From turbulent to laminar bubble breakup: capillary splitting of gas filaments

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At the ocean-atmosphere interface, breaking waves generate bubbles which then drive low-solubility gas transfers, such as O_2 [1]. They are also responsible for up to 40% of the CO_2 transfer from the atmosphere to the oceans [2]. Below breaking waves, the bubble size distribution (BSD) exhibits two power-law scalings separated by a critical size, called the Kolmogorov-Hinze scale d_h at which inertial forces balance in average capillary forces. Bubbles smaller than d_h, are statistically stable and their distribution follows $d^{-3/2}$, while bubbles larger than d_h can still break and their distribution follows $d^{-10/3}$. We showed previously that sub-Hinze bubbles are produced via the capillary splitting of gas filaments generated during the inertial deformations of super-Hinze bubbles [3]. In this work we build a numerical simulation, using Basilisk, to characterize filaments generation and their subsequent splitting.

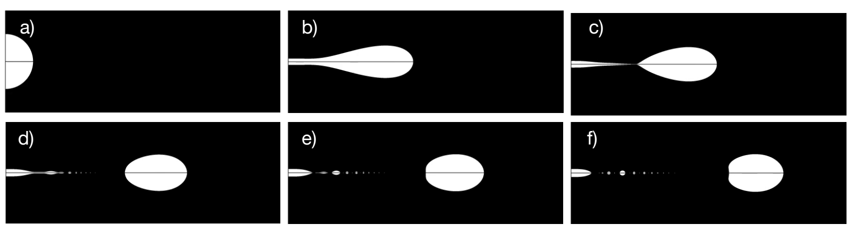

Figure 1. Enlargement around a typical temporal evolution of an axi-symmetric gas bubble (in white), at the center of a uniaxial straining flow. The axis of symmetry is the horizontal axis. The flow goes from top and bottom to the right. The initially spherical bubble deforms (a-c) and breaks (d), creating an elongated structure, a filament, which subsequently breaks into dozens of child bubbles with varying sizes (e-i).

We consider an axi-symmetric bubble fixed at the center of a uniaxial straining flow, a typical flow geometry encountered around breaking bubbles in turbulent flows. In this numerical set-up, when the bubble breaks, it creates a filament (fig. 1). The filament length and width increase with decreasing Reynolds number, Re, the ratio between inertial and viscous forces at the bubble scale. Strikingly, when Re is sufficiently low ($\mathrm{Re} < O(100)$) so that we can resolve numerically the filament splitting dynamics, we find that the splitting of a single filament generates a distribution following $d^{-3/2}$. We propose a deterministic model based on geometrical considerations and capillary effects which explains the physical origin of this distribution. We conclude that the BSD observed below breaking waves for sub-Hinze bubbles arises as the sum of the BSD of hundreds of filaments which all produce a $d^{-3/2}$-distribution.

References

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