Aerospace Engineering 321-501
Dynamics of Aerospace Vehicles
Credit 3: (3-0), Required
Fall 2017

Instructor: Dipanjan Saha (dipanjan1989@email.tamu.edu)
PhD Student

Class Location / Time: HRBB 105, TR 1245 – 1400

Office Hours: RDMC 301, MW 1500 – 1600 or by email / appointment

Grader: Han-Hsun (Jack) Lu (hanhsun.lu@tamu.edu)

Textbook and Required Material:

Roskam, Jan, Airplane Flight Dynamics and Automatic Flight Control Part I, Design, Analysis, and Research Corporation, Lawrence, KS, 1994.

Supplementary Texts (these are for reference)

Schmidt, David K., Modern Flight Dynamics, McGraw-Hill, New York, NY, 2012.

Roskam, Jan, Airplane Design: Part I-VIII, Design, Analysis, and Research Corporation, Lawrence, KS, 1989.

Abbott, Ira H., and Von Doenhoff, Albert E., Theory of Wing Sections, Dover Publications Inc., New York, 1959.

Ward, Donald T., and Strganac, Thomas W., Introduction to Flight Test Engineering, 2nd Edition, Kendall/Hunt Publishing Company, Dubuque, IA, 1998.

Jane's all the World's Aircraft, Jane's Publishing Incorporated, New York, NY.

Software: "Advanced Aircraft Analysis (AAA)", DARcorporation, Lawrence, KS, 1991.

Film: The Right Stuff, USA, 193 minutes, 21 October 1983, Directed by Phillip Kaufman.

Prerequisites: AERO 301 and AERO 310

Course Description:

Derivation of the nonlinear flight dynamics equations; linearization; aircraft static stability and control; longitudinal and lateral dynamic stability; development of state-space models; stability derivatives; longitudinal and lateral modes and transfer functions; flying qualities; elements of configuration design; response to control inputs.

The subject of airplane stability and control is concerned with the reaction of the airplane to externally or internally generated disturbances. Externally generated disturbances, such as turbulence and upset gusts, are caused by the atmosphere, and the airplane must be designed so that it has a built-in tendency to diminish the motion resulting from such disturbances. Internally generated disturbances are caused by the pilot or by an automatic control system, and include changes in control surface deflection, changes in c.g. location, and changes in configuration such as landing gear extension/retraction, and sweeping of the wing in flight. The airplane must be designed so that a human pilot can fly a mission and maneuver the airplane without undue effect, with or without assistance from an automatic control system. Civilian and military operators translate this last statement into detailed specifications for flying qualities. For all of these reasons stability and control is highly interrelated to performance, flight dynamics, and aeroelasticity.

In contrast to airplane performance analyses where the airplane is essentially considered a point mass, in stability and control analysis inertial reactions along and about all axes of the airplane play a role in determining its response to disturbances. The airplane is therefore assumed to be a three-dimensional body with six degrees-of-freedom: three translational, and three rotational. The response of the airplane over very short periods of time (10 to 60 seconds) is of interest.

Learning Outcomes: At the end of this course students, will be able to:

1. Understand and appreciate the relationships between airplane configuration design, flying qualities, and stability & control, and the engineering tradeoffs and balances that result in terms of cost, performance, manufacturing, reliability, maintainability, and supportability.
2. Apply Newton's laws to develop the nonlinear equations of motion for aerospace vehicles, accounting for the aerodynamic, gravitational, and thrust forces and moments.
3. Linearize nonlinear equations about a steady-state equilibrium condition.
4. Develop parameterized relationships for aerodynamic and thrust forcing functions in terms of non-dimensional and dimensional stability and control derivatives.
5. Determine equilibrium (trim) conditions for steady-state straight and level flight, turning flight, and symmetric pull-up flight; takeoff rotation; and One Engine Inoperative (OEI) conditions.
6. Quantify static stability, dynamic stability, and dynamic response characteristics (frequencies, damping ratios, time constants) by developing and analyzing linear state-space models, eigenvalues, eigenvectors, and transfer functions.
7. Know and identify the standard and non-standard airplane dynamic modes of motion (short period, Dutch roll, etc.), their reduced-order approximations, and the specific airplane characteristics which influence them.
8. Understand the relationship between stability & control and pilot workload/acceptance according to the Cooper-Harper scale, and determine the applicable flying qualities of flight vehicles according to Mil-F-8785C or Mil-Std-1797A.

