SWEEP-STICK MECHANISMS OF INERTIAL PARTICLES IN TURBULENCE: A COMPARISON OF VORONOÏ ANALYSIS IN DNS AND EXPERIMENTS.

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Abstract Particle laden flows are of big interest in many industrial and natural systems. When the carrier flow is turbulent, a striking phenomenon called preferential concentration takes place: particles denser than the fluid have the tendency to in-homogeneously distribute in space, forming clusters and depleted regions. We present a study of preferential concentration and clustering in homogeneous and isotropic turbulence based on Voronoï diagrams. We have formerly quantified preferential concentration as a function of the Stokes number (defined as the ratio of the particle viscous relaxation time to dissipation timescale of the flow) in moderate turbulence conditions, up to Reynolds number based on Taylor microscale of the order of $R_\lambda \sim 120$. Using an active grid that was recently implemented in our windtunnel, we investigate the effect of Reynolds number on particles clustering in the range $R_\lambda \sim 200400$. Clustering level is found to be significantly higher than previous measurements at lower Reynolds number. In addition, we present an analysis of the geometry of clusters and voids and investigate the possible connection with stick-sweep mechanisms using direct numerical simulation data of homogeneous isotropic turbulence.

A striking feature of turbulent flows laden with inertial particles is the so-called preferential concentration or clustering that leads to very strong inhomogeneities in the concentration field at any scale. This has now been widely observed in many experimental and numerical realizations including homogeneous and isotropic turbulence[1]. That the concentration field is more intermittent for particles whose Stokes number (defined as the ratio of the particle relaxation time to the Kolmogorov viscous time) is close to unity, is a very robust result of the experiments.

A theoretical description of preferential concentration remains a challenge, and the set of parameters that rules this phenomena remains unknown. Lately, Vassilicos and his collaborators have elaborated a new vision of particle clustering in homogeneous isotropic turbulence (HIT)[2]. In their pioneering work, they show visualizations where a strong correlation is found, in a wide range of scales, between distributions of heavy inertial particles on one hand, and zero-acceleration points on the other.

In this work we compare experimental observations of inertial particle clustering with zero-acceleration points obtained with numerical simulations in HIT. The main goal is to show new phenomena in active grid turbulence and to corroborate the presence of the sweep-stick mechanism.

Experiments are conducted in a large wind tunnel with a square cross-section of 0.75 m x 0.75 m (see figure in table 2). Turbulence is generated with an active grid, capable to produce moderate turbulence with still relatively good homogeneity and isotropy levels. The mean velocity of the wind was varied from 3.4 m/s up to 7.6 m/s, corresponding to a range of Reynolds number R_λ from 230 up to 400. Table 1 summarizes the main turbulence parameters of the flow generated at the measurement volume location (3 m downstream the active grid) for the 6 mean wind velocities investigated. Inertial particles are water droplets generated by 36 injectors (a 6x6 mesh with identical spacing than the grid) located in a transverse plane 15 m downstream the grid. The diameter of the particles is constant for all velocities: $D \sim 60$ μm. A laser sheet of approximately 1 mm lightened the particles. Images were recorded with a high speed camera (Phantom V12 from Vision Research Inc).

Re_λ	U m/s	L (cm)	η (μm)	ϵ m^{3}s^{-3}	St
234	3.4	13.0	280	0.69	2.1
264	4.0	13.2	240	1.2	3.3
295	4.8	13.5	208	2.0	4.3
331	5.7	13.8	178	3.4	5.8
357	6.4	14.0	160	4.0	6.6
400	7.6	14.3	104	7.7	9.9

Table 1. Experimental parameters : Reynolds number based on Taylor microscale (Re_{lambda}), mean wind velocity (U), dissipation scale (η), energy dissipation rate per unit mass (ϵ), Stokes number (St)

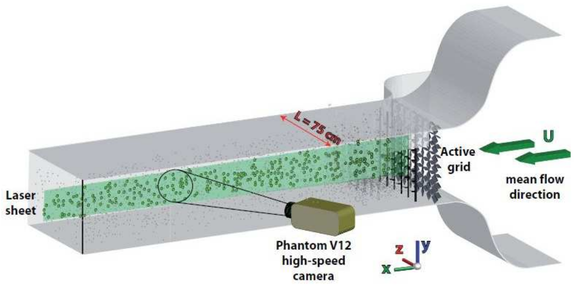

Table 2. Sketch of the experimental setup.

