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Publication date:
2013

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Citation (APA):

Hejlesen, M. M., Koumoutsakos, P., Leonard, A., & Walther, J. H. (2013). *An improved interface penalisation for vortex methods*. Abstract from 3rd International Conference on Particle-Based methods, Stuttgart, Germany.

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An improved interface penalisation for vortex methods

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ABSTRACT

When using particle-mesh methods for fluid mechanic applications, the Brinkman penalisation method [1] offers a convenient way of enforcing the no-slip boundary condition at complex boundaries. The penalisation method is based on introducing a local source term to the governing equations which enforces a no-flow condition within the solid. Kevlahan [2] proposes a method to use the Brinkman penalisation with the vorticity equation. Here a split-step algorithm is used to update the vorticity as the curl of the penalised velocity field. The updated vorticity penalisation has been implemented in the vortex-in-cell method by Rasmussen et al. [3] and Gazzola et al. [4] where it has been validated on different geometries, both fixed and moving. The updated vorticity penalisation has difficulties handling acceleration of either the flow or the solid that is normal to the penalised boundary. The underlying problem is the lack of a normal stress coupling when calculating the vorticity from the penalised velocity field. This results in an inefficient update of the surface vorticity on boundaries when the penalisation force becomes perpendicular to the flow. For geometries with large surfaces perpendicular to the flow it is shown that an effective penalisation of the velocity field is not reached before a certain number of time steps. In the presented work we show that by iterating the vorticity update from the penalisation, the surface vorticity can be fully updated within a single time step. We investigate methods to improve the update of surface vorticity and test the methods on the case of an impulsively started flow perpendicular to a thin plate. The efficiency and accuracy of the penalisation method is compared with literature [5] and recent vortex particle simulations using the boundary element method (BEM). The flow perpendicular to the thin plate is characterised by the early formation of strong tip vortices resulting in high initial drag force. By comparing the penalisation force and the change in vorticity moment with that from the vortex method using BEM, it is seen that the penalisation method is capable producing results which agrees well with that of other numerical methods.

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