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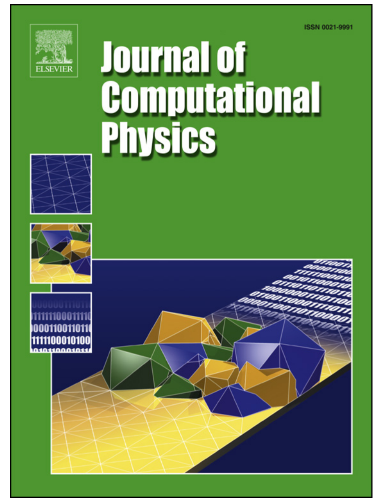

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An efficient iterative penalization method using recycled Krylov subspaces and its application to impulsively started flows

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Abstract

We formulate the penalization problem inside a vortex particle-mesh method as a linear system. This system has to be solved at every wall boundary condition enforcement within a time step. Furthermore, because the underlying problem is a Poisson problem, the solution of this linear system is computationally expensive. For its solution, we here use a recycling iterative solver, rBiCGStab, in order to reduce the number of iterations and therefore decrease the computational cost of the penalization step. For the recycled subspace, we use the orthonormalized previous solutions as only the right hand side changes from the solution at one time to the next. This method is validated against benchmark results: the impulsively started cylinder, with validation at low Reynolds number (Re = 550) and computational savings assessments at moderate Reynolds number (Re = 9500); then on a flat plate benchmark (Re = 1000). By improving the convergence behavior, the approach greatly reduces the computational cost of iterative penalization, at a moderate cost in memory overhead.

Keywords: Brinkman penalization, Krylov subspaces recycling, Recycling BiCGStab, Vortex methods, Particle-mesh methods, Linear solver

1. Introduction

Vortex methods use the vorticity-velocity formulation of the (incompressible) Navier-Stokes equations. Re-meshed vortex particle (VP) methods have been shown to efficiently and accurately simulate complex viscous vortex flows [1–5]. The Lagrangian treatment of the convection term, combined with the re-meshing operation leads to a method with accurate treatment of the convection. The re-meshed and hybrid approach, as in [2, 3, 6–10], here called the Vortex Particle-Mesh (VPM) method, sometimes also called the Vortex-In-Cell (VIC) method, combines the advantage of a particle method with those of a mesh-based approach. Several techniques have been proposed for embedding solid bodies with arbitrary geometries in VPM methods [4, 5]. Most recent efforts use Immersed Interface method (IIM) [11, 12] or penalization techniques [13–15]. For the latter, an iterative penalization method has been proposed by Hejlesen et al. [16], in order to improve the accuracy at the boundary, avoid diffusion errors [17] and keep the time-step sufficiently large. However, this iterative procedure is highly expensive since, at each iteration, one needs to recover velocity from vorticity by solving a Poisson equation. When considering unbounded problems, this can be carried out on a small sub-domain around the body; yet it still remains the bottleneck operation of such method. Moreover, in a parallel computing context, this domain change implies some important data

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