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Preferential concentrations of finite-size massive particles by turbulence

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In a turbulent flow vortexes act as centrifuges ejecting particles heavier than the fluid and entrapping lighter ones. Since Maxey (1987)[1] and Squires & Eaton (1991)[2], this phenomenon has been dubbed *preferential concentration*. Recently, tools borrowed from the theory of dynamical systems have been adopted to gain better insight into the problem and raised a renewed interest [3],[4].

We present new results from a series of direct numerical simulations where collisionless suspensions of particles of variable density and size are tracked in a incompressible homogenous isotropic turbulent flow. The equation of motion we adopt is the following:

$$\ddot{\mathbf{x}} = \beta \left(\partial_t \mathbf{u} + (\mathbf{u} \cdot \partial)\mathbf{u} \right) - \left(\dot{\mathbf{x}} - \mathbf{u} \right) / \tau \qquad (1)$$

where $\beta \equiv 3\rho_f/(\rho_f + 2\rho_p)$ and $\tau \equiv a^2/(3\beta\nu)$, with ρ_f and ρ_p respectively fluid and particle densities, a the particle's radius, ν kinematic viscosity. We track up to 500 sets of particles, corresponding to couples of values in the parameter-phase-space β-St, where $St \equiv \tau/\tau_\eta$ stands for the Stokes number and τ_η is the dissipative time-scale. The total number of particles ranges between $10^7 - 10^8$. Numerics are performed at different resolutions, 64^3,128^3,512^3, corresponding to $Re_\lambda = 60, 87, 185$.

We study Lyapunov exponents of infinitesimal separations in the position-velocity phase space, Kaplan-Yorke (d_{KY}) and Correlation dimension. Particle spatial distributions are also contrasted by looking at their relative concentration conditioned to the local topology of the flow field. Heavy particles are shown to concentrate up to $\sim 60\%$ in high-strain regions, while extremely light particles concentrate up to $\sim 90\%$ in elliptic regions. Acceleration statistics is finally addressed. In particular acceleration probability density functions and a detailed map, in the β-St parameter-space, of the root mean square acceleration values have been measured. We observe that light particles acceleration display larger level of intermittency as compared to fluid passive tracers, while heavy particles acceleration is less intermittent.

References

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