Segregation of inertial particles in turbulence via the Full Lagrangian Approach

R.H.A. IJzermans[1], M.W. Reeks[1], E. Meneguz[1], M. Picciotto[2], A. Soldati[2*]

[1] School of Mechanical and Systems Engineering, University of Newcastle Upon Tyne, NE1 7RU, United Kingdom

[2] Dipartimento di Energetica e Macchine, University of Udine, via delle Scienze 208, 33100 Udine, Italy

June 8, 2009

Abstract

Suspensions of small heavy particles in turbulent flows are found in a variety of natural and industrial applications such as droplets in clouds [1], soot particles in post combustion devices and reacting particles in chemical processs facilities [2]. It is well known from experimental results [3], numerical simulations [4] and theoretical studies [5] that particles in turbulent flows tend to concentrate preferentially due to inertia. This non-trivial behavior is associated with a nonlinear dynamical system that is far from equilibrium, which combines properties of kinetics and hydrodynamics and has caustics superimposed on a multifractal structure. Inertial particles are generally ejected from regions of high vorticity and accumulate in regions of high strain rate, thereby inducing non-zero gradients occur in the particle number density, $n(\mathbf{x}, t)$, i.e. the number of particles situated inside an infinitesimally small volume located around position $\mathbf{x}$ at time t. It is associated with a non-zero compressibility of the particle velocity field (PVF) $\overline{\mathbf{v}}(\mathbf{x}, t)$ which is defined as the mean velocity of particles at a certain position $\mathbf{x}$ at time t. Indeed, it is well-known [**?**] that the particle velocity field may be compressible even if the turbulent carrier flow is incompressible. Local gradients of $n(\mathbf{x}, t)$ and $\overline{\mathbf{v}}(\mathbf{x}, t)$ control the rates of inter-particle collisions, coalescence, break-up and possibly sedimentation and resuspension.

One possibility to measure the concentration of discrete particles and the particle velocity field is to use 'box counting' (see e.g. [7]). This method is as intuitive as it is complicated, its complication being caused by the large number of particles required to determine steep concentration gradients; specifically, there may be regions devoid of particles close to regions of particle accumulation.

In the present study we propose an alternative method to quantify the compressibility of the particle velocity field, namely the "full Langrangian method" (FLM) [8, 9], and compare it to the "mesoscopic Eulerian formalism" (MEF) [6] which is essentially a box counting method. We show that the FLM can be used to predict local concentration gradients at small scales in a more accurate and computationally cheaper way than the MEF. The potential of the FLM is illustrated in a simple two-dimensional synthetic turbulent flow field and we benchmark the two methods in a direct numerical simulation (DNS) of turbulence. The method will be applied to Homogeneous Isotropic Turbulence and to bounded Turbulent flow.

References

1. G. Falkovich and A. S. Fouxon and M. G. Stepanov, (2002) "Acceleration of rain initiation by cloud turbulence," *Nature*, 468, 283-315.
2. M. Campolo, A. Cremese, and A. Soldati (2008) "Controlling particle dispersion in a transverse jet by synchronized injection" *AIChE J.* 54 1975-1986
3. J. R. Fessler and J. D. Kulick and J. K. Eaton, (1994) "Preferential concentration of heavy particles in a turbulent channel flow," *Phys. Fluids*, 6, 3742–3749.
4. L. P. Wang and M. R. Maxey, 1993, "Settling velocity and concentration distribution of heavy particles in homogeneous isotropic turbulence," *J. Fluid Mech.*, 256, 27–68.
5. E. Balkovsky and G. Falkovich and A. Fouxon (2001) "Intermittent distribution of inertial particles in turbulent flows" *Phys.Rev.Lett.*, 86, 2790-2793
6. O. Simonin and L. I. Zaichik and V. M. Alipchenkov and P. Février (2006) "Connection between two statistical approaches for the modelling of particle velocity and concentration distributions in turbulent flow: The mesoscopic Eulerian formalism and the two-point probability density function method," *Phys. Fluids*, 18, 125107.
7. S. Sundaram and L. R. Collins (1997) "Collision statistics in an isotropic particle-laden turbulent suspension. Part 1. Direct Numerical simulations," *J. Fluid Mech.*, 335, 75–109.
8. M. Picciotto, C. Marchioli, M. Reeks, A. Soldati (2005) "Statistics of velocity and preferential accumulation of micro-particles in boundary layer turbulence" *Nucl.Eng & Des* 235 1239-1249
9. R. IJzermans, M. Reeks, E. Meneguz, M. Picciotto, A. Soldati (2009) "Measuring segregation of inertial particles in turbulence by Full Lagrangian Approach" *Phys. Rev. E*, 79, 063003.

*corresponding Author email: soldati@uniud.it