11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

Fluid–Structure Interaction Analysis of Bioprosthetic Heart Valves

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Key Words: *Fluid–Structure Interaction, Isogeometric Analysis, Immersed Boundary Method, Weakly Enforced Boundary Conditions, Bioprosthetic Heart Valves.*

The aim of this work is to develop a robust and accurate computational fluid–structure interaction (FSI) framework to simulate a tri-leaflet heart valve function over the complete cardiac cycle. Due to the large, complex deformation of the heart valve leaflets, traditional boundary-fitted or interface-tracking FSI techniques, such as Arbitrary Lagrangian–Eulerian method, may suffer from numerical issues like mesh distortion, remeshing, or change of topology (e.g. the contact problem). In this work, we take a non-boundary-fitted approach (i.e. the immersed boundary method) to circumvent these difficulties.

The proposed method allows an embedded structure to move through and intersect with the stationary background fluid elements—both are discretized using B-spline or NURBS functions to represent the geometry exactly. We combine the method with adaptive quadrature rules near the unfitted immersed boundaries to numerically integrate more accurately [1]. The variational formulation for immersed-boundary FSI is derived using the augmented Lagrangian approach. The kinematic and traction constraints at the immersed interfaces are imposed weakly [2]. The framework also includes a penalty-based dynamic contact algorithm for shell structures represented by NURBS surfaces.

The accuracy of the proposed method is verified using several well-known benchmark problems by extensive comparisons between simulation results obtained from both boundary-fitted and immersed-boundary approaches. Finally, the framework is applied to the simulation of a bioprosthetic heart valve interacting with the surrounding blood flow under physiological pressures. The simulation results will be shown and discussed.

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