LAGRANGIAN CONDITIONAL STATISTICS OF INERTIAL PARTICLE FLOWS

Chibbaro Sergio[1], Marchioli Cristian [2] Salvetti Maria Vittoria [3] & Soldati Alfredo [2]
[1]*Institut Jean Le Rond D'Alembert, University Pierre et Marie Curie and CNRS, UMR 7190, France*
[2]*Centro Interdipartimentale Fluidodinamica e Idraulica and Dip. Energetica e Macchine, Università di Udine, Italy*
Dip. Ingegneria Aerospaziale, Università di Pisa, Italy

Abstract We present conditional Lagrangian statistics of a turbulent channel flow with inertial particles released within the flow. Statistics are obtained via a Direct Numerical Simulation (DNS) of the fluid at moderate Reynolds number $Re_\tau = 150$ with a Lagrangian particle tracking. Different particle diameters are considered. An analysis of the effect of a filter is also carried out in order to find out insights for sub-grid Large Eddy Simulations modelling.

METHODOLOGY

We used pseudo-spectral DNS [1] to compute the turbulent flow of air (incompressible and Newtonian) in a two-dimensional channel at $Re_\tau = u_\tau h/\nu = 150$, where u_τ is the friction velocity[**?**], ν is fluid viscosity and h is the channel half-height. The reference geometry consists of two infinite vertical flat parallel walls with periodic boundary conditions in the streamwise (x) and spanwise (y) directions and no-slip conditions at the walls. The size of the computational domain is $L_x \times L_y \times L_z = 4\pi h \times 2\pi h \times 2h$, corresponding to $1885 \times 942 \times 300$ wall units (*i.e.* in terms of variables identified with the superscript "+" made dimensionless using ν and u_τ) in x, y and z, discretized with $128 \times 128 \times 129$ grid nodes. A two level, explicit Adams-Bashforth scheme for the non-linear terms, and an implicit Crank-Nicolson method for the viscous terms are employed for time advancement.
We tracked three swarms ($O(10^5)$) of particles, characterized by values of the Stokes number, St, equal to 1, 5, and 25. The two smaller values, $St = 1$ and $St = 5$, were thus chosen to highlight trends in the behavior of the filtering error as preferential concentration effects become weaker. Particles are modeled as pointwise, non-rotating rigid spheres; they are much heavier than the carrier fluid ($\rho_p/\rho \simeq 769$, ρ_p being the particle density) and are injected into the flow at concentration low enough to consider dilute system conditions (no inter-particle collisions) and one-way coupling between the two phases (no turbulence modulation by particles). In our simulations, particles are pointwise, rigid, elastically rebounding spheres for which periodic boundary conditions apply along the homogeneous flow directions.
For filtered statistics, in the a-priori tests, LPT is carried out replacing $\mathbf{u}_s$ with the filtered fluid velocity field, $\bar{\mathbf{u}}(\mathbf{x_p}, t)$. This field is obtained through explicit filtering of the DNS velocity by a cut-off filter that has filter width $CF = 4$ with respect to DNS (corresponding to 32×32 Fourier modes) and is applied in the wave number space in the homogeneous directions.

RESULTS

The dynamics of each set of particles in DNS has been characterized in terms of Lagrangian pdf of particle position, velocity and of fluid velocity seen by the particles. Lagrangian pdfs are obtained by conditioning the particle trajectories at the initial instant. Two different types of tests are carried, starting by tracking in DNS velocity fields particles which are conditioned to be initially released in regions characterized by sweep and ejection events respectively. In order to identify these regions, the same criterion as in [2] was used, i.e. the sign of the fluid Reynolds stress component $|u'|w'$ was analyzed on five horizontal planes in the near wall region (at $z^+ = 4, 6, 8, 10, 12$). An event is recorded at a given point when at least on four of the five considered planes $|u'|w'$ has the same sign. In the instantaneous flow field used as initial condition for LPT, ten regions characterized by sweep events are detected, as well as ten ejection zones. As previously mentioned, two sets of initial conditions were considered for LPT in DNS flow fields; in the first one, 10000 particles are released in each sweep region on the plane at $z^+ = 8$, while in the second one 10000 particles are released in each ejection zone on the same plane. In all cases the initial particle velocity is the same as that of the fluid at the particle location. For each type of boundary conditions, three sets of particles having $St = 1, 5, 25$ respectively, are tracked.
In figure the pdfs of the wall-normal position computed at $t^+ = 182$ for the particles initially seeded in sweep and ejection regions are reported, together with that obtained at the same instant for particles initially uniformly distributed on the horizontal plane at $z^+ = 5$. The probabilistic results assess the criterion chosen to disentangle different structures. Results are in line with the present understanding of particle deposition onto walls, whose mechanism seems dominated by these features [2]. A complete analysis of Lagrangian PDF will be presented in order to underline the role of coherent structures in particle dynamics with particular regard to the filtering effect on this statistics. Preliminary results confirm the stochastic and non-Gaussian nature of filtering error in non-homogeneous flows. Compared to Eulerian PDFs, however,

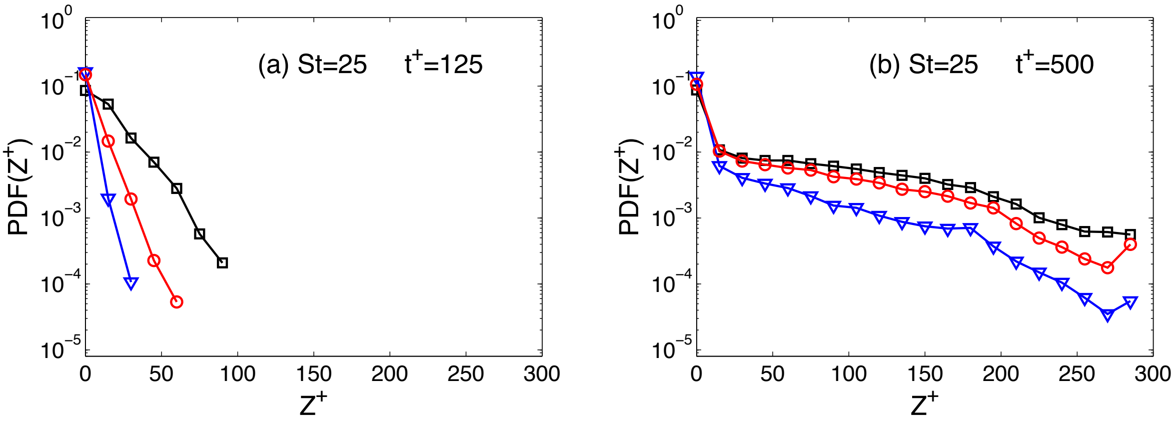

Figure 1. Sinus of x as a function of x.

Lagrangian conditional PDFs exhibit differences which may offer useful insights for physical modelling. Specifically, for short times upon particle release, PDFs indicate a strong subgrid anisotropic effect of sweeps and ejections along the wall-normal direction. This feature underlines the link between turbulent coherent structures and strain, suggesting the possibility to model coherent structures with a direct link to velocity gradients. Asymptotically, the Lagrangian conditional PDFs recover the Eulerian behavior showing Stokes number effects limited to the PDF tails. Perspective for sub-grid modelling will be given.

References

[1] Y. Pan and S. Banerjee. Numerical simulation of particle interactions with wall turbulence. *Phys. Fluids* **17**, 2733 (1996).

[2] C. Marchioli and A. Soldati. Mechanism for particle transfer and segregation in a turbulent boundary layer. *J. Fluid Mech.* **468**, 283 (2002).