EECE 7905/8905: Computational Science & Engineering III: Fluid-Structure Interaction (Syllabus)

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EECE 7905 / 8905
Computational Science and Engineering 3: Fluid-Structure Interaction
Spring Semester 2015

Lectures: 220 Engineering Science Bldg; Tuesday and Thursday, 5.30 pm to 6.55 pm

Instructor: Madhu Balasubramanian
Office: 208D Engineering Science Building
Telephone: (901) 678-1199
Email: mblsbrmn@memphis.edu (more reliable)
Office hours: Tuesday 6.55 pm to 7.55 pm (right after class)
Or by appointment (email for appointment)

Recommended Text
a. Lecture notes

Additional References

Website: https://elearn.memphis.edu

Prerequisites: Graduate standing or consent of the instructor

Grades
- Attendance and learning the materials
- Five assignment / homework implementing the following problems in MATLAB:
  1) Static linear elasticity problem (2-D finite element solution including 2-D mesh generation)
  2) Dynamic linear elasticity problem (2-D)
  3) Advection-Diffusion based 2-D flow simulation
  4) 2-D simulation of flow past an elastic (cantilever) beam, and
  5) 3-D simulation of inflation of a balloon (3-D finite element model and solution).
- Students may work on their relevant research projects and receive additional credits.

2. Course Objectives:
   a. Learn computational modeling of coupled systems governed by multiple physical laws and their interactions.
   b. Learn the theoretical foundations of the finite element method in multiphysics, and
   c. Lay foundation for multiphysics research in drug delivery, power generation, computer graphics, and biomedicine as well as for basic mathematical / computational research in the area of fluid-structure interaction.
3. **Catalog Title Abbreviation:** Cmptnl Sc Eng 3: Multiphys-FSI

4. **Catalog Description:** Multiphysics simulations are useful for modeling the behavior of coupled systems governed by two or more physical laws and their interactions. Examples are modeling of blood flow in arteries and veins, pulmonary gas exchange and transport, hydrodynamics and aerodynamics during power generation and electro-thermal-structural interface during drug delivery. Emphasis of this course is on computational modeling of fluid-structure interaction in a moving domain. Topics covered will emphasize on deriving theoretical models from physical laws and constitutive equations governing fluid-structure interaction, and developing finite element procedures for modeling fluid-structure interaction in a moving domain. PhD students registering at the 8000 level will exhibit deeper understanding by submitting / presenting a research paper based on their projects or on more advanced topics in multiphysics.

5. **Course Outline:**
   
a. Course Introduction
   b. Introduction to multiphysics and fluid-structure interaction
   c. Brief review of elementary mathematical techniques for solving differential equations:
      i. Analytic solution; ii. Concept of Hilbert space, function spaces, and the spectral method; and iii. Reformulation as an optimization problem using calculus of variation
   e. Finite element method for non-moving domain problems.
      - **Practice assignments** on 1-D finite element method
   f. Partitioned computational analysis of fluid flow and structural dynamics:
      i. Physical laws and governing equations of static linear elasticity.
         1. Development of Galerkin FEM for static linear elasticity (vector formulation)
         2. Mesh generation in 2-D (triangular element) and 3-D (tetrahedral element).
         3. Lagrange basis functions for 2-D and 3-D elements.
         4. Gaussian quadrature (numerical integration procedure)
         5. Assembly of stiffness matrix and force vector in higher dimensions
         6. FEM implementation of an example linear elastostatics problem (in MATLAB).
      - **Homework 01:** Static linear elasticity problem (2-D finite element solution including 2-D mesh generation)
      ii. Galerkin implementation of dynamic linear elasticity
         - **Homework 02:** Dynamic linear elasticity problem (2-D)
      iii. Navier-Stokes equations governing incompressible fluid flow.
         - **Homework 03:** Advection-Diffusion based 2-D flow simulation
   g. Fundamental concepts of: a) space-time formulation; and b) arbitrary Lagrangian-Eulerian (ALE) formulations.
   h. ALE and space-time formulations of the Navier-Stokes equations on a moving domain.
      - **Homework 04:** 2-D simulation of flow past an elastic (cantilever) beam
   i. Isogeometric analysis (IGA) for discretization of equations governing fluid and structural dynamics.
   j. Non-uniform rational B-splines for Isogeometric analysis
   k. ALE and space-time methods for moving boundaries and interfaces
   l. ALE and space-time methods for fluid-structure interaction.
      - **Homework 05:** 3-D simulation of inflation of a balloon (3-D finite element model and solution)