Method of Evaluation:

bi-weekly quizzes	= 40%; lowest quiz dropped
final exam	= 20%
labs	= 10%
homework	= 30%; lowest homework dropped

class participation: +, 0, -

FINAL EXAM Wednesday, Dec 13, 0800 - 1000

Approximate Grading Scale:

90 - 100	A
80 – 89	B
70 – 79	C
60 – 69	D
below 60	F

In borderline cases the class participation score will be used to influence the final grade.

Quiz Policy

1. **<u>There is no makeup quiz unless the student has a university excused absence</u>**.
2. There will be a quiz given **at the beginning of class every other Thursday**. The first quiz is on Thursday, September 14th. All quizzes will be closed book and notes.
3. Material to study for each quiz will be either announced in class or emailed to class.
4. If a student takes a quiz, it will be collected and graded and will count toward the course grade.
5. There will be problems where the final answer(s) will be instructed to be boxed. No box will automatically result in a grade of zero for the problem.
6. The lowest quiz grade will be dropped before assigning the final letter grade.

Recommended Practices for Quizzes

1. Quizzes will focus more on your understanding of the concepts than detailed derivations. However, important parts of derivations and the assumptions made therein may be asked. You may also be asked to name some important quantities related to aircraft dynamics and identify aircraft along with their stability and control characteristics.
2. Plan the preparation ahead of time and start as early as you can.
3. Discuss questions with the instructor during office hours.
4. Given a quiz, skim quickly through the problems. Start with the ones you feel confident about and then proceed to the ones you need to think over.
5. When the instructor gives the two-minute warning, make sure that you have written your name, and that all the problems saying "Box your answer" have the answers boxed.
6. Note down the correct answers during the quiz reviews. Reflect on your mistakes and see the instructor if needed.

Homework Policy and Standards

1. **<u>There is no makeup homework unless the student has a university excused absence</u>**.
2. Homework is due **at the beginning of class every Tuesday starting September 12th**. Homework is considered late as soon as the grader picks it up.
3. Late assignments will not be accepted, except for university approved excused absences.
4. Each student must turn in their own assignment in their own hand. No team assignments unless otherwise specified will be accepted.
5. Written work must be professional, neat, and readable. Otherwise, it will be returned with a grade of zero.
6. All handwritten solutions and/or calculations must be on engineering green paper, or AIAA engineering paper. **Notebook paper or white paper is not acceptable.**

7. For AAA assignments, **the file with the .aaa extension must be emailed to the grader by Tuesday 1245**. The file should have the name “<Your First Name>_<Your Last Name>_HW<Homework Number>_<Problem Description (optional)>.aaa”, e.g. “Dipanjan_Saha_HW7_Aerodynamic_Center.aaa”. **In addition, handwrite neatly all the relevant results obtained from AAA on engineering green paper or AIAA engineering paper and turn it in with the rest of the homework.**
8. Write only on the front side of each sheet.
9. Staple all of your pages together. Folded or paper clipped homework will NOT be accepted.
10. Write your *name* and the *page number* at the top right corner of **<u>each</u>** sheet.
11. Draw a box around the final answer, and include the proper units. **Failure to draw a box around the answer and include units will result in a grade of zero for that problem.**
12. The lowest homework grade will be dropped while assigning the final letter grade.

FAILURE TO COMPLY WITH ALL OF THE STANDARDS ABOVE WILL RESULT IN A GRADE OF ZERO FOR THE ENTIRE ASSIGNMENT.

Recommended Practices for Homework

1. Plan ahead of time and start as early as you can. Do not wait until the day before it is due.
2. Discuss questions with the instructor during office hours on Mondays and Wednesdays.
3. Review all your solutions carefully once you are done. Watch out for silly mistakes.
4. Make sure that every page has your name and page number, and that the pages are stapled.
5. The common mistakes found in every homework assignment will be discussed at the time of handing back the homework. Note down all the important points.
6. See the grader for any discrepancy in homework grade.

Attendance Policy

- Students are expected to attend class. Only university excused absences will be accepted.
- See http://student-rules.tamu.edu/rule07 regarding attendance and Excused Absences.

