# ASEN 3128
# Aircraft Dynamics

# Syllabus

| | | | |
|---|---|---|---|
| Lecture: | Zoom/Canvas | T, Th | 1:15 – 2:30 pm |
| Lab: | Zoom/AERO N100 | F | 10:40 am – 12:30 pm, 1:40 – 3:30 pm |

## Instructors

Professor Brian Argrow
Office: AERO 224N Phone: (303) 492-5312 Email: brian.argrow@colorado.edu
Office Hour: Wed 3:30-4:00 pm; Thu, 3:30 – 4:30 PM. Course Zoom link

Professor Nisar Ahmed
Office: AERO 265 Phone: (303) 492-0286 Email: nisar.ahmed@colorado.edu
Office Hour: Wed 3:30-4:00 pm; Thu, 3:30 – 4:30 PM. Course Zoom link (start Week 9)

### Teaching Fellows

Jack Center jack.center@colorado.edu
Office Hours: Tue, 2:45-3:45 pm

Stephen Chamot stephen.chamot@colorado.edu
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## Text

Required: *Dynamics of Flight: Stability and Control*, Bernard Etkin and Lloyd Reid, John Wiley and Sons. 3rd Ed., 1996

Supplemental: *Small Unmanned Aircraft: Theory and Practice*, Randal W. Beard and Timothy W. McLain, Princeton University Press, 2012.

Supplemental: *Flight Stability and Automatic Control, 2nd Ed.*, Robert C. Nelson, McGraw-Hill, 1998.

# Prerequisites

ASEN 2002, 2003, 2004, and APPM 2360 (min grade C).

# Overview

This course covers the key ideas that enable an understanding of how aircraft work and tools for quantitative analysis and design methods to achieve specified dynamical behavior. Because aircraft exist in many different forms, and new designs continue to be developed, the focus is on the common principles that underlie atmospheric flight, so that a solid basis can be formed for future work in most any direction. Concrete treatment of these ideas, tools, and methods is provided through working problems in assigned groups, consisting of analysis, simulation, and design problems, including development of MATLAB simulation models for two very different vehicles: a quad-copter and a conventional airplane.

In their full expression, aircraft dynamics possess astounding complexity, and it is a tribute to the ideas developed by aviation's pioneers that a relatively simple understanding can often be obtained, leading to clear insights and design principles. While these concepts are not inherently difficult, they do lie outside most common experience, and they depend on new nomenclature and strange notation that can seem overwhelming at first. It is only through diligent and careful use of this new language that the underlying simplicity can be grasped and conveyed on exams; mastery of the language of aircraft dynamics is perhaps the most important predictor for success in the course.

The course has been designed to develop a conceptual grasp of the key ideas below, and to demonstrate proficiency in using these concepts to solve problems, construct and validate simulations, and to explain behaviors and results obtained. In particular, engineering reasoning skills using these concepts are stressed in assignment solutions and examinations. The key learning objectives are:

**Vector mechanics**

- Vector representation in coordinate frames
- Change of coordinate frame representation (coordinate rotation)
- Relative motion, frame derivatives
- Change of derivative frame: velocity rule

**How aircraft dynamics models are created and what the terms mean**

- 3D rigid body translational model
    - Kinematics
    - Dynamics, external forces
    - Effects of wind
- 3D rigid body rotational model
    - Kinematics, Euler angle attitude representation
    - Dynamics, Euler moment equations, external moments
- External forces and moments
    - Aerodynamic effects

- Control effects
- Steady flight conditions, trim states

**How aircraft dynamics models are simulated**

- State space models
- Matlab integration
- Good naming and commenting habits

**How dynamical behavior is understood and specified**

- Linearization
- Decoupling
- Stability derivatives
- Modal solutions
- Stability characterizations
- Modal specifications

**How feedback control is designed to meet behavioral objectives**

- Sensor selection, control structure
- Effects on mode eigenvalues

# Teaching Modalities

**Lecture** – Lectures will be remote and online throughout the semester, with no option for in-person lectures. Lectures will be delivered live over Zoom. They will be recorded and uploaded to the course Canvas page. Lectures will be recorded in two formats – Zoom recordings will be posted in short blocks (e.g. 4 separate files per lecture) and the CU Course Capture system will also record and post the lectures to the Canvas site.

