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Very heavy particles in incompressible flows: the large Stokes number asymptotics

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Particles, as e.g. pollutants, are usually characterized by their finite size and mass density that typically differ from that of the surrounding fluid, think to dust in the atmosphere. Interestingly they do not evolve as simple (point-like) fluid tracers, and possess inertia whence the name “inertial particles”. They are commonly encountered in geophysical and even astronomical fluids (such as dust in the solar system).

When such particles are smaller than the smallest active scale of the flow (e.g. the Kolmogorov length-scale in turbulent flows) and denser than the fluid it is possible to write a very simple evolution law for their velocity. Indeed the particle velocity is simply relaxing to the fluid one with a Stokes time τ. We are here interested to the case in which such time scale is much larger than any time scale of the flow. In this limit, particles behave as if suspended in a Gaussian δ-correlated in time flow.

The focus is here put on two-particle motion at very small scales, i.e. we analyse the case in which the fluid velocity field can be considered as differentiable. In this condition, and assuming incompressible homogeneous and isotropic carrier flows, the particle dynamics is shown to depend on a single parameter, the Stokes number St, defined as the time τ non-dimensionalized by the typical gradient of the fluid velocity. Studying two-particles motion is relevant to understand collisions between particles, which is important for example in rain formation. Moreover, it allows for catching the salient features and the basicmechanisms of particle clustering which is one of the most well known phenomenological and experimental facts about inertial particles, which is typically dubbed *preferential concentration.*

Following an approach originally devised by Piterbarg [SIAM Journal on Applied Mathematics 62 (2001) 777] for simplifying a model for the motion buoyant particles in the ocean, we reduce the two particle dynamics to a non-linear system of three stochastic differential equations with constant diffusion. This reduced dynamics represents one of the simplest models for heavy particles. Mostly considering two dimensional flows, we reinterpret the long known phenomenon of preferential concentration, i.e. the inhomogeneous and fractal spatial distribution of particles, within this approach. The assumptions at the basis of this model are physically relevant when $St \gg 1$. Scaling arguments are used to predict the behavior in this asymptotics of the Lyapunov exponent and the distribution of the stretching rate are predicted. Moreover, the probability distribution function of the longitudinal velocity difference between two particles is shown to have power law tails with exponent -3, which is related to the events when the particles approach very close to each other. Finally, simulations at small and intermediate Stokes numbers reveal that the investigated model catches most of the qualitative features of particle clustering observed in realistic flows.