DNS simulations have been performed in order to contrast the experimental results. We have made use of a pseudo-spectral code with random forcing (fore further details see [4]). The simulations have been performed with a grid of

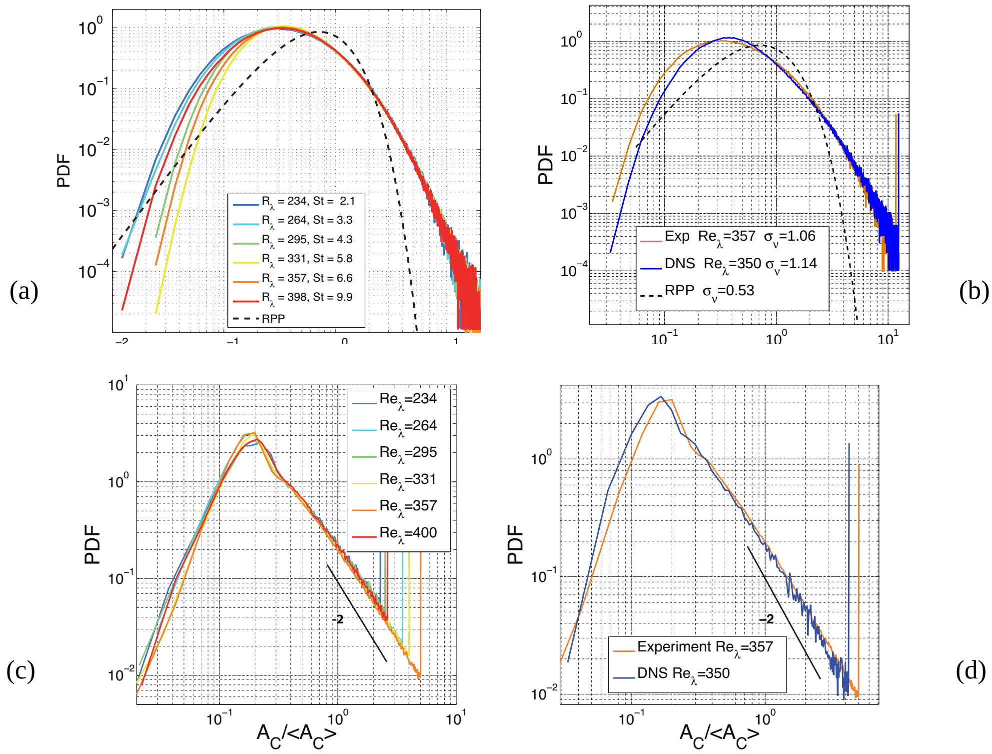

Figure 1. (a) Probability distribution of normalized Voronoï area ν for different Reynolds and Stokes numbers. (b) PDF of normalized Voronoï area ν for the experiment (orange line) and the simulation (blue) for Re_λ 350. In both figures the black dashed line is a RPP distribution. (c) PDF of normalized clusters area for experiments. (d) PDF of clusters area for the experiment (orange line) and the simulation for Re_λ 350 (blue)

512^3 and $Re_\lambda = 350$. This value of Re_λ was chosen very close to the fifth velocity, case compared with the simulation. The Lagrangian acceleration field was calculated and zero-acceleration points were identified. In order to obtain two-dimensional images from the simulation box, sections similar to the experimental laser sheet were extracted.

In a previous work [3], experimental probability distributions (PDFs) of normalized Voronoï area ν have been obtained (as shown in figure 1a). We have superimposed in the figure the distribution expected for a uniform random Poisson process (RPP). Clearly, the measured distribution is not that of a uniform random process. Large Voronoï areas are significantly over-represented compared to the RPP case, case that indicates the existence of large depleted regions. Similarly, areas smaller than $V = 0.5$ are significantly over-represented, indicating the presence of clustering phenomenon. In figure 1b experiments and simulations are compared and a very good agreement is evidenced.

Once that the Voronoï tesselations are obtained, voids and clusters can be identified. A systematic analysis of its areas an perimeters has been performed. Figure 1c shows the experimental PDFs for the different values of Re_λ. All the clusters' areas of the PDFs have a similar behaviour, with a clear peak for $A/ < A >\sim 0.15$. This result suggests that there is a characteristic area of clusters which has not been observed in previous experiments [1]. Once again, there is a very good agreement with the numerics (figure 1d).

To summarize, experimental realizations and DNS has been compared in order to analyse preferential concentration phenomena and its relation with sweep-stick mechanism. Voronoï diagrams allowed us to compare both kinds of results in an easy and non-expensive way. Their clear agreement supports the role of this mechanism in preferential concentration and the pertinence of Voronoï diagrams for this kind of analysis.

References

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