

ABET Course Syllabus**ENAE 423H Vibration and Aeroelasticity (Honors)**

Credits & Contact Hours:	3 credits (3 hours of lecture)
Course Status:	Required
Schedule:	Offered every Fall semester
Course Description:	Dynamic response of single and multiple degrees of freedom systems, finite element modeling, wing divergence, aileron reversal, wing and panel flutter.
Pre-Requisites:	ENAE 324
Co-Requisites:	None
Textbooks:	(1) D. Inman. Engineering Vibration. Prentice Hall, third edition, 2007 (recommended).
Other Required Material:	Course lecture notes and handouts
Course Oversight:	Structures and Vibration Committee
Syllabus Prepared By/Date:	Dr. Norman Wereley on June, 2011

Course Objectives/Student Learning Outcomes:

1. Understand fundamentals of vibration such as natural frequencies and modes, resonance, and effect of mass, stiffness and damping on vibration characteristics
2. Understand dynamic aeroelastic instability due to interactions among aerodynamics, structure and inertia effect such as flutter
3. Understand fundamentals of modeling and analysis techniques, including the energy approach.

Topics Covered:

1. Introduction to Aerospace Vibrations & Aeroelasticity
2. Transient Response of a Mass-Spring System
3. Transient Response of a Mass-Spring-Damper
4. Damping
5. Response to Sinusoidal Vibrations I: Viscous Damping
6. Response to Sinusoidal Vibrations II: Structural Damping
7. SDOF Transient Response: Forced Response
8. SDOF System Step Response
9. Impedance
10. Transmissibility
11. Vibration Absorbers
12. Introduction to Two Degree of Freedom (2DOF) Systems
13. 2DOF Eigenstructure and Orthogonality
14. Multiple DOF Eigenstructure and Orthogonality
15. SDOF Transient Response: Coulomb Damping
16. Proportional Damping vs. Modal Damping

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Relationship of Course Objectives to Program Outcomes

This course addresses program outcomes: 1, 2, 3, 4, 5, 9

ABET Course Syllabus**Lecture Schedule (Tentative)**

Lecture 1	Introduction to Aerospace Vibrations & Aeroelasticity – Get organized, discuss goals of the course, and discuss grading scheme. What are aerospace vibrations and aeroelasticity? Rationale for taking this course. Videos of Takoma Narrows Bridge and Catastrophic Ground Resonance of CH-47.
Lecture 2	Transient Response of a Mass-Spring System – Analysis of the transient response of a mass-spring system. Governing equation. Method of characteristic solutions, and the characteristic equation. Amplitude and phase. Persistence of the transient solution. Feasible initial conditions.
Lecture 3	Transient Response of Mass-Spring-Damper – Analysis of the transient response of a mass-spring-damper (MSD) system. Governing equation. Method of characteristic solutions, and the characteristic equation. Overdamped, critically damped, and underdamped solutions. The envelope function for underdamped systems.
Lecture 4	Damping – Estimating damping from logarithmic-decrement analysis. The nature of damping. Viscous damping. Coulomb damping. Hysteretic or material damping. Quadratic or air damping. Equivalent viscous damping.
Lecture 5	Response to Sinusoidal Vibrations I: Viscous Damping - Steady state response of SDOF systems with viscous damping. Notions of gain and phase. The Bode diagrams.
Lecture 6	Response to Sinusoidal Vibrations II: Structural Damping - Steady state response of a mass-spring-damper system to a sinusoidal excitation where the nature of the damping is hysteretic damping or structural damping. Comparison of viscous and structural damping in terms of the steady state sinusoidal response, static (DC) displacement, damped natural frequency, and other key frequency domain properties.
Lecture 7	SDOF Transient Response: Forced Response - Response to arbitrary forcing. Impulse theorem of mechanics. Green's function.

