

ASEN 3128 AIRCRAFT DYNAMICS

SPRING 2023

SYLLABUS

LECTURE

Tuesday & Thursday 8:30 - 9:45 am AERO 120

LAB

Tuesday 2:45 - 4:35 pm AERO 141
Wednesday 8:30 - 10:20 am AERO N100
Wednesday 10:35 - 12:25 pm AERO N100

INSTRUCTORS

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Teaching Fellows

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TEXTBOOK

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: (i) an understanding of how aircraft work and tools for quantitative analysis, and (ii) 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 individually and 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. 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
 - o Vector representation in coordinate frames
 - o Change of coordinate frame representation (coordinate rotation)
 - o Relative motion, frame derivatives
 - o Change of derivative frame: velocity rule

- How aircraft dynamics models are created and what the terms mean
 - o 3D rigid body translational model
 - Kinematics
 - Dynamics, external forces
 - Effects of wind
 - o 3D rigid body rotational model
 - Kinematics, Euler angle attitude representation
 - Dynamics, Euler moment equations, external moments
 - o External forces and moments
 - Aerodynamic effects
 - Control effects
 - Steady flight conditions, trim states

- How aircraft dynamics models are simulated
 - o State space models
 - o Matlab integration
 - o Good naming and commenting habits

- How dynamical behavior is understood and specified
 - o Linearization
 - o Decoupling
 - o Stability derivatives
 - o Modal solutions
 - o Stability characterizations
 - o Modal specifications

- How feedback control is designed to meet behavioral objectives
 - o Sensor/feedback selection, control structure
 - o Effects on mode eigenvalues

TEACHING MODALITIES

Lecture – Lectures will be in person throughout the semester. All lectures will be automatically recorded and uploaded to the course Canvas page via CU's Classroom Capture system.

Lab Sections – Students are expected to register for one of the three lab sections and be available for interaction during the scheduled lab section. Groups for lab assignments will be made from students in the lab sections only, and groups will be periodically shuffled prior to the start of certain assignments.

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 provide individual 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 learning opportunities.

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 naively dividing work is a certain recipe for failure on 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 are planned for week 6 and week 13; the final exam is TBD by the university. 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** – office hours for Instructors and TAs will be held nominally during the arranged “lab” times for the course, in AERO 141 and 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 to enable this “first-pass” in advance. Additional office hours with instructors and TAs/TFs will also be scheduled. Private meetings with instructors or TA/TFs can also be arranged if needed.
2. **Email & Piazza questions** – Students are encouraged to post and discuss questions on Piazza (accessed via Canvas). Instructors actively monitor the discussions on Piazza and post answers or comments if necessary. Students may only email the instructor(s) questions not related to homework/labs. DO NOT expect an immediate response. Any question received by 2 PM should typically receive a response by evening 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** – 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 TFs will be present and available 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** – 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 will be regularly administered through Canvas every week, except when there is an exam. Students will have at least 48 hours to complete each quiz from the time of release.
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 later. 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.
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 and TF 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 on Gradescope any time prior to the due date. It is your responsibility to manage assignment submissions and deadlines.

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. As with all other standards that you will encounter throughout your professional, these standards are non-negotiable.

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/TF help to answer questions and refine and deepen your understanding.

Grades for the course are earned 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.

In this course, students will be graded on a positive/“value added” system – that is, graders will assess whether responses provided by students reflect knowledge, understanding and reasoning processes that meaningfully contribute to answering questions posed on assignments. Empty and “fluff” responses, e.g., repeating questions, verbal/buzzword spaghetti throwing, random diagram drawing, etc., are easily seen through and will not suffice. This subject is difficult and non-intuitive, and since this is the first time most (if not all) students have seen this material, it is naturally assumed that all students must work hard and put in effort to learn the concepts. Therefore, hard work is necessary, but not sufficient by itself, to do well. Your effort must translate to demonstrable individual understanding for success.

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 than 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

The first two exam dates are subject to possible revision to later dates (if needed) during the semester:

Exam 1:	Thursday Feb, 23	8:30 – 9:15 am
Exam 2:	Tuesday April, 11	8:30 – 9:15 am
Final Exam	TBD by university	

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) for at least 48 hours from the initial posting time. Two attempts are provided for each quiz with the highest score recorded. Reading quiz submissions will not be accepted after the deadline.

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.

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](#).

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. In this class, inform the instructors of such conflicts at least three weeks in advance.

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

Schedule

The expected course schedule is as follows (some updates and adjustments may occur during course of the semester):

Week			Tuesday		Thursday		Lab Day	
No.	Dates							
1	1/17-1/19	Equations of Motion; Intro to Aircraft Dynamics and Control: Quadrotor Example	Introduction; Nomenclature		Coordinate Frames and Euler Angles (Ch 4.1, 4.4, App. A.4)	Quiz 1		Lab 1 Assigned
2	1/24-1/26		Equations of Motion – Kinematics (Ch. 4.1, 4.4)		Equations of Motion – Dynamics (Ch. 4.2-4.3,4.5,4.7)	Quiz 2		
3	1/31-2/02		Quadcopter Dynamics	HW 1 Due	Linearization	Quiz 3		
4	2/07-2/09		Quadcopter Modal Solutions		Quadcopter Stability and Control	Quiz 4	Lab 1 Due	Lab 2 Assigned
5	2/14-2/16		Quadcopter Guidance	HW 2 Due	Longitudinal Forces/Moments (Ch2.1-2.3)	Quiz 5		
6	2/21-2/23		Longitudinal Trim and Stability (Ch. 2.1-2.4)		Exam 1	-	Lab 2 Due	Lab 3 Assigned
7	2/28-3/02	Fixed-Wing Aircraft: Longitudinal Stability and Control	Longitudinal Stability Derivatives (Ch 5.1-5.5)	HW 3 Due	Longitudinal Linear Model (Ch. 4.9-4.10)	Quiz 6		
8	3/07-3/09		Longitudinal Modes (Ch. 6.2)		Short Period Approximation (Ch. 6.3)	Quiz 7	Lab 3 Due	Lab 4 Assigned
9	3/14-3/16		Longitudinal Control (Ch. 7.1-7.7)	HW 4 Due	Lateral Forces and Moments	Quiz 8		
10	3/21-3/23		Lateral Stability Derivatives; Yaw Stiffness (Ch. 3.8-3.9; Ch. 4.11)		Dihedral Effect (Ch. 3.11-3.12)	-	Lab 4 Due	Lab 5 Assigned

11	3/28-3/30	SPRING BREAK	NO CLASSES		NO CLASSES	NO LAB		
12	4/04-3/06	Fixed-Wing Aircraft: Lateral Stability and Control	Lateral Damping Derivatives	HW 5 Due	Lateral Cross Coupling and Side Forces (Ch. 5.6-5.8)	Quiz 9		
13	4/11-4/13		Exam 2		Lateral Linear Model (Ch.4.7-4.10)	-		Lab 6 Assigned
14	4/18-4/20		Lateral Dynamic Modes (Ch. 6.7)		Lateral Modal Approximations	Quiz 10	Lab 5 Due	
15	4/25-4/27		Lateral Control Derivatives; State and Stability Augmentation (Ch. 6.8)	HW 6 Due	Aircraft Handling Qualities and Control Design Criteria			
16	5/02-4/04		Fixed-Wing Aircraft: Stability and Control of Complete Aircraft	Aircraft Transfer Function Matrices		Last Class: Review (students come with questions; no slides except to work problems)		Lab 6 Due
	5/09-5/11	Final Exam: Date/Time TBD						