Course Outline

AE 566 AEROELASTICITY

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Background Requirements(s):

Proficiency in Structural Dynamics (free and forced response of discrete and continuous systems) and Aerodynamics and/or Fluid Dynamics is strongly recommended. Additionally, students are expected to be able to have some background in advanced mathematics.

Course Objectives:

This course mainly intends to introduce the classical solution methods in aeroelasticity. Additionally, computational methods are introduced via demonstrations and theoretical classes utilizing the aeroelasticity module of MSC Nastran and MSC Flightloads. For dynamic aeroelastic problems, understanding the underlying principles of unsteady aerodynamics is crucial to have firm understanding of the dynamic aeroelastic phenomena. Therefore, in the course special emphasis is given to the subject of unsteady aerodynamics of oscillating airfoils and arbitrary motion of airfoils. Static aeroelastic and dynamic aeroelastic problems are introduced utilizing 3D and 2D models to teach the classical solution methods. Classical solutions methods are complemented with computational examples utilizing MSC Nastran and MSC Flightloads to explain the methodologies involved in aerodynamic-structure coupled problems. Solution of dynamic response problems of aeroelastic systems are explained for arbitrary motion and gust response of lifting surfaces.

By the end of the semester students are expected to:

- formulate and perform classical solutions of aeroelastic problems,
- appreciate the significance of load redistribution in the response of aerospace vehicles,
- understand the static and the dynamic aeroelastic instabilities such as divergence, control surface reversal and flutter
- realize the effect of unsteady aerodynamics on the behavior of aeroelastic systems,
- incorporate the aeroelastic constraints into the design aerospace structure,
- learn how set up aeroelastic models in MSC Flightloads and perform static (divergence) and dynamic aeroelastic (flutter) solutions utilizing MSC Nastran.

Course Outline:

1. Introduction of aeroelastic effects in structures (3 hours)

- General introduction of aeroelasticity
- Aeroelastic triangle
- Aeroelastic phenomena : Classification of fluid-structure interaction problems
  - Static aeroelasticity: Divergence, load distribution, control effectiveness, control system reversal
  - Dynamic aeroelasticity: Flutter, buffeting, dynamic response
  - Aeroelastic effects on static and dynamic stability of aircraft
- Aeroservoelasticity
- Video presentations of some common aeroelastic stability problems

2. Fundamentals of steady aerodynamics (6 hours)

- Momentum and continuity equations of 2D and 3D incompressible flow
- Vorticity and definition of rotational/irrotational flows
- Kelvin's equation / Bernoulli equation / Laplace's equation
- Small disturbance concept for linearizing aerodynamics
- Thin airfoils in steady motion
- Determination of pressure distribution over a thin airfoil
  - Vortex flow
  - Circulation
  - Kutta condition
- Calculation of lift for a flat plate by integrating pressure distribution
- Calculation of pitching moment for a flat plate by integrating pressure distribution
- Definition of aerodynamic center
- Finite wings in steady motion
- Strip theory for finite wings

3. Static aeroelasticity (9 hours)

- Static aeroelastic analysis of 2D typical section model (wall mounted uniform wing models)
  - Calculation of equilibrium twist
  - Divergence instability
  - Load distribution: flexible lift
  - Demonstration of strongly coupled (direct method) and loosely coupled (iterative method) approach of static aeroelastic analysis
- Control surface reversal
  - Control surface effectiveness
  - Determination of control surface reversal speed
- Static aeroelastic analysis of 3D slender straight wings
  - Determination of elastic twist distribution
  - Calculation of divergence dynamic pressure
  - Aeroelastic airload distribution at sub-critical speeds
  - Structural engineer’s perspective: determination of stress distribution under aeroelastic airload distribution
  - Sweep effects – derivation of bending-torsion coupled equation of motion of slender wings
- Demonstration of static aeroelastic problems in MSC Nastran
  - Brief review of formulation of static aeroelastic problems in MSC Nastran
  - Generation of a simple stiffened rectangular lifting surface in MSC Flightloads, flat plate aero modeling
  - Aero-structural coupling, splining aero and structural meshes
  - Checking up of aspect ratio of the aerodynamic mesh and box/wavelength criterion
  - Generation of Nastran input file for divergence analysis and divergence analysis in Sol 144, interpretation of the results of divergence analysis
  - If time permits demonstration of static aeroelastic trim analysis in MSC Nastran (rigid loads, incremental loads)