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Lecture 8	SDOF System Step Response - Response of a mass-spring system with or without damping. Distinguishing between static and dynamic deflections. An example of a total solution which is the sum of a homogeneous and a particular solution. Illustration of the homogeneous solution as that part of the total solution that results from excitation of modes.
Lecture 9	Impedance - Definition of impedance for a 2DOF system. Frequency response and transfer functions. Bode gain diagrams versus amplitude diagrams.
Lecture 10	Transmissibility - Classical transmissibility of a simple mount or suspension. Force transmissibility to the base when the sprung mass is excited. Transmissibility to the sprung mass when the base is excited. Similarities between the two. Trade-off between the addition of damping to mitigate resonance and the resulting increase in high frequency transmissibility.
Lecture 11	Vibration Absorbers – Classical Den Hartog vibration absorbers for harmonic load canceling. Formulation of design problem. Example for an unbalanced engine.
Lecture 12	Introduction to Two Degree of Freedom (2DOF) Systems – Transient solutions from the perspective of the normal mode coordinates. ICs in normal mode coordinates. transformation back to physical coordinates. Solving the "old fashioned way," and an illustration of the extensive algebraic pain one must endure. Solution procedure in MATLAB.
Lecture 13	2DOF Eigenstructure and Orthogonality – Development of the 2DOF eigenvalue problem. Eigenvectors as mode shapes. Orthogonality of eigenvectors or mode shapes with respect to mass and stiffness matrices. Modal transformation and diagonalization. Normal mode equations. Rayleigh-Ritz quotient.
Lecture 14	Multiple DOF Eigenstructure and Orthogonality - Generalization to multiple degree of freedom systems. Orthogonality of eigenvectors or mode shapes with respect to mass and stiffness matrices. Modal transformation and diagonalization. Normal mode equations. Why linear algebra a good thing.

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Lecture 15	Dynamic Response Solution Procedure I – Analysis of a 2DOF lumped parameter model using eigenstructure analysis. Compute modal frequencies and mode shapes, and determine the normal mode equations. Physical interpretation of eigenvectors as mode shapes. Development of software code to compute the total solution of a 2DOF (or MDOF) system using MATLAB. Develop pseudocode on the blackboard.
Lecture 16	Dynamic Response Solution Procedure II - Analysis of a 2DOF lumped parameter model using eigenstructure analysis. Compute modal frequencies and mode shapes, and determine the normal mode equations. Physical interpretation of eigenvectors as mode shapes. Development of software code to compute the total solution of a 2DOF (or MDOF) system using MATLAB. Develop pseudocode on the blackboard.
Lecture 17	SDOF Transient Response: Coulomb Damping - Derivation of the transient response of a mass-spring system incorporating a Coulomb damper. This is a lecture to read on your own.
Lecture 18	Laboratory – Excitation of beam mode shapes using piezo-electric PZT-5H actuators to produce pure bending. Measurement of first five natural frequencies, and node locations. This class demonstration will be conducted by Dr, Wei Hu.
Lecture 19	Proportional Damping vs. Modal Damping - Examination of damping and resulting obstacles to diagonalization to obtain normal mode equations. Use of proportional damping models where the damping matrix is a linear combination of mass and stiffness matrices. Problems with such an approach. Testing for modal damping and empirically correcting the normal mode equations.
	Quiz in class
Lecture 20	The Euler–Bernoulli Beam Equation – Derivation of the governing partial differential equation describing longitudinal bending motion in the presence of transverse and axial loading. Initial conditions and boundary conditions.
Lecture 21	Exact Solution of the Euler-Bernoulli Equation Determine the exact solution for bending motion of a cantilevered beam. Introduction of modes, modal frequencies, and the transcendental equation required to determine the modal frequencies. Discussion of displacement and strain mode shapes.

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Lecture 22	Wave Equation - Wave equation to describe vibration of a string, a rod in extension, and a shaft in torsion. Separation of variables solution. Modal frequencies and mode shapes.
Lecture 23-24	Energy Methods - Introduction to Lagrange's equation. Generalized coordinates. Independence of generalized coordinates. Kinetic and potential energy. The Lagrangian. Simple Pendulum. A number of worked examples to illustrate the methodology: slung load on a helo, complex pendula, problems involving quadratic energy forms.
Lecture 25-26	Rayleigh-Ritz and Galerkin's Method – Discussion of assumed modes methods as an energy method. Requirements for assumed modes for each method. Rayleigh-Ritz quotient. Examples.
Lectures 27-28	Finite Element Method – Introduction to the finite element method for the Euler-Bernoulli beam equation. Development of element properties of stiffness and consistent mass for a four DOF bending element. Specialization to a uniform beam. Assembly process to determine global mass and stiffness matrices. Application of constraints. Development of an FEM code in MATLAB. Examples.
Lecture 29	FEM for the Wave Equation - The finite element method for a rod in extension. Example of a uniform rod. Example of a non-uniform rod. Extension to torsion of a rod and trasverse motion of a string.
Lecture 30	Issues in FEM – Memory and Sparse matrices. Curse of Dimensionality. Computational issues. Non-uniform beams: tapers and steps.
Lecture 31	Static Aeroelasticity: Divergence - Notion of effectiveness stiffness being the sum of wing torsional stiffness and the aerodynamic torsional stiffness. Stability boundary, and divergence speed.
	Final Exam at 8 am in CCC1111