TUMBLING RATES IN TURBULENT AND RANDOM FLOWS

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Abstract We analyse the tumbling of small non-spherical particles in random flows with finite correlation length and time. The orientational dynamics can be systematically analysed in terms of a perturbation expansion in the Kubo number, a dimensionless measure of the correlation time of the flow. We compare our results to those of experimental and numerical studies of tumbling in turbulent flows.

The dynamics of turbulent aerosols (suspensions of particles in turbulent flows) is important for the understanding of key processes in the Natural Sciences and Technology (turbulent rain clouds, planet formation in circumstellar accretion disks, and fibre suspensions, to name but a few). In recent years our understanding of the dynamics of turbulent aerosols has increased substantially, by means of direct numerical simulations, and by model calculations - often based on idealised models of the underlying flow and of the interactions between the flow and the particles. The analysis of models of spherical particles moving subject to Stokes force in random flows (with the appropriate statistics) has contributed to our understanding of the fundamental mechanisms giving rise to spatial clustering and collisions between spherical point particles suspended in such flows.

Less is known about the dynamics of asymmetrical, non-spherical particles, despite the fact that non-spherical particles are of interest in a wide range of contexts. For example, tumbling ice particles in turbulent clouds may play an important role in cloud-particle interactions [8]. Dust grains in circumstellar accretion disks are not spherically symmetric [7] and the relative orientation at which such grains collide may have important consequences for the outcome of the collision process. The competition between tumbling and rotational diffusion of non-spherical particles determines the rheology of fibrous suspensions [4, 2, 6]. Patterns of non-spherical particles suspended in random flows were investigated in [9, 1, 10], identifying singularities in the orientational patterns of rheoscopic suspensions.

Recently, the tumbling rate of small particles in turbulent flows was investigated experimentally and by means of direct numerical simulations [5]. It was found that disks tumble, on average, at a much higher rate than rods, and this fact was related to the observation that rods tend to preferentially align with the vorticity of the flow (see [11] and references cited therein).

Here we analyse the tumbling of small non-spherical particles in random flows with finite correlation length and time. We analyse the orientational dynamics systematically in terms of a perturbation expansion in the Kubo number [3]. This makes it possible to address the following questions. First, how and when do disks and rods tumble differently? How does the nature of the Lagrangian flow statistics influence the tumbling? What is the effect of inertia on the orientational dynamics of small particles? We compare the results to those of recent experimental and numerical studies of non-spherical particles tumbling in turbulent flows.

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