SHARP INTERFACE IMMERSED BOUNDARY METHODS FOR FLUID-STRUCTURE INTERACTION

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Abstract. The immersed boundary (IB) method [1] is a framework for fluid-structure interaction (FSI) that avoids the use of body-conforming discretizations of the fluid and solid. Instead, the IB formulation uses an Eulerian description of the momentum, viscosity, and incompressibility of the fluid-solid system, and it uses a Lagrangian description of the deformations and stresses of the immersed structure. In the conventional IB method, the Eulerian and Lagrangian frames are connected by integral equations with Dirac delta function kernels, and when these equations are approximated, the singular delta function kernel is replaced by a regularized delta function. Because this conventional method regularizes jump discontinuities in the pressure and shear stress along the fluid-solid interface, this method is generally first-order accurate. Approaches to improve the accuracy of the IB method include the immersed interface method (IIM) [2, 3, 4] and the immersed boundary smooth extension (IBSE) method [5]. The IIM is able to achieve high-order accuracy, but a limitation of existing IIM formulations is that they assume idealized interface representations. We present an IIM that uses faceted surface representations for applications involving stationary interfaces as well as full FSI with volumetric structural models. A challenge of the IIM is that it requires the derivation and implementation of corrected finite difference approximations that include known jump conditions. Because the discontinuities are localized to fluid-structure interfaces, an alternative to imposing jump conditions is to decompose the discontinuous fields into fields that are continuous over their domains of definition. We also present initial results from an IB method that uses this splitting approach to improve the treatment of the pressure discontinuity. This approach is similar to the IBSE method, but allows for the use of non-stationary, flexible bodies. In both cases, we obtain higher-order accurate methods while maintaining the use of non-conforming meshes and general structural geometries.

Keywords: immersed boundary; immersed interface; fluid-structure interaction

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References

[1] C. S. Peskin. The immersed boundary method. *Acta Numer*, 11:479–517, 2002.

[2] Z.-L. Li and M.-C. Lai. The immersed interface method for the Navier-Stokes equations with singular forces. *J Comput Phys*, 171(2):822–842, 2001.

[3] L. Lee and R. J. LeVeque. An immersed interface method for incompressible Navier-Stokes equations. *SIAM J Sci Comput*, 25(3):832–856, 2003.

[4] S. Xu and Z. J. Wang. Systematic derivation of jump conditions for the immersed interface method in three-dimensional flow simulation. *SIAM J Sci Comput*, 27(6):1948–1980, 2006.

[5] D. B. Stein, R. D. Guy, and B. Thomases. Immersed Boundary Smooth Extension (IBSE): A high-order method for solving incompressible flows in arbitrary smooth domains. *J Comput Phys*, 335:155–178, 2017.

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