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Particle Methods for Viscous Flows: Analogies and Differences Between the SPH and DVH Methods

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Abstract. In this work two particle methods are studied in the context of viscous flows. The first one is a Vortex Particle Method, called Diffused Vortex Hydrodynamics (DVH), recently developed to simulate complex viscous flows at medium and high Reynolds regimes. This method presents some similarities with the SPH model and its Lagrangian meshless nature, even if it is based on a different numerical approach. Advantages and drawbacks of the two methods have been previously studied in Colagrossi et al. [1] from a theoretical point of view and in Rossi et al. [2], where these particle methods have been tested on selected benchmarks. Further investigations are presented in this article highlighting analogies and differences between the two particle models.

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Key words: Particle methods, meshless methods, vortex methods, Smoothed Particle Hydrodynamics (SPH), Diffused Vortex Hydrodynamics (DVH).

1 Introduction

This work is addressed to the analysis of two particle methods: the Smoothed Particle Hydrodynamics (SPH) and the Diffused Vortex Hydrodynamics (DVH). The latter is a Vortex Particle Method (VPM) recently presented in Rossi et al. [2] and validated on classical viscous flows around bodies in Rossi et al. [3].

The basic concepts underlying the SPH and the VPM have been previously studied in Colagrossi et al. [1] were the main focus was on the theoretical aspects of two particle methods. More recently in Rossi et al. [2] the DVH method has been introduced and compared with the SPH model in terms of similarities on the convergence properties of

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the two schemes. In the present work the investigation on these two particle methods has been extended by completing some lacking points of the research.

To better focus the framework of the current investigation, a classification in four families of the most popular Navier-Stokes Lagrangian solvers is reported in Table 1. The advantages in using Lagrangian solver is mainly in the treatment of the direct advection of the particles which leads to a reduction of the numerical dissipation with respect to mesh based approaches. The first subdivision of Table 1 is based on the primary variables adopted: pressure-velocity or vorticity fields.

Table 1: A possible classification of the most popular Navier-Stokes Lagrangian solvers.

	Pressure & Velocity	**Vorticity** (VPM)
Need topological connections (for evaluating spatial derivatives)	P-FEM, α-NEM, PIC (Particle in Cell), FLIP (Fluid - Particle in cell [4]) Voronoi moving mesh	VIC (Vortex in Cells), Remeshed-Vortex-Method
Meshless approach (use of Kernel convolutions)	SPH, ISPH (incompressible SPH), MPS (Moving Particle Semi-implicit method), FVPM (Finite Volume Particle Method)	DVH, PSE (Particle Strength Exchange), DVM (Diffused Velocity Method), VVD (Viscous Vortex Domains method), VRM (Vorticity Redistribution Method), RVM (Random Vortex Method)

The use of the vorticity as a primary variable brings several advantages when solving the Navier-Stokes equation for incompressible flows:

1. the pressure field is not a direct unknown of the problem,
2. the continuity equation is automatically satisfied,
3. the vorticity formulation allows to discretize only the rotational region of the flow (self-adaptivity),
4. high accuracy on the evaluation of the velocity field (because it is obtained through a spatial integration),
5. the boundary conditions at infinity are automatically satisfied, therefore large spatial domains are not required to correctly enforce them.

These points represent the main differences between VPM and the Pressure-Velocity based Lagrangian solvers. For the latter the velocity-divergence constraint need to be explicitly handled, requiring the discretization of the whole fluid domain. Moreover, the radiation boundary conditions cannot be imposed easily in these methods, implying the use of very large domains. On the other hand the Pressure-velocity Lagrangian solvers have the advantage of a direct evaluation of the fluid deformation in the whole domain which can be quite useful for many engineering/industrial applications. For example