Seventeenth International Conference Zaragoza-Pau on Mathematics and its Applications
Jaca, September 4–6th 2024

A Multiresolution Vortex Particle-Mesh method†

Pierre Balty[1], **Gilles Poncelet**[1], **Matthieu Duponcheel**[1], **Philippe Chatelain**[1]

SUMMARY

The Vortex Particle-Mesh (VPM) method is one of the state-of-the-art methods to perform large-scale simulations of wake flows. It is a hybrid method that solves the velocity-vorticity form of the Navier-Stokes equations for incompressible flows and combines the advantages of a particle method, i.e. low numerical dissipation and dispersion errors, with those of a mesh-based approach: highly efficient Poisson solvers and finite difference stencils. Physical quantities are interpolated from the particles onto the mesh and vice-versa using high order kernels.

The VPM approach has been applied to many fields including wind energy and aircraft wakes and has been proven to be a fast and accurate alternative to pseudospectral solvers to simulate vortical flows. However, those simulations using uniform grids often result in prohibitive computational costs, especially in three-dimensions. Adaptive Mesh Refinement (AMR) tackles the issue by adapting the local grid resolution to the flow characteristics but brings additional complexity in terms of algorithm and (parallel) implementation. The AMR algorithm must identify the need for refinement or coarsening and adapt the grid while preserving the conservation properties of the simulated physics. At the same time, the cost of the adaptation machinery must be as low as possible to have a minimum impact on the computational gain made by reducing the number of unknowns.

This work presents a scalable and efficient implementation of the VPM method capitalizing on adaptive grid refinement. Our solver has been developped within `murphy` [1], a wavelet-based multiresolution framework for scientific computing on 3D block-structured collocated grids. We build a new approach to represent the particles, that allows their refinement or coarsening, thereby facilitating the interpolation between particles and mesh of varying resolutions. To solve the Poisson equation, we employ a Multigrid approach combined with an FFT-based direct solver [2]. The resulting software is designed to leverage massively parallel architectures. It will be applied to study the collision of vortex rings.

Keywords: adaptive mesh refinement, vortex particle-mesh method, multiresolution,. . .

AMS Classification: 65M06, 65M50, 76D05

References

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[1]Institute of Mechanics, Materials and Civil Engineering
UCLouvain
email: `pierre.balty@uclouvain.be`

†With contributions from J. Gabbard, T. Gillis, J. Lambrecht, and W. van Rees.