Bubble break-up is always sub-critical

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Bubble fragmentation in turbulent flows controls gas transfers at the ocean-atmosphere interface [1]. Nevertheless, characterizing the flow-interface coupling that leads to break-up remains challenging both experimentally and numerically, even in simpler geometries. Inspired by Masuk and co-authors [2], we identify the uni-axial straining flow as the main geometry leading to break-up at high Reynolds number, Re (ratio between kinetic and viscous forces). Since the original work of Miksis [4], the stationary bubble shapes in this flow have been studied extensively as a function of the Weber number, We, ratio of kinetic forces and surface tension forces. They lead to the identification of a critical Weber, We_c^S, separating stable, $\mathrm{We} < \mathrm{We}_c^S$, from unstable bubbles, $\mathrm{We} > \mathrm{We}_c^S$.

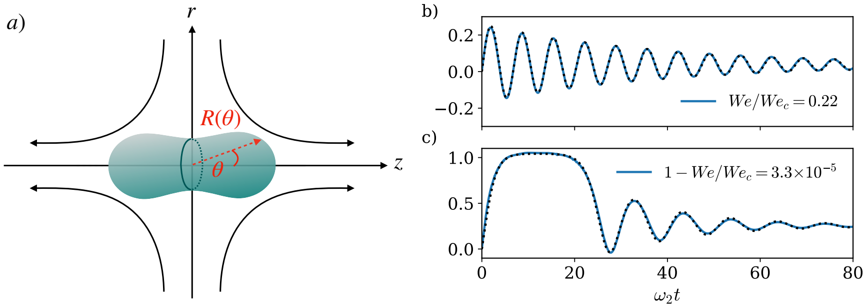

Figure 1. a) Bubble in a uni-axial extensional flow. Arrows are typical streamlines in the absence of bubble. b) and c) Amplitude of the second Rayleigh mode, far from We_c, (b), and close to We_c, (c), at $\mathrm{Re} = 400$. ω_2 is the mode pulsation. The model (1) is super-imposed (black dotted line) and perfectly reproduces the dynamics.

Through direct numerical simulations starting from a sphere, we show that the dynamical break-up threshold, We_c, is always significantly smaller than We_c^S. Indeed, bubble break-up is in reality sub-critical and the transition must be described dynamically. We describe the whole interface dynamics by a one dimensional non-linear oscillator on the amplitude x of the second Rayleigh mode of oscillations [3]:

$$\ddot{x} + \lambda \dot{x} = -\nabla V(x) \tag{1}$$

where λ is the damping factor, and V a non linear potential with non trivial dependency on the initial shapes. We show that this one-dimensional model perfectly captures the dynamics, both far from We_c (see black dotted line in figure 1b) and close to We_c (same in figure 1c). This model can then be applied to predict bubble deformations and lifetime in more complex turbulent flows.

References

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