**Lab Sections** – Students are expected to register for one of the two lab sections and be available for in-person or remote interaction during the scheduled lab section. Lab groups will be made from students in the lab sections without considering if they plan to attend in-person or remotely. Lab sections are the only opportunity for in-person interaction during the semester. However, students are not required to attend lab sections in-person and can complete all lab assignments remotely.

**Online** – The course is designed for remote (live, synchronous) interaction for the lectures and the lab sections. However, the course can be completed if a student must take the course online (asynchronously). Students who plan to complete the course online must contact the instructor within the first week of the course so a plan can be created for participating in lab assignments and for taking exams.

# Course Components

Material and concepts are introduced, and student mastery is evaluated using several mechanisms throughout the course:

**Reading** – The textbook provides the essential basis for the course, including the concepts, terminology, notation, methods, and examples used to convey the course topics. Specific reading assignments will be given covering key sections of the book; some book sections are not covered in the course. Some supplementary material will also be provided. The textbook contains a wealth of information, but the concepts and notation are new to most: some sections need to be read more than once to fully grasp the material.

**Lectures** – These are intended to emphasize key ideas and methods that make the material easier to grasp. They are therefore a counterpart to the reading, not a replacement. The value of lectures is dependent on your participation in them. Passive "watching" will provide little benefit. Active note taking is critical to developing first-hand familiarity with the notation, terminology, and methods, and to gaining comfort in using them. Although lectures will be recorded, this is a poor substitute for your own lecture notes. Questions are encouraged during lectures, and will be prompted often.

**Homework** – Homework problems are assigned every other week, out of sync with the lab assignments. They provide practice in solving problems of varying difficulty and sometimes will also involve computing. Collaboration on homework is allowed (copying is not); however, students are encouraged to use homework as a means to ensure their individual mastery of the subject. In-class group problem solving and labs will allow for considerable collaborative problem solving.

**Reading Quizzes** – These will cover the reading material, lectures, and portions of the lab assignments. Quiz grades will contribute to your individual course grade and are designed to encourage you to come to class and lab prepared. They will consist of true-false and multiple-choice-style questions similar in format to questions that will be on the exams.

**Lab Assignments** – These provide first-hand experience employing the reading and lecture material. They consist of analysis and computation exercises, simulation development, and simulation use to address aircraft stability and control design problems. Assignments will be carried out in small groups. Students are expected to use these assignments and the associated group learning opportunities to strengthen their **individual** mastery of the subject. Dividing the learning on assignments by dividing the work is a recipe for failure on the individual exams in this course.

Proper presentation of engineering work is important throughout the ASEN curriculum, as in professional life thereafter, and students are expected to properly describe what was done and explain results using graphical and written descriptions based on the precise terminology and notation introduced in the course.

A secondary objective of the Assignments is the development of proficiency with numerical simulation, and to develop good programming habits. Simulation is becoming an indispensable tool in engineering, and proficiency is expected of professionals in this field.

**Exams** – These are the primary means of evaluation of your individual grasp of the course material. In-class, written exams will be conducted in week 6 and week 11; the final exam is

Sunday 2 May, 4:30 – 7:00 pm. Exams will include both conceptual questions and quantitative problems. Precise use of terminology and notation is stressed. The final exam is comprehensive in that it will contain material from the entire course, but emphasis will be placed on the final quarter of the course material.

