FLUID-STRUCTURE INTERACTIONS

ENME489U/ ENME809C

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UNIVERSITY OF MARYLAND

Lectures: TuTh 9:30am - 10:45am in EGR 3106

Office hours: TuTh 10:45am - 11:45am

Course Goals

The objective of this course is for students to learn the key topics in fluid-structure interaction (FSI) problems for engineering applications so that they can understand and predict **fluid-elastic effects** and their implications on the design of flexible structures. Possible domains of applications are **civil engineering, aerospace engineering, ocean engineering, biomechanics, and soft robotics**. Examples include tall bridges, aircraft wing, parachutes, solid rocket motor, turbomachinery, offshore platform, subsea pipelines, paper printing, MEMS microchannels, blood flow in arteries, and heart valves. The **fish swimming mechanics** will be studied to inspire novel efficient propulsion mechanisms for soft robotics applications.

Course Learning Objectives

At the completion of this course, students will be able to do the following:

- apply the physics behind the coupled mechanical aspects of the fluid-structure interaction problems;
- theoretical understanding of mathematical concepts and theories;
- model fluid-structure interaction in a rigorous manner with advanced computational techniques and reduced-order models;
- Familiarise with flow-induced vibration phenomena such as flutter, vortex-induced vibration, galloping in engineering applications

Course Learning Outcomes

- an ability to apply knowledge of mathematics, science, and engineering to FSI problems;
- an ability to analyze and interpret experimental data;
- an ability to identify and formulate relevant critical parameters for fluid-elastic problems;
- apply different methods of dynamical analysis of structures and coupled fluid-structure analysis.

Course Content

1. Concepts and Methods for FSI problems

Discrete and distributed parameter systems, Galerkin method for conservative and nonconservative systems, self-adjoint and positive definite continuous systems, diagonalization, forced vibrations of continuous systems, equations of fluid flow, linear and nonlinear dynamics.

2. Pipes Conveying Fluid
   2.1 *Linear Dynamics*: Pipes with supported ends and cantilever pipes, bifurcations, equations of motion (Newtonian and Hamiltonian derivations), nondimesionalization, numerical methods of solution, pressurization, tensioning, gravity and dissipation effects, pipes on elastic foundation. Destabilization of cantilever pipes by damping. Systems with added springs, masses, and supports. Fluid follower forces.
   2.2 *Long Pipes and wave propagation*: Wave propagation, infinitely long pipe on elastic foundation, periodically supported pipes, refined flow theory.
   2.3 *Nonlinear and Chaotic Dynamics:* The nonlinear equations of motion of cantilever and supported pipes, the effect of amplitude on frequency, the post-divergence dynamics, pipes with an axially sliding downstream end, 2D and 3D limit cycles motion of cantilever pipes.

3. Engineering applications of pipes conveying fluid
   Submerged pipes: aspirating pipes and ocean mining, the Coriolis mass-flow meter, hydroelastic ichthyoid propulsion, vibration attenuation, stability of deep-water risers, and vibration-induced flow.

4. Cylindrical shells containing or immersed in flow
   Inviscid model, steady viscous effects, wave propagation and simplified stability theory, swirling flow and rotofluidelasticity, turbulence-induced vibration, collapsible tubes/pliable shells, pressure waves in horizontal systems, physiological systems (veins and arteries), and sloshing.

5. Prisms in Cross-Flow – Galloping
   5.1 *The mechanism of galloping.* The linear threshold of galloping, nonlinear aspects. Low-Speed Galloping. Torsional galloping: linear quasi-steady analysis, nonlinear quasi-steady analysis, unsteady theory.
   5.2 *Further work on translational galloping.* The effect of sectional shape, Novak's "universal response curve" and continuous structures, unsteady effects, analytical models, shear-layer reattachment.

6. Vortex-Induced Vibrations (VIV)
   6.1 *Two-Dimensional VIV Phenomenology*. Bluff-body wake instability, wake instability of a fixed cylinder, wake of a cylinder forced to move, cylinder free to move.
   6.2 *Modeling VIV*. A classification of models: type A - forced system models, type B- fluidelastic system models, type C- coupled system mode.

7. Fish Swimming Mechanics
   7.1 Fish Propulsion: lift, resistance, reaction forces.
   7.2 Fish Propulsion: efficiency, optimal frequency, wave propagation.

Learning Assessments:

For *Undergraduate Students*:
35% Homework (Total number of homework: 6); 30% Midterm; 35% Final Exam
For *Graduate Students*:
20% Homework (Total number of homework: 6); 20% Midterm; 30% Final Project; 30% Final Exam

<u>Homeworks</u>: in every homework one problem will be different between undergraduate and graduate students. Late homework will only be accepted under extenuating circumstances.