Classroom Etiquettes

1. Students are expected to be on time for every class.
2. Students are expected to pay full attention to the lectures. Reading books, notes, newspapers, magazines or any other material not relevant to the class during lectures is not allowed.
3. No food or beverage is allowed in the classroom.
4. All electronic gadgets (laptops, cellphones, iPads, etc.) must remain turned off during class.

Aggie Code of Honor:

An Aggie does not lie, cheat, or steal or tolerate those who do. Any form of cheating, plagiarism, and/or academic dishonesty may result in an "F" grade and/or other disciplinary action. http://aggiehonor.tamu.edu

Notice:

The Americans with Disabilities Act (ADA) is a federal anti-discrimination statute that provides comprehensive civil rights protection for persons with disabilities. Among other things, this legislation requires that all students with disabilities be guaranteed a learning environment that provides for reasonable accommodation of their disabilities. If you believe you have a disability requiring an accommodation, please contact Disability Services, currently located in the Disability Services building at the Student Services at White Creek complex on west campus or call 979-845-1637. For additional information, visit http://disability.tamu.edu.

ABET Outcomes

Contributions to Professional Component

1. Required course in dynamics and aerodynamics. Prepares students for required course AERO 422 Active Control of Aerospace Vehicles, and AERO 401/402 Design of Aerospace Vehicles, which is the two semester capstone design course.
2. Builds on foundation established in the core subjects and prerequisites.
3. Part of the required engineering topics portion of the curriculum. Helps prepare students for engineering practice.
4. Prepares students for knowledge of theory and application of stability and automatic control.

RELATIONSHIP TO PROGRAM OUTCOMES

Objectives	Assessment Method	ABET Outcome
Understand and appreciate the relationships between airplane configuration design, flying qualities, and stability & control, and the engineering tradeoffs and balances that result in terms of cost, performance, manufacturing, reliability, maintainability, and supportability.	Homework, quiz, final exam.	3(a), 3(e), 3(k), Dyn. & Control AIAA Program Criteria
Apply Newton's laws to write the nonlinear equations of motion of an aerospace vehicle including aerodynamic, gravitational, and thrust forces and moments.	Homework, quiz, final exam.	3(a), 3(e), 3(k), Dyn. & Control AIAA Program Criteria
Linearize nonlinear equations about a steady-state equilibrium condition.	Homework, quiz, final exam.	3(a), 3(e), 3(k), Dyn. & Control AIAA Program Criteria
Develop parameterized relationships for aerodynamic and thrust forcing functions in terms of non-dimensional and dimensional stability and control derivatives.	Homework, quiz, final exam.	3(a), 3(e), 3(k), Dyn. & Control AIAA Program Criteria
Determine equilibrium (trim) conditions for steady-state straight and level flight, turning flight, and symmetric pull-up flight; takeoff rotation; and One Engine Inoperative (OEI) conditions.	Homework, quiz, final exam.	3(a), 3(e), 3(k), Dyn. & Control AIAA Program Criteria
Quantify static stability, dynamic stability, and dynamic response characteristics (frequencies, damping ratios, time constants) by developing and analyzing linear state-space models, eigenvalues, eigenvectors, and transfer functions.	Homework, quiz, final exam.	3(a), 3(c), 3(d), 3(e), 3(g), 3(k), Dyn. & Control AIAA Program Criteria
Know and identify the standard and non-standard airplane dynamic modes of motion (short period, Dutch roll, etc.), their reduced-order	Homework, quiz, final exam.	3(a), 3(c), 3(d), 3(e), 3(g), 3(k), Dyn. &

approximations, and the specific airplane characteristics which influence them.		Control AIAA Program Criteria
Understand the relationship between stability & control and pilot workload/acceptance according to the Cooper-Harper scale, and determine the applicable flying qualities of flight vehicles according to Mil-F-8785C or Mil-Std-1797A.	Homework, quiz, final exam.	3(a), 3(c), 3(d), 3(e), 3(g), 3(k), Dyn. & Control AIAA Program Criteria

Course Topics: (The weekly break-up shown here is approximate; it may change as the semester progresses)