# Logistics

1. Office hours for Instructors and TAs will be held nominally during the arranged "lab" times for the course, in the Co-Pilot Laboratory (AERO N100). This is intended to provide ease-of-access to instructor and TA help, primarily during group work on the weekly assignments, but any questions about course material are welcome. To help avoid congestion, students assigned to a lab section have priority for that section. However, instructors and TAs are available to all students during these "lab" times. This mode of "supervised learning" can be quite efficient, particularly if groups are prepared by attempting the assignments ahead of time, and come to the "lab" sessions with questions. The assignments are handed out the week before the intended "lab" time in order to enable this "first-pass" in advance. Additional office hours with instructors and TAs will also be scheduled. Private meetings with instructors or TAs can also be arranged if needed.
2. Email questions: Students are able to email the instructor questions throughout the week regarding course material. DO NOT expect an immediate response. Any question received by 2 PM should receive a response by 5PM the same day. Questions received after 2 PM may not receive a response until 5PM the next day. Always include "3128" in the subject of any emails related to the class (enables efficient search).
3. Attendance at all lectures and lab sessions is essential. Students who come to class prepared and participate in discussions typically have a more rewarding experience. Attendance at lab sections is equally important. The instructors and TAs will be present and available remotely for all lab sessions, and the individual assistance this affords can be extremely valuable.
4. Taking your own notes: Firsthand contact with the notation and diagrams is key to understanding the material in this course, and to conveying your understanding on exams. Lectures will be recorded for repeated viewing, to ensure details are not missed. But there is no substitute for taking your own notes.
5. Homework - Collaboration is permitted on homework. This means you may discuss the means and methods for solving problems and even compare answers, but you are not free to copy solutions from classmates or from Internet resources. **The work that you turn in must be your own**--copying is not allowed for any assignments. Students who are caught copying homework solutions will be reported for violation of honor code and may incur both academic and non-academic sanctions. Homework is **submitted individually** through Canvas. Please indicate clearly where each problem begins and ends. (You do not need to use a separate sheet for each problem.) Written work must be neat and readable with adequate spacing and margins. Final answers must be indicated with an arrow, underline, or box. Very messy work will be returned to you without being graded and a score of zero recorded.
6. Reading Quizzes will be given weekly in an on-line format through Canvas. These will cover the reading material, lectures, and portions of the weekly Assignments. Quiz grades will contribute to your individual course grade. Reading quizzes are administered through Canvas

every Thursday, except on days where there is an exam. Quizzes will be available to take from Tuesdays at 8:00 PM until 1:15 PM on Thursdays; .

7. Examinations & Comprehensive Final - Exams will be given during the class periods. The final exam is scheduled according to University policy. Any type of collaboration or copying on an exam, or final constitutes cheating and will result in an F for the course. An honor code violation or accusation report will be filed. **There will be a statute of limitations on when exam grades can be corrected. Any corrections on exam scores must be made before the next exam, or two weeks after the exam was returned, whichever comes second**. The only corrections made after this time period will be for simple addition errors in scoring. Students will be expected to complete both portions during the scheduled course time, with some extra time given to allow for uploading the completed exam.
8. Lab Assignments - Simulation and design lab exercises are conducted in small teams. A single assignment is submitted for each lab group. Collaborations with other groups, including shared diagrams or extensive discussion of results, must be acknowledged at the end of your assignment. Lab assignments are not formal reports. Specific requirements for what to submit are given with each assignment.
9. Deadlines – Deadlines must be enforced to ensure fairness and to enable timely grading. Late assignments are subject to a 20% penalty per day. (E.g. 0-24 hours late = 1 day penalty) except under extenuating circumstances. If such a circumstance occurs you are expected to contact the instructor immediately by email, before the due date. No other accommodations will be provided, e.g. a hectic schedule or crashed computer will not be considered. Please plan for these contingencies by including some margin in your schedule. If you know in advance that you will not be on campus for a due date, you may submit your assignment to the instructor any time prior to the due date.

# Grading

### Grading Philosophy

Assignments and exams are graded to an absolute standard designed to indicate your level of competency in the course material. The final grade indicates your readiness to continue to the next level in the curriculum. The AES faculty have set these standards based on our education, experience, interactions with industry, government laboratories, others in academe, and according to the criteria established by the ABET accreditation board.

The course grade is primarily dependent on **individual** measures of competency, i.e. exams. The other course assignments are designed to enrich the learning experience and to enhance individual performance, not to substitute for sub-standard individual competency. Accordingly, group assignment grades are only incorporated into the final grade when the individual grade is a C or better. **In other words, if your individual average is below a C, the group-based grade fraction will not be averaged into your final grade, which will then be based solely on your exam/quiz scores and notebook grade.** This policy makes it important to use the group assignments to enhance *your own* learning. Although it may seem more efficient to split up the assignment among group members, this is dangerous because the learning is also split up, and this

often results in poor performance on exams, and significant risk of repeating the course. Recommended practice is to work the assignments first on your own, then use the group interactions and instructor/TA help to answer questions and refine and deepen your understanding.

