A comparison of the Lagrange multiplier and penalty formulations of the fictitious domain method for modelling fluid-structure interactions.

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Abstract

A numerical study was conducted to compare the advantages and disadvantages of adopting a penalty formulation for the body force in the fictious domain method, as opposed to a Lagrange multiplier formulation. This comparison is fitting as the penalty and Lagrange multiplier approaches have traditionally been rival methods of imposing constraints in both simulations and optimisation problems. The penalty formulation selected was the immersed body method that forms part of the open-source, finite element-based, computational fluid dynamics code, Fluidity. A distributed Lagrange multiplier method was chosen for the Lagrange multiplier approach, and a novel version of this method, which has been incorporated into Fluidity, is presented. The immersed body and distributed Lagrange multiplier methods were evaluated, in terms of both accuracy and computation time, by using each method to solve a series of benchmark problems. The results revealed that the distributed Lagrange multiplier method enforces the no-slip condition at the wetted boundary of the structure with much higher accuracy. Consequently, this method yielded better predictions of the velocity of the fluid and the forces exerted on the wetted boundary. However, this superior accuracy comes at the cost of a significantly higher com-

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putation time than that required by the immersed body method. Therefore, the immersed body method may save a large amount of computation time if it is applied to a simulation for which the lower accuracy it provides is still sufficient.
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