

Stochastic modelling for coupled acceleration and velocity gradient in isotropic turbulence

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In an industrial setting, the evolution of a dispersed phase in turbulent flows is a major issue for the design of efficient combustion chambers and chemical reactors, as well as for predicting pollutant dispersion in the atmosphere. Its accurate description depends strongly on the smallest scales, which are computationally very expensive to resolve and are therefore often neglected. The influence of these scales can be incorporated by complementing Eulerian simulations with a Lagrangian model for the subgrid dynamics. In this context, stochastic models have been developed to describe the Lagrangian evolution of the fluid velocity ([1]), acceleration ([2]), and velocity gradient ([3]). Despite substantial progress in modelling each of these variables separately, no model currently exists that captures their joint evolution. This is a significant gap, as the coupling between velocity, velocity gradients, and acceleration is crucial for accurately describing the dynamics of inertial particles in turbulence, which preferentially sample regions of high strain and low vorticity.

Within this framework, we propose the following stochastic differential equation model :

$$\begin{aligned}dG_{ij} &= f_{ij}(\mathbb{G}, \mathbf{a}, \mathbf{u}) dt + g_{ijkl}(\mathbb{G}, \mathbf{a}, \mathbf{u}) dW_{kl}(t), \\da_i &= h_i(\mathbb{G}, \mathbf{a}, \mathbf{u}) dt + k_{ij}(\mathbb{G}, \mathbf{a}, \mathbf{u}) dW_j(t), \\du_i &= a_i dt,\end{aligned}$$

with \mathbb{G} the velocity gradient tensor, \mathbf{a} the acceleration, \mathbf{u} the velocity, and dW_j and dW_{kl} Wiener increments. The originality of the present work lies in the construction of the functions f_{ij} , g_{ijkl} , h_i and k_{ij} , which enforce the correct coupling between velocity, velocity gradients, and acceleration. They are calibrated from conditional averages extracted from DNS of homogeneous isotropic turbulence up to $Re_\lambda = 200$. The resulting multiplicative model reproduces the non-Gaussian statistics of acceleration and velocity gradients, and also yields the correct alignment between acceleration and the eigenframe of the velocity gradient tensor, which is important for modeling preferential sampling of inertial particles in turbulence.

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