Grades for the course are set based on the following criteria:

| | |
|---|---|
| A, A− | Demonstrates mastery of the course material in both conceptual and quantitative aspects. |
| B+, B | Demonstrates comprehensive understanding of the material, with a solid conceptual grasp of key concepts and strong quantitative work. |
| B-, C+ | Demonstrates good understanding of most key concepts, with few major quantitative errors. |
| C | Demonstrates adequate understanding of the material to proceed to the next level; sufficient quantitative work. |
| C− | Does not demonstrate adequate understanding of the material to proceed to the next level, or makes persistent quantitative errors. |
| D | Very little understanding is evident, consistently poor quantitative work. |
| F | Unsatisfactory performance. |

**Grade Breakdown**

Your final grade is a combination of an individual work (IW) and group work (GW) score.

| **Type** | **Description** | **Percentage** |
|---|---|---|
| Individual Work (IW) | Reading Quizzes | 10% |
| | Exams (2 Exams) | 60% (30% Each) |
| | Final Exam | 30% |
| IW Score | Total Individual Score | 100% |
| | | |
| Group Work (GW) | Homework* | 30% |
| | Lab Assignments | 70% |
| GW Score | Total Group Score | 100% |

**Final Course Score**

Your final course score is computed as follows

- If your Individual Work (IW) grade is **below a C**, then your Final Score (FS) is the Individual Work (IW) score. In this case FS = IW.

- If your Individual Work (IW) grade is **a C or better** then your Final Score is computed as the weighted average of the Individual Work (IW) and Group Work scores (GW). This formula is

FS = 0.6*IW + 0.4*GW,

subject to the limitation that averaging in your GW score does not reduce your FS. Thus the group work score can only help your final grade, often significantly.

This is then equivalent to an overall breakdown:

| | |
|---|---|
| Reading Quizzes | 6% |
| Homework | 12% |
| 2 Exams | 36% |
| Lab Assignments | 28% |
| Final Exam | 18% |
| | 100% |

## Exam Schedule

Exam 1: Tuesday 26 February, 1:15 – 2:30 pm, Canvas (remote)
Exam 2: Tuesday 23 March, 1:15 – 2:30 pm, Canvas (remote)
Final Exam: Sunday 2 May, 4:30 – 7:00 pm, Canvas (remote)

## Homework and Lab Assignment Schedule

Homework and Lab Assignments will be posted and due on alternating weeks. See the end of this document for the full schedule. Homework must be completed individually. Only one lab assignment is submitted per lab group.

## Reading Quiz Schedule

Reading quizzes will be conducted on-line through Canvas. They will be open each week (except when there is an exam) from Wednesdays at 8:00 PM until 1:15 PM on Thursdays. Two attempts are provided for each quiz with the highest score recorded. Reading quiz submissions will not be accepted after the deadline.

## 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 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.

## Requirements for COVID-19

As a matter of public health and safety due to the pandemic, all members of the CU Boulder community and all visitors to campus must follow university, department and building requirements, and public health orders in place to reduce the risk of spreading infectious disease. Required safety measures at CU Boulder relevant to the classroom setting include:

- maintain 6-foot distancing when possible,
- wear a face covering in public indoor spaces and outdoors while on campus consistent with state and county health orders,
- clean local work area,
- practice hand hygiene,
- follow public health orders, and
- if sick and you live off campus, do not come onto campus (unless instructed by a CU Healthcare professional), or if you live on-campus, please alert CU Boulder Medical Services.

Students who fail to adhere to these 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 policies on COVID-19 Health and Safety and classroom behavior and the Student Code of Conduct. If you require accommodation because a disability prevents you from fulfilling these safety measures, please see the "Accommodation for Disabilities" statement on this syllabus.
All students who are new to campus must complete the COVID-19 Student Health and Expectations Course. Before coming to campus each day, all students are required to complete the Buff Pass. ***In this class, you may be reminded of the responsibility to complete the Buff Pass and given time during class to complete it.***

Students who have tested positive for COVID-19, have symptoms of COVID-19, or have had close contact with someone who has tested positive for or had symptoms of COVID-19 must stay home. In this class, if you are sick or quarantined, and complete the Health Questionnaire and Illness Reporting Form remotely. In this class, if you are sick or quarantined, email the instructor if you are unable to participate in class activities remotely or online. Because of FERPA student privacy laws, students are not required to state the nature of their illness when alerting the instructor that they cannot participate.

