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A numerical tool for simulating the fluid-structure interaction of elastic bodies with arbitrary thickness

Fluid-structure interaction (FSI) problems are found in many engineering areas and their computational modeling is particularly challenging. Among different FSI problems, biological applications are becoming of ever increasing interest in the scientific community. In such cases, describing the dynamics of the interaction between the body and the fluid is not a trivial task, since the numerical method needs to be able to handle in an efficient way complex and very thin geometries undergoing large deformations, while preserving accuracy.

A versatile numerical method is presented, to predict the fluid-structure interaction of bodies with arbitrary thickness immersed in an incompressible fluid, with the aim of simulating different biological engineering applications. A direct-forcing immersed boundary method is adopted, based on a moving-least-squares approach to reconstruct the solution in the vicinity of the immersed surface. A simple spring-network model is considered for describing the dynamics of deformable structures, so as to easily model and simulate different biological systems that not always may be described by simple continuum models, without affecting the computational time and simplicity of the overall method. The fluid and structures are coupled in a strong way, in order to avoid instabilities related to large accelerations of the bodies. The effectiveness of the method is validated by means of several test cases involving: rigid bodies, infinitely thin elastic structures with mass, flapping flags and inverted flags in a free stream, with a very good agreement with available experimental data and numerical results obtained by different methods.

Examples of different applications are presented, including: i) the fluid-structure interaction of prosthetic heart valves (both mechanical and bio-prosthetic) inside a realistic geometry of the ascending aorta under physiological conditions, with a numerical estimation of blood damage; ii) the swimming of micro-robots travelling in a quiescent fluid, varying the body geometry and swimming mechanism; iii) the transport of arbitrarily shaped particles in shear flows, varying the size, shape and mechanical stiffness of the membrane enclosing the fluid. In all the cases, the bodies are significantly, the solver being able to manage high pressure differences across the surface, still obtaining very smooth hydrodynamic forces.

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