Week	Topic
1 – 3	BLOCK 1: Equations of Motion and Axis Systems
3	Laboratory 1
4	BLOCK 2: Review of Aerodynamic Fundamentals
5	Laboratory 2
5 – 6	BLOCK 3: Aerodynamic and Thrust Forces and Moments
7 – 9	BLOCK 4: Stability and Control During Steady-State Flight
10 – 13	BLOCK 5: Stability and Control During Perturbed State Flight
13	Laboratory 3
14	BLOCK 6: Flying Qualities, Pilot Ratings, Regulations, Introduction to Human Factors
15	Final Exam

BLOCK 1: EQUATIONS OF MOTION AND AXIS SYSTEMS

Block 1 Desired Outcomes

- Understand the relationship between inertial and body axis systems, and be able to sketch a figure showing these relationships.
- Know how to derive force and moment equations and all assumptions made to arrive at them.
- Know the names and units of all vector components and their specific definitions.
- Recognize the planes of symmetry for arbitrary configurations, and be able to modify the equations of motion accordingly.
- Know how to account for the effect of spinning rotors.
- Be able to transform from inertial axes to body axes, or vice versa, and know the names and definitions of the Euler angles.
- Derive the kinematic equations.

- Know the definitions of steady-state and perturbed state flight.
- Know the restrictions for steady-state rectilinear flight, steady-state level turning flight, and steady-state symmetric pull-up flight.
- Linearize an arbitrary nonlinear function using both the Taylor series expansion method, and the perturbation substitution method.

– Course Overview and Introduction
1.1 Coordinate Systems and External Forces
1.2 Derivation of the Equations of Motion
1.6 Components of the Gravitational Force
– Moments and Products of Inertia
– Methods to Estimate Moments of Inertia
  - Regression analysis
  - Radius of Gyration
1.3 Effect of Spinning Rotors
1.4 Orientation of the Airplane Relative to the Earth Fixed Coordinate System X'Y'Z'
1.5 Airplane Flight Path Relative to the Earth
1.7 Review of the Equations of Motion
1.8 Steady State Equations of Motion
  Case 1: equations of motion for steady state rectilinear flight
  Case 2: equations of motion for steady state turning flight
  Case 3: equations of motion for steady symmetrical pull-up
– Nonlinearity
– Definition And Properties Of Linearity
– Linearization Of Nonlinear Functions
  - Taylor series expansion
  - Perturbation substitution
1.9 Perturbed State Equations of Motion

BLOCK 2: REVIEW OF AERODYNAMIC FUNDAMENTALS

Block 2 Desired Outcomes

- Know the basic airfoil parameters.
- Know the exact definition and similarities/differences between center of pressure and aerodynamic center.
- For a given configuration be able to compute the aerodynamic center, and the fuselage induced shift to aerodynamic center.
- Understand and apply the Prandtl-Glauert transformation.
- Be able to compute and explain the concepts of downwash, downwash gradient, upwash, and dynamic pressure ratio.
- Understand the factors relating to the effectiveness of hinged control surfaces, and be able to compute the effectiveness.

2.2 Airfoil Aerodynamic Characteristics
- 2.2.1 Airfoil aerodynamic center
- 2.2.2 Airfoil lift curve slope

2.4 Coefficients and Reference Geometries

2.5 Aerodynamic Characteristics of Planforms and Fuselage
- 2.5.2 Aerodynamic center
- 2.5.4 Moment coefficient about the aerodynamic center
- 2.5.5 Downwash, upwash, and dynamic pressure ratio
- 2.5.6 Effect of the fuselage on wing aerodynamic center

2.6 Effectiveness of Control Surfaces

BLOCK 3: AERODYNAMIC AND THRUST FORCES AND MOMENTS

Block 3 Desired Outcomes

- Understand the definitions and transformations between the body axes, stability axes, and wind axes systems.
- Determine the longitudinal aerodynamic force and moments for arbitrary configurations:
- drag buildup (Eq. 6.29)
- lift buildup (Eq. 6.17)
- moment buildup (Eq. 6.Y)
- Quantify the conditions for static longitudinal stability of flight vehicles in terms of configuration, aerodynamics, weight & balance, flight condition (Mach number), and perturbation type.
- Derive an equation for aerodynamic center of an airplane, for conventional configurations, canard configurations, and three-surface configurations.
- Derive expressions for, and with the help of sketches and graphs, explain the following stability and control derivatives:

