6th European Conference on Computational Mechanics (ECCM 6)
7th European Conference on Computational Fluid Dynamics (ECFD 7)
11-15 June 2018, Glasgow, UK

A comparative analysis of the Lagrange multiplier and penalty methods for simulating fluid-structure interactions

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Keywords: *fluid-structure interactions, fictitious domain method, Lagrange multiplier method, penalty method, finite element method*

When simulating fluid-structure interactions (FSI), correct enforcement of the no-slip condition at the wetted boundary of the structure is often critical to obtain an accurate solution. In the immersed boundary and fictitious domain methods, this condition is treated as a constraint that is satisfied by subjecting the fluid to an artificial body force. The Lagrange multiplier and penalty methods are two approaches that are commonly used to impose this type of constraint. The aim of this study is to evaluate the relative strengths and limitations of the Lagrange multiplier and penalty methods in the context of simulating fluid-structure interactions (FSI). In order to accomplish this, a distributed Lagrange multiplier (DLM) method [1] is applied within the framework of a fictitious domain approach in a novel manner. This method has been integrated into the open-source, finite element-based, computational fluid dynamics code, Fluidity. The performance of this new implementation is then compared to that of a penalty method that was already present in Fluidity, called the immersed-body (IB) method [2].

The DLM and IB methods were each used to solve two FSI benchmark problems: laminar flow through a channel and the harmonic motion of a cylinder immersed in a stationary fluid. The results obtained indicate that the DLM method enforces the no-slip condition with higher accuracy than the IB method. Consequently, this method also provides superior predictions of the velocity field of the fluid and the force that the fluid exerts on the wetted boundary. However, this improved accuracy potentially comes at the cost of higher computational times than those required by the IB method. Therefore, the penalty method may still be preferable if it is used to execute simulations for which its accuracy is adequate as it may save computational time.

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