trajectories for Soaring 2 (+)		Dynamic Path (Re)Planning for Guidance in Wind (+)	HW12 due
Finals	5/8-512				Final Project due	