INTERACTION BETWEEN A LARGE BUBBLE AND TURBULENCE

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Abstract Bubble dynamics in turbulent flows has been extensively studied using the point-bubble approximation. But when the carrier flow varies on length scales smaller than the bubble size, this approximation is no longer appropriate and one needs to resolve all the scales present in the two-phase flow. 3D Direct Numerical Simulations of turbulent bubbly flows are carried out for bubbles ten times larger than the Kolmogorov length scale. The dynamics of large bubbles subjected to homogeneous isotropic turbulence and the turbulence modulation induced by their presence are investigated by mean of conditional statistics.

Keywords: finite-size bubbles, turbulence modulation, interphase coupling.

MOTIVATIONS

The ability to describe the behavior of turbulent bubbly flows is crucial to design and operate industrial equipment for a wide range of applications (oil/gas transport, nuclear reactors, CO_2 capture). However one is bound to rely on empirical correlations to predict the behavior of such systems. Turbulence and multiphase flows are two of the most challenging topics in fluid mechanics, and their coupling is an issue wide open for fundamental investigation [1]. As the presence of the dispersed phase makes experimental measurements difficult, numerical simulations have become a valuable tool to explore the physics of turbulent bubbly flows.

The standard approach for the simulation of turbulent dispersed flows is based on the Eulerian description of the carrier phase while bubbles are tracked in a Lagrangian fashion. The bubbles equation of motion is derived from a force balance established under the assumption that bubbles length and time scales are much smaller than those of the surrounding flow [5]. In such situations the point-bubble approximation is appropriate and has been used to investigate the dynamics of small bubbles in turbulent flows [7].

But in many situations of practical interest, bubbles interact with turbulent structures whose size is smaller than that of the bubbles. Parameters such as bubble-to-liquid length and time scales ratios, as well as turbulence intensity and interface deformation can be expected to play a key role in bubble dynamics. As the carrier flow is not uniform at the scale of the bubble, the notion of slip velocity must be revisited to extend existing models to finite-size bubbles. This issue has been recently addressed in the case of solid particles [6, 2]. In addition, the backreaction of the bubbles on the surrounding flow must be included in the description of the carrier phase (two-way coupling). The influence of finite-size solid spherical particles on turbulence has been the subject of several recent studies [6, 4]. It was found that turbulence statistics are modified over a region that extends much further than the viscous layer, therefore particles may interact even at relatively low volume fraction (four-way coupling). While it is well-established that bubbles can also modify turbulence in their surroundings, the mechanisms of turbulence modulation and their parametric dependence are poorly understood [1].

As compared to solid particles, the understanding of the interactions between large fluid particles and turbulence is very sparse and to the best of our knowledge, no similar investigations have been carried out for bubbles. The present study contributes to filling this gap.

METHODS

Simulating the interactions between large bubbles and turbulence requires resolving the flow down to Kolmogorov scale as well as the smallest scale of the disturbances induced by the presence of bubbles. For that purpose we developed a DNS code which solves both the liquid and the gas flow in a periodic 3D domain. The interface is captured by a level-set method and is free to deform, and surface tension is accounted for. Statistically stationary homogeneous isotropic turbulence is sustained by a linear forcing in the liquid phase. The two-phase flow code has been validated against [3], amongst others. In the absence of carrier phase turbulence, the dynamics of bubbles is fully determined by a set of five dimensionless groups: the Reynolds number, the Weber number, the density ratio, the viscosity ratio, and the volume fraction of bubbles. Once these parameters are set, turbulence intensity is determined by a single additional parameter related to the forcing.

Simulations of turbulent bubbly flows with $Re_\lambda = 32$ were carried out for a bubble that would otherwise be spherical or ellipsoidal and rise in quiescent liquid at $Re_b = d_b\, U_{\text{rise}}/\nu$ between 10 and 60, where d_b is the bubble diameter, U_{rise} is its terminal rise velocity, and ν is the liquid kinematic viscosity. The density and viscosity ratios are that of air/water (10^{-3} and 10^{-2}, respectively), and the domain size was chosen so that periodicity does not affect the bubble and its surroundings. Turbulence intensity, defined as $\beta = u'_{\text{rms}}/U_{\text{rise}}$ where u'_{rms} is the root mean square of liquid velocity fluctuations, is of order 1. The bubble-to-turbulence length scales ratios are such that $d_b = 10\,\eta = 0.94\,\lambda = 0.44\,L$.

RESULTS

This setup allows us to investigate the dynamics of bubbles subjected to homogeneous isotropic turbulence and the mechanisms of turbulence modification induced by the presence of bubbles of size larger than the Kolmogorov length scale. A sample simulation is illustrated in Fig. 1. A significant reduction of the bubble rise velocity compared to its value in still liquid has been observed, similarly to what was obtained for point bubbles. The role of lift forces and vortex trapping is assessed and compared to the case of microbubbles [7]. Interphase coupling is studied through statistics conditioned on the presence of a bubble and presented in polar coordinates with the origin taken as the bubble center of mass and the vertical axis oriented along the bubble instantaneous velocity. The applicability of the notion of slip velocity similar to that defined for finite-size solid particles by [6, 2] is evaluated in the present case. The modification of turbulence in the bubble surroundings is investigated through Eulerian statistics of the liquid phase conditioned on the distance to the interface and on the upstream, downstream and transversal sectors. Results are compared to those obtained for solid particles in [6, 4, 2].

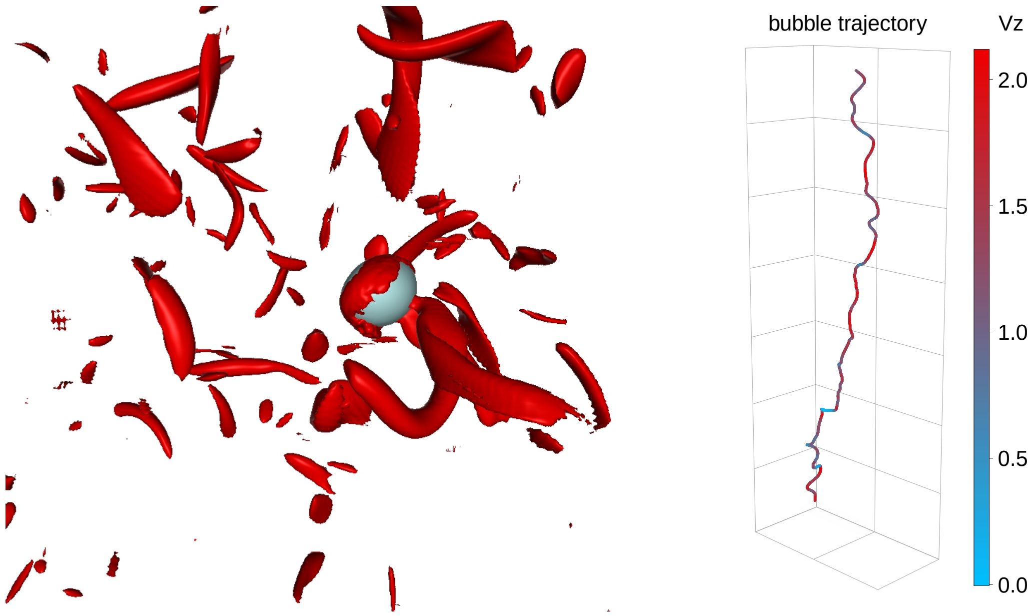

Figure 1. Left: instantaneous enstrophy isocontours (red) and bubble shape (blue-gray). Right: sample bubble trajectory (color coding corresponds to bubble vertical velocity).

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