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BREAKUP OF INERTIAL PARTICLES DUE TO VISCOUS SHEAR AND DRAG STRESS IN TURBULENCE

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Abstract:
Breakup of aggregates and clusters of loosely bond particles due to hydrodynamic stress is an important process in many technical and natural applications, including e.g. processing of nanoparticles, production of graphene by hydrodynamic exfoliation, fragmentation of marine snow, etc. Turbulence in the dispersing fluid plays a distinct role in the breakup of aggregates. On the one hand side, velocity gradients caused by the turbulent fluid motion generate viscous shear stress acting on the aggregates. On the other hand, differences in the velocity between the aggregate and the surrounding fluid generate a drag stress acting on the aggregate.

In a previous work we considered tracer-like aggregates for which the hydrodynamic stress is dominated by viscous shear stress [1]. Assuming the aggregates to be brittle such that breakup is instantaneous once the shear stress exceeds a critical threshold value, we derived breakup frequencies by monitoring the viscous shear stress along tracer trajectories obtained from a DNS of a homogenous isotropic turbulent flow field.

In this work we extend our analysis to small aggregates whose density differs from the fluid density. The aggregates are assumed to be small or comparable to the the viscous length scale of the flow and to have a spherical shape. From a kinematic point of view, such aggregates resemble inertial particles whose dynamics is described by a reduced Maxey-Riley equation $\dot{\boldsymbol{v}} = \beta D\boldsymbol{u}/Dt + 1/\tau_p[(\boldsymbol{u}-\boldsymbol{v})]$, where $\boldsymbol{v}$ and $\boldsymbol{u}$ are the particle and fluid velocity, respectively, τ_p is the particle relaxation time and $\beta = 3\rho_f/(\rho_f + 2\rho_p)$ is a buoyancy parameter, where ρ_p and ρ_f are the particle and fluid density, respectively. We analyze a large dataset of particle trajectories obtained from evolving the Maxey-Riley equation in homogeneous isotropic turbulence [2, 3]. By monitoring the shear stress and the drag stress along these trajectories we derived the time-lag between the release of the aggregate and its breakup, caused by the first occurrence of a total stress that exceeds the breakup threshold for the aggregate. Furthermore, by Stokesian dynamics simulations we analyzed the effect of drag and shear on the mechanical stress distribution in the aggregate structure.

Results show that (*i*) the breakup of neutrally buoyant aggregates ($\beta = 1$) is dominated by viscous shear stress, thus confirming the common assumption in the modeling of breakup of small aggregates in liquid suspensions. (*ii*) A small density mismatch gives rise to a drag stress that rapidly becomes dominant as β is deviating from 1. Indeed, contrasting the parameter values from our analysis to real world systems, we conclude that many particle systems, such as e.g. crystal suspensions in pharmaceutical crystallization, or bubble in liquid-gas systems fall in the region where drag stress are relevant, an aspect which has been widely overlooked in the modeling of such systems. (*iii*) Stokesian dynamics can be effectively used to study the redistribution of the hydrodynamic stress on the aggregate structure to possibly infer the breakup mechanism.
Finally, our work aims at completing the picture of the breakup of small and brittle aggregates in turbulent flows.

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References

[1] Bäbler M. U., Biferale L. & Lanotte A. S., *Breakup of small aggregates driven by turbulent hydrodynamical stress*, Physical Review E, **85**, 025301, (2012).

[2] Calzavarini, E., Cencini M., Lohse D. & Toschi F., *Quantifying turbulence-induced segregation of inertial particles*, Physical Review Letters, **101**, 084504, (2008).

[3] Bec J., Biferale L., Lanotte A. S., Scagliarini A., & Toschi, F. *Turbulent pair dispersion of inertial particles*, Journal of Fluid Mechanics, **645**, 497-528, (2010).