4. Unsteady aerodynamics for oscillating airfoils (3 hours)

- Introduction of Theodorsens's method of analyzing unsteady aerodynamics of thin air foils
- General equation of small disturbance assumption of oscillating air foils
- Non-circulatory and circulatory portions of the unsteady flow
- Kelvin's circulation theorem and formation of starting vortex
- Noncirculatory flow solution
  - Kelvin's equation written in terms of disturbance potential
  - Pressure difference across the thin air foil
  - Noncirculatory lift and pitching moment for a chordwise rigid pitching and plungingthin air foil
- Circulatory flow solution
  - Satisfaction of Kutta's condition at the trailing edge
  - Circulatory lift and pitching moment for a chordwise rigid air foil pitching and plunging thin air foil
  - Reduced frequency (measure of unsteadiness of incompressible flow)
- Total lift and pitching moment for oscillating airfoil undergoing pitching and plunging motion
- Explanations of the terms appearing in the lift and pitching moment expressions for an oscillating thin airfoil

5. Basic structural dynamics (3 hours)

- Lagrange's equation of motion
- Pitching-plunging equation of motion of a typical wing section model

6. Flutter of wings (9 hours)

- Fundamentals of flutter analysis
  - Stall flutter
  - Aeroelastic analysis of a typical airfoil section
  - P method
  - Classical flutter analysis
- Engineering solutions of flutter analysis

- The K method
- The PK method

- General formulation of flutter equation for a 3D lifting surface in modal coordinates
- Demonstration of flutter phenomenon in MSC Nastran
  - Brief review of formulation of flutter problem in MSC Nastran
  - Briedfexplanation of doubletlattice lifting surface aerodynamics
  - Generation of a simple stiffened rectangular lifting surface in MSC Flightloads, flat plate aero modeling, aero-structural coupling, splining aero and structural meshes
  - Setting up flutter solution in MSC Flightloads
    - Generation of Mach-Frequency pairs
    - Preparation of flutter parameters
    - Spline (aero-structure) verification
  - Flutter solution by MSC Nastran Sol 145 and postprocessing of flutter solution
    - Examination of .f06 files, preparation of velocity-damping, velocity- frequency plots and determination of flutter frequency and flutter velocity
    - Animation of flutter mode shapes
  - Matched point flutter solutions
    - Determination of divergence speed of the simple stiffened rectangular lifting surface utilizing the results of Sol 145 and comparison with the divergence speed obtained by Sol 144.

7- Dynamic response (9 hours)

- Sources of rapidly applied forces
- Arbitrary motion of thin airfoils in incompressible flow
  - Lift build-up due to step change in incidence (or airspeed)- Wagner's function
  - Forced motion in the presence of external loads depending on the motion
  - Lift due to a sinusoidal gust – Sear's function
  - Lift due to a sharp-edged gust – Kussners's function

- Dynamic response to a discrete gust
    - Response of a rigid wing to discrete gust
    - Response of a flexible wing to discrete gust

Total: 14 weeks

Textbooks:

Introduction to Structural Dynamics and Aeroelasticity, by D. H. Hodges and G.A. Pierce, Cambridge UniversityPress , 2nd edition

Reference Material:

Aeroelasticity, by R. L. Bisplinghoff, H. Ashley, and R. L. Halfman, Dover Edition [TL570.B56]

An Introduction to Theory of Aeroelasticity, byY. C. Fung, , John Wiley and Sons, Inc., 1955, Dover Edition. [TL574.A37 F8 1969]

Introduction to Aircraft Aeroelasticity and Loads, by J.R. Wright and J.E. Cooper, AIAA Education Series, John Wiley and Sons, 2007.

A Modern Course in Aeroelasticity, byE. H. Dowell, et. al., 3rd edition (1995), Kluwer Academic Publishers

Introduction to the Study of Aircraft Vibration and Flutter, by R. H., Scanlan, R. Rosembaum, The Macmillan Co., New York, NY, 1951 [TL574.V5 S35]

Introductionto Aircraft Loads Analysis, byPaul F. Taylor, Mark E. Ray, Douglas R. McKissack, AIAA Course Notes

Principles of Aeroelasticity, by R. L. Bisplinghoff, H. Ashley, Dover Edition. [TL570.B562]

Aeroelastic analysis user's guide, MSC Software Corporation (any year)

MSC Flightloads and Dynamics user' guide, MSC Software Corporation (any year)

Course Conduct:

Formal lectures, term project assignment, computer applications

Grading: (subject to change depending on the feedback from the class)

- **Assignments:** %30 (includes homework, mini-project, computer assignments etc.)

- **Midterm examination:** %20

- **Project:** %30

- **Final examination:** %20