A Simple FSI Model for Optimal Shape Design

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abstract

A Fluid-Structure Interaction model is studied based on Koiter's shell model for the structure, Navier-Stokes equations for the fluid and transpiration for the coupling. It accounts for wall deformation while yet working on a fixed geometry. The model is established first. Then a numerical approximation is proposed and some tests and comparison with other models are given. The model is then used for optimal design of an hemodynamic stent and possible recovery of the arterial wall elastic coefficients by inverse methods.

Hemodynamics, a special branch of computational fluid dynamics, poses many problems of modeling, data acquisition, computation and visualization. Numerical simulations software are valuable tools to understand aneurisms, to design stents and heart valves, etc.

Large scale simulations on super computers are possible but expensive and not suited or at least awkward in the medical environment so there is room for cheaper methods to couple fluid and structures.

At least two classes of FSI problems have been investigated numerically extensively: blood flows (L. Formaggia & A. Quarteroni) and free motions of objects in flows, whether self-propelled or passive and rigid or deformable.

A number of algorithms have been proposed, each with different coupling mechanisms. We shall review some of them and recall the mathematical results known for immersed boundaries (C. Peskin), artificial density, fluid as solid, both with Finite Elements (M. Bergman & A. Iollo) or SPH (D. Violeau), Eulerian/Lagrangian formulations (P. Le Tallec & J. Mouro), etc. Algorithms that iterate between the structure and the fluid have usually restricted stability because of the "added mass effect"; we shall present a method that solves the fluid and solid variables in the same variational formulation by using a semi-linearization called "transpiration condition" (T. Chacon, V. Girault, F. Murat & O. Pironneau). The method is unconditionally stable. It will be illustrated with numerical results for blood flow and comparison with others methods (M. Bukaca, S. Canic, R. Glowinski, J. Tambacac & A. Quainia).

Because the code runs on a laptop within minutes it is convenient to solve inverse problems. As the geometry is fixed, an optimal design problem becomes a parameter identification problem for the coefficients of the structure model. We shall show the performance of the method on the design of a stent in the aorta.

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