Microbubbles and turbulence: towards a modelling of the mechanisms of drag reduction

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Abstract :

Friction reduction in turbulent flows is a major challenge for controlling the energy consumption of transport systems and industrial processes. The injection of microbubbles can reduce wall drag, but the mechanisms linking the bubble distribution to the dynamics of turbulence remain poorly understood. This project aims to characterise the preferential concentration of microbubbles in vortical structures and to develop a description of their influence on vorticity. A six-month Master 2 internship will first exploit an existing numerical database of microbubble trajectories in homogeneous isotropic turbulence, in order to identify correlations between bubble distribution, vortex stretching and enstrophy production. On this basis, a model will be proposed and then adapted to channel turbulence simulated with OpenFOAM. The effects of the Reynolds and Stokes numbers will be examined. The results will constitute a first step towards predictive models of bubble-turbulence interactions and, in the longer term, towards the optimisation of drag reduction strategies.

Project description

Scientific challenge and originality

Turbulent flows encountered in pipes, hydraulic circuits and transport systems dissipate a significant part of the supplied energy in the form of friction. The addition of microbubbles is a promising route to drag reduction, whose understanding requires establishing how bubbles distribute themselves relative to the coherent structures of the flow. The proposed approach focuses on the analysis of vorticity and its stretching, rather than on a purely statistical description of the velocity field. It thus establishes a direct link between preferential concentration and the mechanisms of enstrophy production.

Scientific approach and internship programme

The first component will consist in analysing an already available numerical database containing microbubble trajectories in homogeneous isotropic turbulence (HIT). The student will identify the vortical structures, in particular using the Q-criterion, then quantify the conditional distribution of the bubbles and its relations with vorticity and vortex stretching. These results will be used to propose a model for the evolution of vorticity in the presence of microbubbles.

The second component will address the adaptation of this approach to a turbulent channel flow simulated with OpenFOAM. The microbubbles will be represented as point particles of low density, with their feedback on the fluid taken into account within the framework of the envisaged modelling. The study will seek to determine how the presence of walls and the variation of the Reynolds and Stokes numbers influence the accumulation of bubbles and the dynamics of the coherent structures.

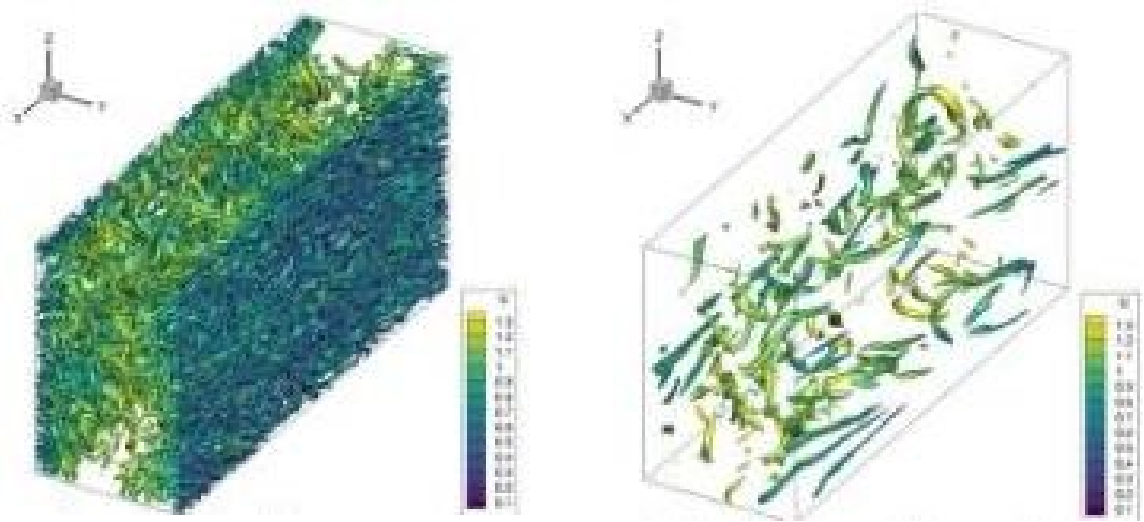


Figure 1 – Isosurfaces of the Q-criterion in a turbulent channel: (a) reference flow; (b) flow with reduced vortex stretching.

Expected results and contribution to the GI-EIF

The project will produce quantitative indicators of preferential concentration, a first model formulation in HIT and its assessment in a wall-bounded flow. It will contribute to connecting the fundamental mechanisms of bubble-turbulence interactions with the challenge of controlling friction losses, which is relevant to the energy efficiency of industrial installations. The internship can serve as a starting point for subsequent studies on finite-size effects and effective drag reduction.

References

Marie, J.-L. (1987). A simple analytical formulation for microbubble drag reduction. PhysicoChemical Hydrodynamics, 8, 213-220.

Bos, W. J. T. (2021). Three-dimensional turbulence without vortex stretching. Journal of Fluid Mechanics, 915, A121.

Procaccia, I., Lvov, V. S. & Benzi, R. (2008). Theory of drag reduction by polymers in wall-bounded turbulence. Reviews of Modern Physics, 80, 225-247.