EXPLORING THE EFFECTS OF A RIGID BODY ON THE EVOLUTION OF THE RAYLEIGH-TAYLOR INSTABILITY

Christopher Brown, Stuart Dalziel
Department of Applied Maths and Theoretical Physics, University of Cambridge, Cambridge, UK

Abstract This talk discusses the effects of a rigid solid boundary impeding the evolution of the Rayleigh-Taylor (RT) instability. The introduction of an obstacle completely alters the evolution of RT growth, instead of mixing the domain rapidly, a quasi-steady flow, rich in dynamics is established for long periods of time. Using a combination of low Atwood number experiments and ILES simulations, this talk will present a non-dimensional analytical model for a multi-stage mixing process, discussing the effects of the opening size and topology on the density change of each layer, buoyancy driven flux through the opening and mixing efficiency.

RESULTS

The motivation for this work stems from the desire to understand the fundamental dynamics for Rayleigh Taylor growth in materials with strength. We consider the extreme situation of a material with strength, where a rigid solid boundary is created and restricts the natural evolution of the RTI. In the simplest case we place a transparent rigid object at the interface between two layers of RT unstable fluids. This creates a single constricted opening on one side in a solid barrier experiment see figure 1 [1, 3]. For the single opening a RT mixing zone grows in the opening on the interface, resulting in a horizontal buoyancy gradient, which establishes two circulations cells one in each layer. The circulation forces fluid from both layers onto the open interface resulting in a RT mixing zone superimposed on the circulation cells. Near to the end wall the two circulation cells are deflected vertically, stretching the mixing zone vertically along the end wall rapidly. This results in fluid being carried around the layer and returned to the interface by a combination of wall plumes, gravity currents and fountains for the single opening, see figure 2 for a time series from an LIF experiment. For other topologies the dynamics differ, depending much more on the specifics of the setup.

From measuring the density field using in laboratory experiments and ILES simulations we have identified a multistage mixing process, which is unique for cases with an obstruction. We present a non-dimensional analytical model for a range of obstruction sizes and discuss the effect of an obstruction on the mixing efficiency.

Whilst the primary aim of this research is to get a theoretical footing for understanding RTI in materials with strength; there are other immediate applications to buoyancy driven ventilation problems, industrial mixing and geophysical processes [2, 4].

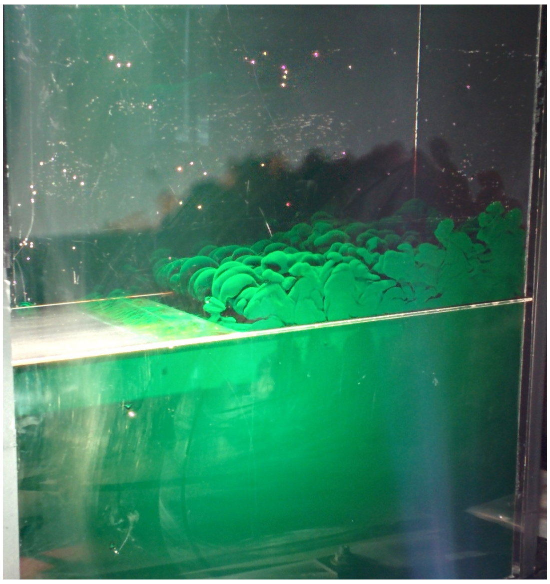
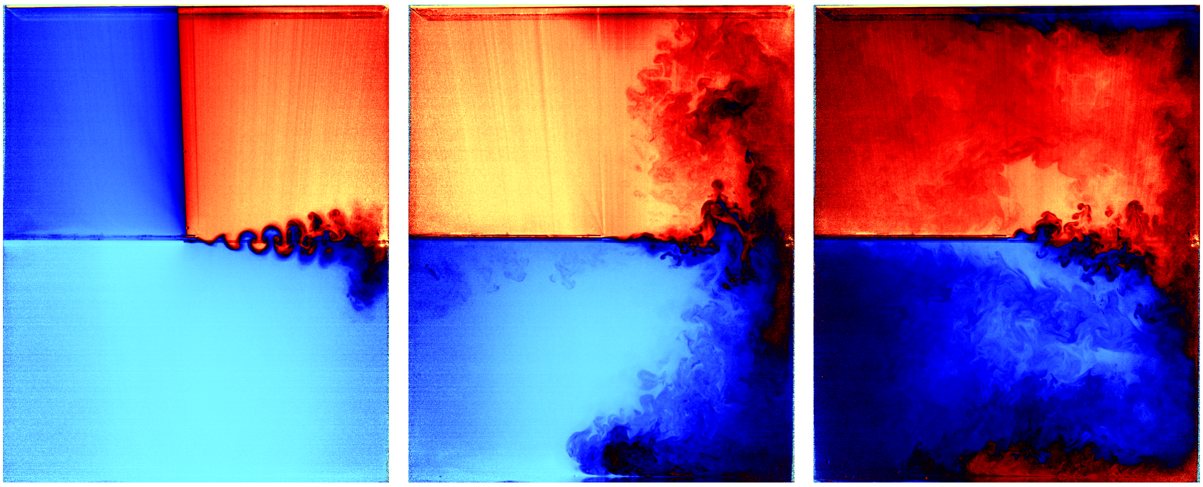


Figure 1: Perspex tank used in experiments with the stainless steel barrier left partially in. The lower layer is dyed with fluorescein and food dye to make it appear solid. The 3D growth of the RTI instability is clearly seen as are the initial stages of the circulation in the upper layer with undyed fluid seen to be moving off the edge of the barrier into the opening.



(a) 3s (b) 11s (c) 24s

Figure 2: LIF half opening experiment at $A = 5 \times 10^{-3}$ with rhodamine dye added to the upper layer. The colour scheme goes from turquoise for $\rho_L(t = 0)$ through black when it is perfectly mixed to light red for $\rho_U(t = 0)$.

References

[1] S B Dalziel. Rayleigh-Taylor instability: experiments with image analysis. *Dynamics of Atmospheres and Oceans*, **20**(1-2):127–153, November 1993.

[2] Michael Epstein and F B Cheung. Complex freezing-melting interfaces in fluid flow. *Annual Review of Fluid Mechanics*, (1978), 1983.

[3] P F Linden, J M Redondo, and D L Youngs. Molecular mixing in Rayleigh-Taylor instability. *J Fluid Mech*, **265**:97–124, April 1994.

[4] Qing Tan and Yogesh Jaluria. Mass flow through a horizontal vent in an enclosure due to pressure and density differences. *International Journal of Heat and Mass Transfer*, **44**:1543–1553, 2001.