Bubble breakup probability in turbulence

Aliénor Rivière[1], Stéphane Perrard[1]

PMMH, ESPCI, 10 rue Vauquelin, 75005, Paris
`alienor.riviere@espci.fr`

Bubbles play a crucial role in mass transport across interfaces. By increasing the surface of exchange they lead chemical and gas transfers in various industrial processes, as homogenizers, and geophysical situations, such as rivers, waterfalls and oceans. Since the gas exchanges are bubble size dependent, predicting breakups is central to first understand the bubble size distribution and then quantify the transfers. In turbulence, bubble fate is controlled by the ratio between inertial and capillary forces, namely, the Weber number, We. Bubbles tend to deform for large We, while they are statistically stable for low We. The limit between these two regimes is defined in a statistical sense as, in theory, any bubble can encounter a large enough pressure fluctuation and break.

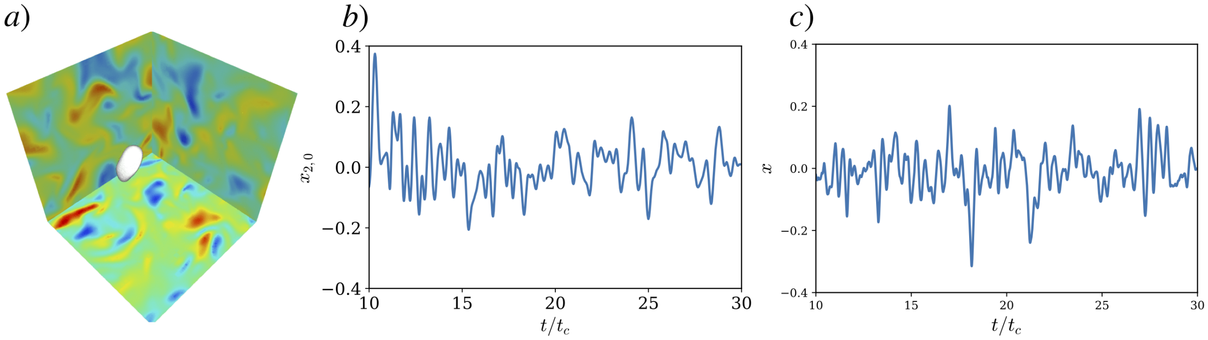

Figure 1. a) Snapshot of a bubble in a turbulent flow. The bubble is in white. The velocity field can be visualized with the three background planes. b) Typical temporal evolution of the mode $(2,0)$ at We $= 0.71$ in the DNS. c) Typical temporal evolution given by our reduced linear model for the same Weber number.

Using direct numerical simulations (DNS) of a single bubble in an homogeneous and isotropic turbulent flow, we quantify the probability that a bubble breaks within a time window by modeling bubble deformations. We decompose the bubble surface onto the spherical harmonics base and show that each mode stochastic dynamics can be well described by a damped linear oscillator randomly forced by turbulence. We measure the values of the natural frequency and the damping factor, together with the statistical properties of the stochastic forcing. Then, by simulating these reduced dynamics for the five most relevant bubble modes, corresponding to oblate-prolate oscillations, we show that bubble breakup in turbulence is a memoryless process. The associated breakup rate varies exponentially with We^{-1} suggesting a mechanism of random activation process, which has been similarly observed in drop breakups [1]. Eventually, we find a quantitative agreement between our predicted breakup rate and several experimental datasets on bubble breakups. Our model can then be used to quantify the probability for a bubble to break, in homogeneous turbulence as well as in more realistic turbulent flows, which are non stationary and inhomogeneous.

References

1. A. Vela-Martín, M., Avila, M., *Science Advances*, **8 (50)**, p.eabp9561 (2022)