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Second order stable explicit interface advancing scheme for fluid-solid interaction with applications to fish swimming simulation

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We propose a temporally second order numerical scheme for fluid-solid interaction when there are both elastic and rigid bodies inside the fluid. This scheme is very efficient as it uses explicit interface advancing and hence decouples the computation of the mesh position and the fluid solid velocities. We show how rigid body mechanics fits into the frame work of finite element discretization. This fitness, together with Temam's trick for convection terms, and the finite increment formula for nonlinear materials, allows us to handle all the nonlinear terms in the governing equations semi-implicitly. Consequently, we do not need Newton type iterations. Our scheme uses arbitrary Lagrangian Eulerian (ALE) formulation for the fluid and is characteristics-free and Jacobian-free. An exact solution for the fluid-elastic-solid interaction problem is derived and is used to check numerically the $O(\Delta t^2 + h^{m+1})$ convergence of our scheme, where we use $P_m/P_{m-1}/P_m$ finite elements for the fluid velocity, fluid pressure and solid velocity. We prove a stability result of our fully discrete scheme. By comparing it with the stability result of a well-known second order ALE scheme for heat equation on a time varying domain with given variation, we show that explicit interface advancing does not damage the stability of our scheme. As an application, we perform the fish swimming simulation and confirm numerically some observations made by Purcell in 1976 concerning how microorganisms swim in viscous fluid..

Keywords: Fluid-Structure interaction, Arbitrary Lagrangian Eulerian, Stable Explicit Interface Advancing Scheme, Fish Swimming Simulation, Crank-Nicolson Scheme.