MECH 570C-FSI: Coding Project 2 Fluid-structure interaction with nonlinear hyperleastic structure

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Abstract

This project extends the exploration of Fluid-Structure Interaction (FSI) to encompass the dynamics of hyperelastic materials in fluid flows, advancing from the simpler interactions of rigid cylindrical structures. Our focus transitions to simulating the complex behavior of a hyperelastic flag subjected to fluid dynamics, employing a comprehensive three-dimensional nonlinear structural model. By integrating the St. Venant-Kirchhoff material model, characterized by Lamé coefficients, Young's modulus, and Poisson's ratio, we detail the structural displacements within a Lagrangian framework. The methodology involves discretizing the governing equations using finite element analysis, coding the resulting model in MATLAB as "hyperelasticMaterial.m", and employing the Newton-Raphson technique for iterative solutions. Initial validation is conducted through isolated structural tests based on the Turek cylinder-bar benchmark, progressing to the integration of fluid forces and the subsequent application to a flapping filament problem at specified Reynolds numbers. Comparative analysis with established benchmarks underscores the solver's efficacy and fidelity in replicating the nuanced physics of FSI in hyperelastic structures. This project not only broadens the understanding of hyperelastic material dynamics in fluid flows but also lays foundational work for advanced simulations in the realm of fluid-structure interactions.

Introduction

The genesis of this project lies in the quest to extend our comprehension and simulation capabilities beyond rigid cylindrical structures interacting with fluid flows, as explored in our preliminary assignment. The focal point shifts towards the modeling and simulation of a flexible hyperelastic structure, such as a flag, subject to the dynamic forces of a surrounding fluid. This progression is not merely academic but a necessary leap towards capturing the real-world complexities encountered in engineering and design. Hyperelastic materials, characterized by their ability to undergo large deformations and return to their original state, necessitate a nonlinear structural analysis to accurately predict their behavior under load.

Methodology

The methodology adopted in this project is a multi-step process beginning with the discretization of the governing structural equations using the finite element method (FEM). This approach enables the approximation of the equations' solutions over a discretized model of the structure. Following the discretization, the nonlinear equations are coded into a MATLAB script, hyperelasticMaterial.m, akin to the format used in our initial exploration of Navier-Stokes equations for fluid flow simulation. Critical to solving the nonlinear structural equations is the Newton-Raphson technique, renowned for its efficiency in handling nonlinear systems through iterative approximation.