An improved interface penalisation for vortex methods

Hejlesen, Mads Mølholm; Koumoutsakos, Petros; Leonard, Anthony; Walther, Jens Honore

Publication date:
2013

An improved interface penalisation for vortex methods

Mads M. Hejlesen[1], Petros Koumoutsakos[2], Anthony Leonard[3] and Jens H. Walther[1,2]

[1]Department of Mechanical Engineering
Technical University of Denmark
Nils Koppels Alle, Building 403, DK-2800 Kgs. Lyngby, Denmark
e-mail: mmhej@mek.dtu.dk, web page: http://www.mek.dtu.dk

[2] Computational Science and Engineering Laboratory
ETH Zürich
Clasiusstrasse 33, CH-8092 Zürich, Switzerland
e-mail: petros@ethz.ch, walther@mavt.ethz.ch, web page: http://www.cse-lab.ethz.ch

[3] Division of Engineering and Applied Science
California Institute of Technology
1200 E California Blvd., CA 91125 Pasadena, USA
e-mail: tony@galcit.caltech.edu, web page: http://www.eas.caltech.edu/

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.

REFERENCES

[1] P. Angot, C.-H. Bruneau, P. Fabrie. A penalization method to take into account obstacles in incompressible viscous flow. *Numer. Math.*, **81**, 497-520, (1999).

[2] N. K.-R. Kevlahan, "Computation of turbulent flow past an array of cylinders using a spectral method with Brinkman penalization", *Eur. J. Mech. B-Fluids*, **20**, 333-350 (2001).

[3] J.T. Rasmussen, G.-H. Cottet, J. H. Walther. A multiresolution remeshed Vortex-In-Cell algorithm using patches, *J. Comput. Phys.*, **230,** 6742–6755 (2011) .

[4] M. Gazzola, P. Chatelain, W. M. van Rees, P. Koumoutsakos. Simulations of single and multiple swimmers with non-divergence free deforming geometries, *J. Comput. Phys.*, **230**, 7093-7114 (2011).

[5] P. Koumoutsakos, D. Shiels, Simulations of the viscous flow normal to an impulsively started and uniformly accelerated flat plate, *J. Fluid Mech.*, **10**, 177-227, 1996.