Meshfree number density field reconstruction for two-way coupling of particle-laden flows using the Fully Lagrangian Approach

C. P. Stafford[a], O. Rybdylova[a]

The simulation of particle-laden flows has evolved into an area of continued importance, with a diverse range of industrial and environmental applications leading to the development of a variety of computational approaches for modelling droplet and particle behaviour. Of central importance in the modelling of such flows is the accurate representation of the spatial distribution of particles, which can exhibit wide variation in unsteady or turbulent flows, and plays a key role within simulations for interphase momentum and energy coupling in dilute suspensions. For this reason, accurate determination of the dispersed phase number density field is paramount to ensuring physically correct behaviour can be reproduced within simulations.

The present work seeks to address this need by utilizing a mathematical model known as the Fully Lagrangian Approach (FLA), which is able to calculate the local number density of particles along their trajectories, and thereby include detail of the behaviour experienced by individual particles[1]. The advantage of this method is that relatively few particles need to be tracked to reproduce a faithful representation of the particle number density field, when compared to conventional box-counting methods such as the Cloud-In-Cell approach[2]. The novelty of the present research comes from using the statistical learning approach of kernel regression estimation to accumulate the contributions from individual trajectories and reconstruct the particle number density field. In particular, the domain of influence for the kernel associated with a given particle is determined directly from FLA data in accordance with the spatial structure of the particle number density field. This enables a high level of detail to be retained at a reduced computational cost, and also has the benefit of being straightforward to extend to the consideration of polydisperse particles.

The developed methodology has been implemented as a custom solver within OpenFOAM, and applied to some benchmark simulations for flow around a cylinder in steady and unsteady cases for both monodisperse and polydisperse particles. The kernel estimator is shown to provide a reliable means of reconstructing the particle number density field, and thereby also the momentum and energy source terms, across this range of flow configurations. When compared to a Cloud-In-Cell approach, the computational cost is seen to be significantly decreased due to the ability of kernel regression estimation to utilise knowledge of the spatial structure of the particle number density field, and demonstrates the potential of the FLA methodology for upscaling to the simulation of industrially relevant systems.

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[a] Advanced Engineering Centre, School of Architecture, Technology and Engineering, University of Brighton, Brighton BN2 4GJ, UK

[1] Osiptsov, *Astrophys. Space Sci.* **274**, 377 (2000).

[2] Healy and Young, *Proc. R. Soc. A* **461**, 2197 (2005).