

Mechanical Engineering Dissertation Defense

Multiphysics simulations with spectral element methods: conjugate heat transfer, fluid-structure interaction, and acoustics

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Abstract

Realistic engineering, physical and biological systems are very complex in nature, and their response and performance are governed by multitude of interacting processes. In computational modeling of these systems, the interactive response is most often ignored, and simplifications are made to model one or a few relevant phenomena as opposed to a complete set of interacting processes due to a complexity of integrative analysis. In this talk, I will develop new high-order computational approaches that reduce the amount of simplifications and model the full response of a complex system by accounting for the interaction between different physical processes as required for an accurate description of the global system behavior. Specifically, I will develop multi-physics coupling techniques based on spectral-element methods for the simulations of such systems. I focus on three specific applications: fluid-structure interaction, conjugate heat transfer, and modeling of acoustic wave propagation in non-uniform media. Fluid-structure interaction illustrates a complex system between a fluid and a solid, where a movable and deformable structure is surrounded by fluid flow, and its deformation caused by fluid affects the fluid flow interactively. To simulate this system, two coupling schemes are developed: 1) iterative implicit coupling, and 2) explicit coupling based on Robin-Neumann boundary conditions. A comprehensive verification strategy of the developed methodology is presented, including a comparison with benchmark flow solutions, h-, p- and temporal refinement studies. Simulation of a turbulent flow in a channel interacting with a compliant wall is attempted as well. Another problem I consider is when a solid is stationary, but a heat transfer occurs on the fluid-solid interface. To model this problem, a conjugate heat transfer framework is introduced. Validation of the framework, as well as studies of an interior thermal environment in a building regulated by an HVAC system with an on/off control model with precooling and multi-zone precooling strategies are presented. The final part of this talk is devoted to modeling an interaction of acoustic waves with the fluid flow. The development of a spectral-element methodology for solution of Lighthill's equation, and its application to a problem of leak detection in water pipes is presented.



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