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## Dynamics of air bubbles crossing a horizontal interface

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Air bubbles crossing a horizontal interface separating two fluids otherwise at rest are encountered in a wide variety of applications, from iron processing to liquid-liquid extraction and scenarios of nuclear accidents or ascent of plumes in the Earth's mantle. In this talk we report on some findings obtained during an extensive investigation of that problem involving both experiments and direct numerical simulations<sup>1,2</sup>.

Experimentally, we let a single gas bubble rise by releasing it well below an interface between a lower phase made of water or water plus glycerin and an upper, slightly lighter, phase made of silicon oil. We vary the size of the bubble (typically for 1 mm to 20 mm), and the characteristics of the two fluids in order to explore a broad range of physical conditions. A detailed evolution of the various interfaces is obtained using high-speed video imaging and image processing techniques. Computations are carried out with two separate codes, both of which solve the full Navier-Stokes equations with an Eulerian approach based on an interface-capturing technique. One of them handles the three-phase nature of the flow through a Volume of Fluid approach without interface reconstruction<sup>3</sup> while the other employs the phase-field formulation based on the Cahn-Hilliard equation<sup>4</sup>.

The problem depends on six dimensionless parameters, among which the bubble Archimedes ( $Ar$ ) and Bond ( $Bo$ ) numbers and the viscosity ratio  $\Lambda$  of the two liquids are those we may vary by several orders of magnitude. A variety of flow regimes and bubble shapes is observed, including that of small bubbles remaining trapped during a very long time below the fluid/fluid interface in a film-drainage configuration. In most cases, the bubble succeeds in crossing the interface without being stopped near its undisturbed position and, during a certain period of time, tows a column or tail of lower fluid which sometimes exhibits a complex dynamics as it lengthens in the upper fluid. Varying  $Bo$ , or rather the interfacial Bond number  $Bo_I$ , for fixed values of  $Ar$  and  $\Lambda$  makes it possible to shed light on the complex role of  $Bo_I$  in the system dynamics. A simple model is set up to show how  $Bo_I$  influences the slowing down of the bubble at the fluid/fluid interface and why increasing it sufficiently prevents the bubble from remaining trapped below it, leading to a tailing configuration. In contrast, tracking the computed evolution of the film thickness when the bubble stands just below the interface indicates that the larger  $Bo_I$ , the longer the time required to drain the film, in agreement with lubrication-type arguments and previous computational studies performed in the creeping flow limit using boundary integral techniques<sup>5,6</sup>.

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<sup>1</sup>Bonhomme, Magnaudet, Duval & Piar *J. Fluid Mech.*, submitted.

<sup>2</sup>Bonhomme, Magnaudet, & Piar *Mec. Ind.* **12**, 163 (2011).

<sup>3</sup>Bonometti & Magnaudet, *Int. J. Multiphase Flow* **33**, 109 (2007).

<sup>4</sup>Boyer, Lapuerta, Minjeaud, Piar & Quintard, *Transp. Porous Media* **82**, 463 (2010).

<sup>5</sup>Manga & Stone *J. Fluid Mech.* **287**, 279 (1995).

<sup>6</sup>Pigeonneau & Sellier *Phys. Fluids* **23**, 092102 (2011).