C_{D_α} C_{L_α}

C_{ℓ_β} C_{ℓ_p} C_{ℓ_r} $C_{\ell_{\delta_a}}$ $C_{\ell_{\delta_r}}$

C_{m_0} C_{m_α} C_{m_q} C_{m_u} $C_{m_{\delta_e}}$

C_{n_β} C_{n_r} C_{n_p} $C_{n_{\delta_r}}$ $C_{n_{\delta_a}}$

C_{y_β} $C_{y_{\delta_r}}$

3.1 Steady State Forces and Moments

3.2 Perturbed State Forces and Moments

3.3 Overview of Usual Signs for Aerodynamic Coefficients and Derivatives

BLOCK 4: STABILITY AND CONTROL DURING STEADY-STATE FLIGHT

Block 4 Desired Outcomes

- Derive the criteria for each of the ten static stability derivatives.
- With words and diagrams, be able to explain speed stability and the concept of "flying on the back side of the power curve".
- Construct a proper trim diagram that accounts for the range of achievable CG locations.
- Understand the concepts and fundamental differences between stick-fixed and stick-free quantities.
- Determine the stick-fixed and stick-free neutral points, static margins, maneuver points, and maneuver margins, and their effect on flight behavior.
- Determine the horizontal tail size required for takeoff rotation, and the airplane specific parameters which influence it.

4.1 Introduction to Static Stability and its Criteria
4.2 Stability and Control Characteristics for Steady State, Straight Line Flight
4.4 Trim Comparisons for Conventional, Canard, and Three-Surface Configurations
4.3 Stability and Control Characteristics for Steady State, Maneuvering Flight
4.5 Effects of the Flight Control System on Stability and Control in Steady State Flight
4.6 Lateral-Directional Cockpit Control Forces
4.7 A Matrix Approach to the General Longitudinal Trim Problem
4.9 The Takeoff Rotation Problem
4.10 Introduction to Irreversible Flight Control Systems

BLOCK 5: STABILITY AND CONTROL DURING PERTURBED STATE FLIGHT

Block 5 Desired Outcomes

- Quantify first-order and second-order dynamical systems in terms of stability, time constant, frequency, damping ratio, and time history response.
- Be able to determine the eigenvalues of a dynamical system, and plot their location in the S-plane. Know the time history response for the locations of specific eigenvalues in the S-plane.
- Know the longitudinal and lateral/directional standard modal compositions, in terms of number and types of first-order and second-order modes, the names of those modes, and their airplane specific characteristics in terms of time constant, frequency, damping ratio, and time history response.
- Be able to write the linearized equations of motion in vector/matrix form, and extract a desired transfer function.

- Know the assumptions and limitations pertaining to all of the standard longitudinal and lateral/directional mode approximations, and be able to apply them.
- Understand and be able to explain how stability augmentation systems work, and how equivalent stability derivatives are used to design the necessary feedback gains.

5.1 Dynamic Stability and Response Behavior of a Spring-Mass-Damper System and its Stability Criteria
5.2 Longitudinal, Dynamic Stability and Response
5.3 Lateral-Directional, Dynamic Stability and Response
5.5 Equivalent Stability Derivatives, Stability Augmentation, and Dependence on Control Power
5.7 Summary and Review of Chapter 5

BLOCK 6: FLYING QUALITIES, PILOT RATINGS, REGULATIONS, AND AN INTRODUCTION TO HUMAN FACTORS

Block 6 Desired Outcomes

- Understand the purpose and use of the Cooper-Harper Pilot Rating Scale, how to apply it, and the relationship between the ratings and the Mil Spec flying quality levels.
- Define and explain the differences and similarities between the Mil Spec flying quality levels.
- Be able to explain the relationship between flying quality level and failure state in the Civil Airworthiness Code.
- Know the designation of the two documents which contain the military specifications for flying qualities of piloted airplanes.
- Be able to identify and locate the correct specifications for a given air vehicle by Class and Flight Phase, and assess whether or not it meets the relevant specifications. If it does not, know the vehicle parameters which must be changed to make it so.

6.1 Flying Qualities and Pilot Ratings
6.2 Military and Civilian Flying Quality Requirements: Introduction and Definitions
6.3 Longitudinal Flying Quality Requirements
6.4 Lateral-Directional Flying Quality Requirements
6.5 Characteristics of the Flight Control System
6.6 Relationships between Flying Qualities Requirements and Design
6.7 Summary and Review of Chapter 6