ASEN 5111: Introduction to Aeroelasticity

F. Demet Ulker

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E-mail: fatma.ulker@colorado.edu
Web:
Office Hours: T/TH 5:30pm-6:30pm
Class Hours: T/TH 4:00pm-5:15pm

Course Description

This course provides an introductory level knowledge in theoretical and experimental foundations of aeroelasticity. A short review on the 2D aerodynamics and discrete and continuous system vibration analysis methods will be followed by static and dynamic aeroelastic phenomena. Along with the classical flutter analysis, several other critical flutter conditions such as Body Freedom Flutter will be discussed in the class. Analytical and numerical based approximate solution techniques will be introduced. ASWING will be used for coupled flight dynamics and aeroelastic analysis and experimental simulations. Homeworks are designed to complement the subjects covered in the class, hence different aeroelastic phenomena including fixed wing and rotary wing aeroelastic systems, and control couplings will be analyzed.

Prerequisite

Requires corequisite courses of APPM 2360, ASEN 2001.

- Sufficient familiarity with vibrations: response of multimass and continuous systems, free vibration modes, normal coordinates, and variational principles in dynamics. Desirable: MATH 2400, ASEN 3112, ASEN 4123.
- Sufficient familiarity with low-speed aerodynamics and flight dynamics of aerospace vehicles. Desirable: ASEN 3111, ASEN 3128.
- Sufficient familiarity with stability analysis. Desirable: ASEN 5012.
- Prior programming skills in MATLAB.

Reference Materials

[1] J. Wright and J. Cooper, *Introduction to Aircraft Aeroelasticity and Loads*, 2nd ed., ser. aerospace series. Wiley, 2015.

[2] R. L. Bisplinghoff and H. Ashley, *Principles of Aeroelasticity*. Dover, 1962.

[3] D. Hodges and G. Pierce, *Introduction to Structural Dynamics and Aeroelasticity*, ser. Cambridge Aerospace Series. Cambridge University Press, 2011.

[4] M. Drela, *Flight Vehicle Aerodynamics*, ser. Flight Vehicle Aerodynamics. MIT Press, 2014.

[5] D. Schmidt, *Modern Flight Dynamics*. McGraw-Hill Education - Europe, 2011.

[6] J. Katz and A. Plotkin, *Low-Speed Aerodynamics*, 2nd ed. Cambridge University Press, 2001.

Course Learning Goals

At the end of this course, students will be able to perform the following:

- Derive the differential equations governing aeroelastic phenomena
- Assess the underlying assumptions in the aeroelastic analysis of fixed wing and rotary wing aerospace vehicles/systems.
- Experimentally predict the flutter boundary of an aerospace vehicle.
- Evaluate the practical feasibility and predict possible issues of unconventional aerial configurations.

Course Structure

Part I:Introduction to Aeroelasticity

- Description of the aeroelastic phenomenon and historical development
- Review of dynamical systems
  - Equation of motion for single and multi degree of freedom systems, 2D Typical section.
    - justify typical-section concept
    - dynamical model parameters
    - examine in-vacuum case, EOM via Newton's Law, Lagrange's energy method and Hamilton's principle.
    - time domain analysis
    - frequency and complex domain analysis
- Review of aerodynamic concepts, steady and quasi-steady, unsteady aerodynamics
  - Introduction -flow categories
  - Elements of potential flow

    - Steady, quasi-steady, unsteady aerodynamics for typical section
        * aero model parameters, steady aero
        * examine static aeroelastic case, divergence,
        * quasi-steady aero
        * examine dynamic aeroelastic case, gust
        * time domain analysis
        * unsteady aero
        * examine dynamic aeroelastic case, SDOF and MDOF flutter
        * time domain, frequency and complex domain analysis
        * engineering solutions, p-k method
    - Aerodynamics of wing and bodies
        * approximate solution methods, lifting line method
        * swept wing and low aspect ratio wings, vortex lattice method
- Review of structural concepts
    - Basic structural theory
    - Vibrations of continuous systems
        * structure model parameters
        * partial differential equation for SDOF-MDOF flexible wing, bending and torsional vibrations
        * approximate solution of wing deflections, modal methods
- Review of aircraft flight dynamics
    - Representation of aircraft and Flight Control System.
        * Description of frames and axis system
        * Aircraft motion, kinematics and dynamics
        * Flight dynamics formulation, lateral and longitudinal
    - Introduction of ASWING

Part II: Static and Dynamic Aeroelasticity

- Static Aeroelasticity
    - Divergence
    - Control Reversal
- Dynamic Aeroelasticity
    - Classical flutter
        - Coupled aeroelastic model for lifting surface
        - Stability analysis in time and frequency domains
        - Computation of flutter speed via engineering methods
    - Body freedom flutter
        - Problem definition
        - Numerical solution and result analysis
    - Nonlinear effects

    - Discussion on stall flutter
    - Discussion on buffeting
  - Discussion on active control concepts

Part III: Experimental Aeroelasticity and Control

- Model scaling
- Ground resonance testing
- Wind tunnel testing
- Flight flutter tests

Grading Policy

- **30%** Homeworks
- **50%** Take home quiz/midterm
- **20%** Final Project