INVESTIGATING THE INTERACTION BETWEEN TURBULENT FLOWS AND SUSPENDED PARTICLES WITH THE AID OF INVARIANT SOLUTIONS

Markus Uhlmann[1], Tiago Pestana[1], Michael Krayer[1] and Genta Kawahara[2]
[1]*Institute for Hydromechanics, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany.*
E-mail: markus.uhlmann@kit.edu, tiago.pestana@kit.edu, michael.krayer@kit.edu
[2]*Graduate School of Engineering Science, Osaka University, Osaka 560-8531, Japan*
E-mail: kawahara@me.es.osaka-u.ac.jp

Particulate flow systems exhibit a number of puzzling phenomena with important practical consequences. One prominent example is their non-trivial spatial distribution which sometimes manifests itself in the form of clustering and/or preferential concentration with respect to turbulent flow structures [1]. This “de-mixing” of the dispersed phase can significantly affect the operation of diverse processes, such as chemical reactions, heat transfer, growth of droplets in clouds, etc. Modern laboratory experiments and high-fidelity numerical simulations have enabled researchers to gather an enormous wealth of data, with the aid of which a number of aspects pertaining to particle-turbulence interaction have already been elucidated. However, many other questions still elude our understanding, e.g. how to disentangle the roles of density and particle size in determining the particle dynamics.

In order to simplify the problem, we propose to study particles suspended in simple invariant solutions (equilibria, periodic orbits) to the Navier-Stokes equations. Since these flows are believed to be relevant to turbulence [2], they allow us to design tractable numerical laboratories for the investigation of particle dynamics. In a first step we have demonstrated the feasibility of this approach by using Nagata’s equilibrium solution in Couette flow for this purpose [3]. It could be shown that the well-known focusing of heavy particles into low-speed streaks (and subsequent apparent velocity lag) can be captured in this manner. Subsequently we have started to explore a number of solutions in different flow configurations: open channel flow, rectangular duct flow, homogeneous flow under different types of forcing. In addition to using equilibrium solutions, we have also employed periodic orbits, both in wall-bounded and unbounded flows.

At the workshop we are going to report on our ongoing research in this direction. We will discuss the stability of the respective invariant solutions with respect to the addition of finite-size particles, as well as our attempts to extract new physics from these systems.

Figure 1. Trajectory of a spherical particle (diameter $D/h = 0.16$, density ratio $\rho_p/\rho_f = 10$) suspended in the “gentle” Couette periodic orbit of [4] at $Re = 250$ and zero gravity. The temporal interval corresponds to approximately 500 bulk time units. The view is into the streamwise direction (left) and into the span (right); the grey-colored boxes indicate the domain size, while the trajectory is unwrapped in the periodic directions.

References

[1] S. Balachandar and J.K. Eaton. Turbulent dispersed multiphase flow. *Ann. Rev. Fluid Mech.*, 42:111–133, 2010.
[2] G. Kawahara, M. Uhlmann, and L. van Veen. The significance of simple invariant solutions in turbulent flows. *Ann. Rev. Fluid Mech.*, 44:203–225, 2012.
[3] T. Pestana, M. Uhlmann, and G. Kawahara. Can preferential concentration of finite-size particles in plane Couette turbulence be reproduced with the aid of equilibrium solutions? *Phys. Rev. Fluids*, 5:034305, 2020.
[4] G. Kawahara and S. Kida. Periodic motion embedded in plane Couette turbulence: regeneration cycle and burst. *J. Fluid Mech.*, 49:291–300, 2001.