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An implicit Immersed Boundary method for three-dimensional membrane-fluid flow interactions

D.V. Le[1,2], J. White[1,2], J. Peraire[1,3], K.M. Lim[1,4] and B.C. Khoo [1,4]

[1] Singapore-MIT Alliance
4 Engineering Drive 3, National University of Singapore, Singapore 117576
ducvinh@mit.edu, smaldv@nus.edu.sg

[2] Department of Electrical Engineering & Computer Science
Massachusetts Institute of Technology, 77 Massachusetts Avenue, MA 02139, USA
white@mit.edu

[3] Department of Aeronautics and Astronautics
Massachusetts Institute of Technology, 77 Massachusetts Avenue, MA 02139, USA
peraire@mit.edu

[4] Department of Mechanical Engineering
National University of Singapore, 10 Kent Ridge Crescent, Singapore 119260
mpelimkm@nus.edu.sg, mpekbc@nus.edu.sg

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ABSTRACT

We present an implicit immersed boundary method for the incompressible Navier-Stokes equations capable of handling three-dimensional membrane-fluid flow interactions. The goal of our approach is to improve the time step by using the Jacobian-free Newton-Krylov method (JFNK) to advance the location of the elastic membrane implicitly. The most attractive feature of this Jacobian-free approach is Newton-like nonlinear convergence without the cost of forming and storing the true Jacobian. The Generalized Minimal Residual method (GMRES), which is a widely used Krylov-subspace iterative method, is used to update the search direction required for each Newton iteration. Each GMRES iteration only requires the action of the Jacobian in the form of matrix-vector products and therefore avoids the need of forming and storing the Jacobian matrix explicitly. Once the location of the boundary is obtained, the elastic forces acting at the discrete nodes of the membrane are computed using a finite element model. We then use the immersed boundary method to calculate the hydrodynamic effects and fluid-structure interaction effects such as membrane deformation. The present scheme has been validated by several simulations including an oscillatory membrane initially placed in a still fluid and spherical and redblood cell membranes in shear flows.

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