<u>Midterm</u>: one problem will be different between undergraduate and graduate students.

<u>Final exam</u>: one problem will be different between undergraduate and graduate students.

<u>Final project</u>: Graduate students will perform individual projects on FSI topics that they propose. The topics selection will need to be approved by the professor.

Prerequisite Knowledge: ENME361, ENME331.

Textbooks: Lectures will be based on specific chapters of the following books:

1) Païdoussis, M.P., 1998. Fluid-Structure Interactions: Slender Structures and Axial Flow. Volume 1. Academic Press.
2) Païdoussis, M.P., 2003. Fluid-Structure Interactions: Slender Structures and Axial Flow. Volume 2. Academic Press, London, UK.
3) Païdoussis, M.P., Price, S.J., De Langre, E., 2010. Fluid-structure interactions: cross-flow-induced instabilities. Cambridge University Press.

Campus Policies

It is our shared responsibility to know and abide by the University of Maryland's policies that relate to all courses, which include topics like:

- Academic integrity
- Student and instructor conduct
- Accessibility and accommodations
- Attendance and excused absences
- Grades and appeals
- Copyright and intellectual property

Attendance

This class will be conducted **in person**. Each week lectures slides will be posted. Participation in class is highly encouraged.Homework will be assigned on the course ELMS page. Midterm and final exam will be closed books and closed notes.

Academic Integrity

The University of Maryland, College Park has a nationally recognized Code of Academic Integrity, administered by the Student Honor Council. This Code sets standards for academic integrity at Maryland for all undergraduate and graduate students. As a student, you are responsible for upholding these standards for this course. It is very important for you to be aware of the consequences of cheating, fabrication, facilitation, and plagiarism. For more information on the Code of Academic Integrity or the Student Honor Council, please visit http://www.shc.umd.edu.

Grades

Final grades will be calculated as follows

Grades
A+ > 95
90 < **A** < 95
87< **A-** < 90
83 < **B+** < 87
80 < **B** < 83
77 < **B-** < 80
73 < **C+** < 77
70 < **C** < 73
67 < **C-** < 70
63 < **D+** < 67
60 < **D** < 63
F < 60

Week		Lecture Topic
		Concepts and Methods for FSI problems
1	31-Aug	Discrete and distributed parameter systems, Galerkin method for conservative and nonconservative systems, self-adjoint and positive definite continuous systems
2	7-Sep	Diagonalization, forced vibrations of continuous systems, equations of fluid flow, linear and nonlinear dynamics
		Pipes Conveying Fluid
3	14-Sep	Linear Dynamics
4	21-Sep	Long Pipes and Wave Propagation. Nonlinear and chaotic dynamics
		Engineering Applications of Pipes Conveying Fluid
5	28-Sep	Submerged pipes: aspirating pipes and ocean mining, the Coriolis mass-flow meter, hydroelastic ichthyoid propulsion
6	5-Oct	Vibration attenuation, stability of deep-water risers, and vibration-induced flow
		Cylindrical shells containing or immersed in flow
7	12-Oct	Inviscid model, steady and unsteady viscous effects, wave propagation and simplified stability theory, swirling flow and rotofluidelasticity, turbulence-induced vibration
8	19-Oct	Collapsible tubes/pliable shells, pressure waves in horizontal systems, physiological systems (veins and arteries), and sloshing
	21-Oct	Midterm Exam
		Prisms in Cross-Flow – Galloping
9	26-Oct	*The mechanism of galloping.* The linear threshold of galloping, nonlinear aspects. Low-Speed Galloping. Torsional galloping: linear quasi-steady analysis, nonlinear quasi-steady analysis, unsteady theory.
10	2-Nov	The effect of sectional shape, Novak's "universal response curve" and continuous structures, unsteady effects, analytical models, shear-layer reattachment
		Vortex-Induced Vibrations (VIV)
11	9-Nov	Two-Dimensional VIV Phenomenology. Bluff-body wake instability, wake instability of a fixed cylinder, wake of a cylinder forced to move, cylinder free to move
12	16-Nov	Modeling VIV. A classification of models: type A - forced system models, type B- fluidelastic system models, type C- coupled system mode
		Fish Swimming Mechanics
13	23-Nov	Fish Propulsion: lift, resistance, reaction forces
14	30-Nov	Fish Propulsion: efficiency, optimal frequency, wave propagation
		Review Session
15	7-Dec	Review Session
	10-Dec	Final Exam