## General University Policies

**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.

**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**
The University of Colorado Boulder (CU Boulder) is committed to fostering an inclusive and welcoming learning, working, and living environment. CU Boulder 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 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 graduate instructors have a responsibility to inform OIEC when 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 options for reporting and support resources.

**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, you must let the instructors know of any such conflicts within the first two weeks of the semester so that we can work with you to make reasonable arrangements. See the campus policy regarding religious observances for full details.

# Schedule

| Week No. | Dates | | Tuesday | | Thursday | | Friday | |
|---|---|---|---|---|---|---|---|---|
| **1** | **1/14-1/15** | **Equations of Motion; Intro to Aircraft Dynamics and Control: Quadrotor Example** | | | Nomenclature | | | |
| **2** | **1/19-1/21** | | Coordinate Frames, Euler Angles | | Equations of Motion – Kinematics (Ch. 4.1, 4.4) | Reading Quiz 1 | | Lab 1 Assigned |
| **3** | **1/26-1/29** | | Equations of Motion – Dynamics (Ch. 4.2-4.3,4.5,4.7) | HW 1 Due | Linearization and Quadrotor Dynamic | Reading Quiz 2 | | |
| **4** | **2/2-2/5** | | Quadrotor Modal Solutions | | Quadrotor Forces, Moments | Reading Quiz 3 | Lab 1 Due | Lab 2 Assigned |
| **5** | **2/9-2/12** | | Quadrotor Stability and Control | HW 2 Due | Quadrotor Guidance | Reading Quiz 4 | | |
| **6** | **2/16-2/19** | | **Exam 1** | | Longitudinal Forces and Moments | | Lab 2 Due | Lab 3 Assigned |
| **7** | **2/23-2/26** | **Fixed-Wing Aircraft: Longitudinal Stability and Control** | Longitudinal Trim and Stability (Ch. 2.1-2.4) | HW 3 Due | Longitudinal Stability Derivatives | Reading Quiz 5 | | |
| **8** | **3/2-3/5** | | Longitudinal Linear Model (Ch. 4.9-4.10) | | Longitudinal Modes (Ch. 6.2) | Reading Quiz 6 | Lab 3 Due | Lab 4 Assigned |
| **9** | **3/9-3/12** | | Short Period Approximation (Ch. 6.3) | HW 4 Due | Longitudinal Control (Ch. 7.1-7.7) | Reading Quiz 7 | | |
| **10** | **3/16-3/19** | | **Exam 2** | | Lateral Forces and Moments | | Lab 4 Due | Lab 5 Assigned |
| **11** | **3/23-3/26** | **Spring Pause** | **Interim Review** | | **Wellness Day: No Class** | | | |
| **12** | **3/30-4/2** | **Fixed-Wing Aircraft: Lateral Stability and Control** | Lateral Stability Derivatives; Yaw Stiffness (Ch. 3.8-3.9; Ch. 4.11) | HW 5 Due | Dihedral Effect (Ch. 3.11-3.12) | Reading Quiz 8 | | |
| **13** | **4/6-4/9** | | Lateral Damping Derivatives; Lateral Cross Coupling and Side Forces (Ch. 5.6-5.8) | | Lateral SS Models (Ch. 4.7-4.10) | Reading Quiz 9 | Lab 5 Due | Lab 6 Assigned |
| **14** | **4/13-4/16** | | Lateral Dynamic Modes (Ch. 6.7) | HW 6 Due | Lateral Modal Approximations; Control Derivatives; State and Stability Augmentation (Ch. 6.8) | Reading Quiz 10 | | |
| **15** | **4/20-4/23** | | Lateral State and Stability Augmentation (continued); Lateral Transfer Functions | | Lateral Transfer functions (cont'd) | Reading Quiz 11 | Lab 6 Due | |
| **16** | **4/27-4/30** | Fixed-Wing Aircraft: Stability and Control of Complete Aircraft | Aircraft Transfer Function Matrices: complete a/c model; Coordinated Turns (Ch. 7.8) | HW 7 Due | Last Class: Review (students come with questions; no slides except to work problems) | Reading Quiz 12 | | |
| | **5/2** | **Final Exam 4:30-7:00 pm** | | | | | | |