Floating bubbles: a prelude to bursting

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Abstract:

Interfacial phenomena involving the interaction of gas bubbles with the free surface are widespread in practice, for example, as seen at the ocean-atmosphere interface and in a glass of champagne. In such settings, following the birth of bubbles, they rise to the free surface and burst, creating droplets. However, before bursting, they float at the liquid-gas interface. Based on the size of the bubbles, the floating state produces various steady bubble shapes. Moreover, contaminated interfaces can keep bubbles floating for extended times and lead to the appearance of foam. Thus, from both fundamental and application standpoints, examining bubble shapes in the floating state and quantifying their geometrical features is crucial. For an isolated floating bubble, the steady shape can be derived by iteratively solving balance equations of pressure and surface tension across different interfacial regions, namely the bubble cavity, spherical cap, and meniscus. However, this approach becomes impractical as multiple bubbles are introduced. To circumvent this, we rely on direct numerical simulations, where we represent the free surface and individual bubbles using separate volume fraction fields, which allows us to prevent numerical coalescence without using excessive grid resolution. We first validate our numerical implementation with the shapes of isolated bubbles of different sizes. Subsequently, we present the shapes of two vertically aligned floating bubbles of varying sizes and the geometry of raft-like structures emerging from multiple bubbles dispersed along the free surface.

Keywords: bubbles, free surface

Introduction:

The formation of film and jet droplets from bursting bubbles has been widely studied in the literature [1, 2, 3]. However, very little attention is paid to the stage prior to the bursting, which is the floating state. The floating state is sustained by a thin liquid film between the free surface and the top of the bubble. Typically, these liquid films are orders of magnitude thinner than the bubble size. The sudden breakup of the film, which is observed in relatively small bubbles, gives rise to a liquid jet, which breaks and forms droplets. On the other hand, in the case of relatively large bubbles, droplets form through the fragmentation of the liquid film. However, irrespective of the bubble size, interfacial impurities can significantly delay the film breakup, resulting in extremely stable floating bubbles.

Numerical Methods:

The primary challenge in simulating floating bubbles is the high grid resolution required to resolve the thin liquid film at the top of the bubble. However, the influence of the film's weight on the bubble shape can be neglected since the film thickness is orders of magnitude smaller than the bubble radius [1]. This assumption of a weightless film simplifies the problem. Nonetheless, preventing the bubble from coalescing with the free surface in numerical simulations using interface capturing methods is not straightforward. To address this, we use a volume-of-fluid (VOF) implementation that employs separate volume fraction fields for each phase boundary in the system. Our multi-VOF strategy is implemented using the Basilisk flow solver [4].

Discussion and closing remarks:

Figure 1 presents one of the cases from our multi-VOF simulations for a pair of floating bubbles. Due

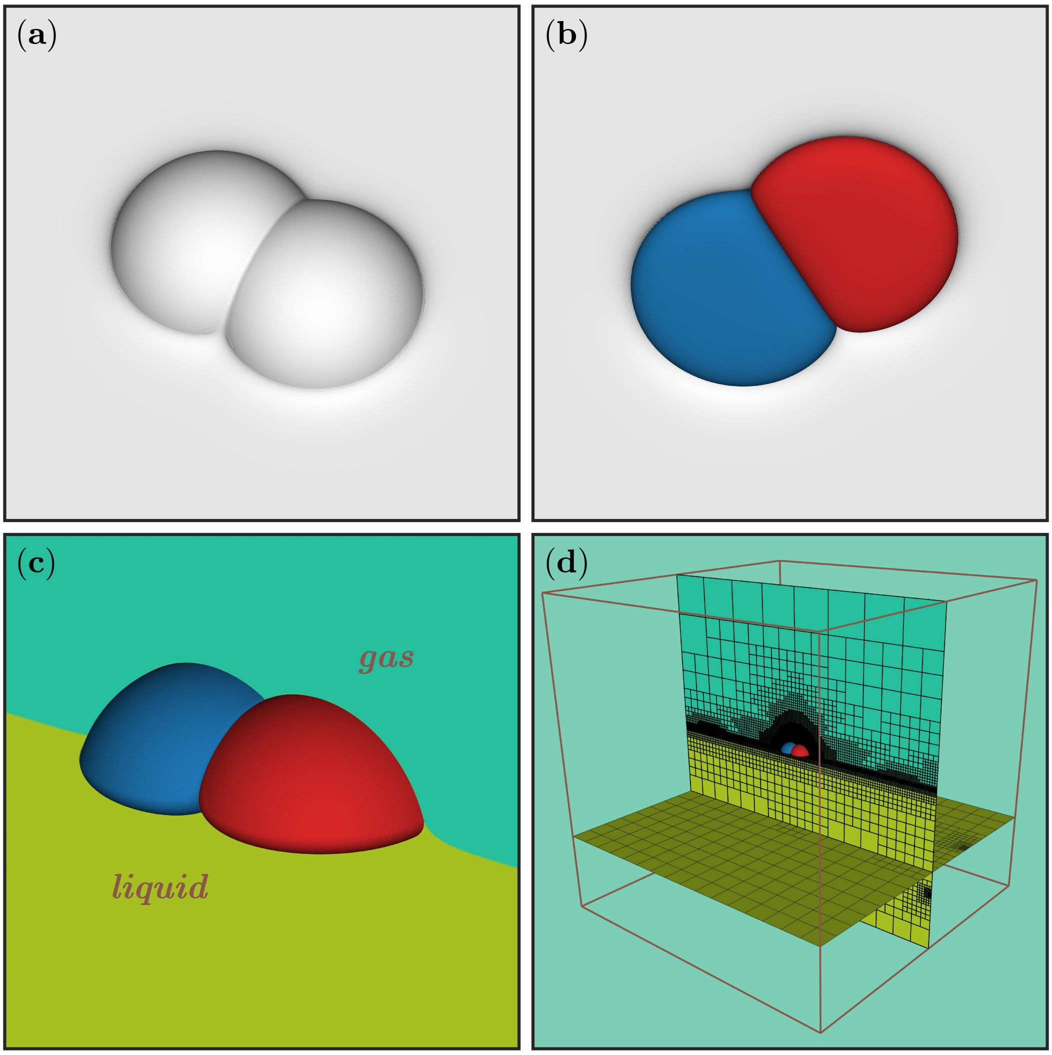

Figure 1: A pair of floating bubbles with a relatively large Bond number.

to the larger bubble size (high Bond number), the bubbles create a dome-like deformation at the free surface. Simultaneously, the bubbles are pressed against each other, resulting in a larger contact area. The quantitative information on bubble shapes from our simulations can help understand film drainage and the onset of bursting in experiments involving two or more bubbles, which may differ significantly from the case of axisymmetric isolated floating bubbles.

References

[1] Lhuissier, H. & Villermaux, E. *Bursting bubble aerosols.*, J. Fluid Mech. **696**, 5–44 (2012).

[2] Brasz, C.F., Bartlett, C.T., Walls, P.L.L., Flynn, E.G., Yu, Y.E. & Bird, J.C. *Minimum size for the top jet drop from a bursting bubble.*, Phys. Rev. Fluids **3**, 074001 (2018).

[3] Deike, L. *Mass transfer at the ocean–atmosphere interface: the role of wave breaking, droplets, and bubbles.*, Annu. Rev. Fluid Mech. **54**, 191–224 (2022).

[4] Popinet, S. *An accurate adaptive solver for surface-tension-driven interfacial flows.*, J. Comput. Phys. **228**, 5838–5866 (2009).