PhD proposal

Clustering and settling dynamics of inertial particles under turbulence

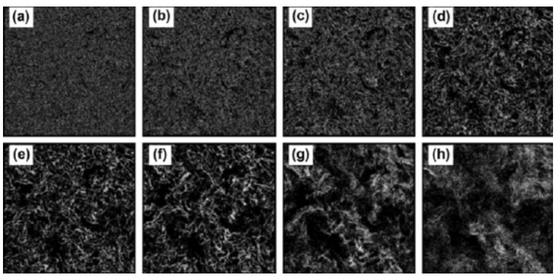
Duration: 3 years, starting 2017.

Location: LEGI (http://www.legi.grenoble-inp.fr/) at Grenoble, France & University of Washington (https://www.washington.edu) at Seattle, USA.

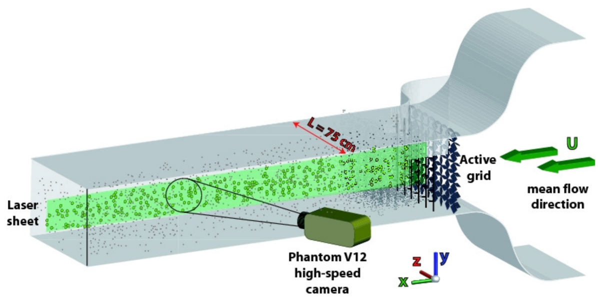
Candidate profile: engineering or physics background with strong formation in fluid mechanics. Interest in experimentation measuring techniques and modelling. Experience using Matlab and/or Python is recommended.

Topic: in spite of its apparent simplicity, the physics of finite size spheres advected by a fluid hides a whole hierarchy of rich imbricated phenomena, some of which are still shrouded in mystery. This is for instance the case when a particle is in a turbulent environment and/or when hydrodynamic couplings emerge between many particles, resulting in subtle collective behaviours. Unveiling the fundamental mechanisms of such phenomena remains crucial to improve our capacity to accurately model and predict particle laden flows. These flows are present in many different processes such as coalescence (rain formation), agglomeration (particles in the atmosphere), settling velocity (sedimentation), chemical transformations (risers), among many others.

All such flow configurations present many open fundamental questions and are subject of great interest in current research. Indeed, because of their higher density compared to the carrier fluid, inertial particles interacting with the underlying turbulence tend to form high (clusters) and low (voids) concentration regions (as exemplified in Fig.1a). These regions span almost the whole range of turbulence scales, i.e. from the Kolmogorov length scale up to the integral length scale or even larger for superclusters, and the widest regions exhibit self-similarity. Such non-trivial spatial organization of particles, a phenomenon referred to as **preferential concentration**, has strong consequences on the flow dynamics by way of momentum exchanges between phases, of velocity fluctuations generation or of collective dynamics, as well as on particle transport and dispersion. Ultimately, these features control the efficiency of all the applications mentioned above.



(a)



(b)

Figure 1: Illustration of the formation of clusters and voids from the simulations of Yoshimoto and Goto 2007 (a) and schema of the experimental set-up at LEGI (b).

This PhD project focuses on the experimental study of inertial spherical particles in wind tunnel grid-generated turbulence. Particles are water droplets generated by a set of injectors. The main challenge of this project is therefore to reach an improved and quantitative understanding of the origin of preferential concentration, of the characteristics of the meso-scale structures and of their consequences on flow dynamics. Particular attention will also be paid to settling velocity

modifications (enhancement or hindering), and the role of different mechanisms on this phenomenon, such as fast tracking or loitering.

Different advances are envisioned:

- On a first stage, measuring campaigns in UGA-LEGI (Grenoble, France) and in Univ. Washington (Seattle, USA) facilities (figure 1b) are envisioned. Measuring techniques such as Phase Doppler interferometry, Particle Image Velocimetry, Phase detection optical probes are already mastered as well as post-processing routines to access drop size, velocity, concentration and combined statistics as done in our former contributions. All the equipment needed is available (except for a new set of injectors and an extra pump needed at LEGI to vary the drop size and the liquid flow rate). **The PhD student will share his/her time between Seattle and Grenoble** to perform and analyze the planed measurements.
- The objective here is to gather new type information from experiments. First, we plan to collect Lagrangian statistics of particle velocity conditioned on the local concentration but also conditioned on the particle size that has never been done. Second, we will attempt to measure the flow field in the vicinity of particles to gather conditional statistics of the settling velocity with the local fluid velocity and acceleration.
- From the results from previous work packages, attempts will be made to derive some ad-hoc modeling to account for particle-turbulence interaction and collective effects on the settling velocity and on dispersion.

The expected outputs are the following: i) clarify the **mechanisms** leading to clusters/voids formation in relation with turbulent flow structures and determine how **clusters/voids characteristics** (size, concentration, shape…) evolve with flow parameters, ii) determine the properties of particles **settling velocity** and how it Is affected by turbulence, iii) identify **scaling law(s) for the settling velocity modification** due to particle-turbulence interactions by disentangling the contributions of fluctuations in velocity and in acceleration of the carrier phase, iv) identify the **effect of volume concentration** on cluster characteristics and on the **competition between collective effects and loitering** and v) establish empirical or phenomenological **models** of these behaviors.

Practical aspects

This project is part of an International Strategic Partnership sponsored by Université Grenoble Alpes, involving A. Cartellier and M. Obligado from LEGI in Grenoble, Prof. A. Aliseda from University of Washington, Prof. C. Vassilicos from Imperial College London and M. Bourgoin from ENS-Lyon (Lyon, France). The PhD candidate will perform experiments in the wind tunnels at LEGI and University of Washington.

Another PhD student, working both at Imperial College London and LEGI will run direct numerical simulations and exploit the collected information, and therefore complement the experimental data acquired. Finally, all the mentioned collaborators will participate in the analysis of data and the development and testing of models.

References

- Aliseda A., Cartellier A., Hainaux F. and Lasheras J., Effect of preferential concentration on the settling velocity of heavy particles in homogeneous isotropic turbulence. J. Fluid Mech., **468**, pp.77-105 (2002).
- Monchaux R., Bourgoin M. and Cartellier A., Analysing preferential concentration and clustering of inertial particles in turbulence. Int. J. Multiphase Flow **40**, 1-18 Review paper (2012).

- Obligado M., Cartellier A. and Bourgoin M., Superclustering of heavy particles in active grid generated turbulence, EPL Europhysics Letters, **112(5),** p. 54004 (2015).
- Sumbekova S., Cartellier A., Aliseda A. and Bourgoin M., Preferential Concentration of Inertial Sub-Kolmogorov Particles. The roles of mass loading of particles, Stokes and Reynolds numbers. Phys. Rev. Fluids **2**, 024302 (2017).

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Applications received until 10/07/2017. For applying send an academic CV to M. Obligado and/or A. Cartellier.