CAUSALITY IN IMMISCIBLE RAYLEIGH-TAYLOR TURBULENCE

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Rayleigh-Taylor instability (RTI) originates at the interface between a layer of heavier and lighter fluid in the presence of an acceleration. At late times, the RTI evolves in a self-similar turbulent state, sustained by the continuous conversion of potential into kinetic energy [1]. RT turbulence phenomenology entails that, by balancing kinetic and potential energy, one obtains a quadratic scaling in time of the mixing zone, i.e. $h(t) = \alpha A g t^2$, where A is the Atwood number (the ratio between the density increment and the mean density) and g the gravitational acceleration. α is a constant coefficient that represents the efficiency at which the potential energy is converted into kinetic energy [2].

When the two phases are immiscible, the interfacial tension does not allow a complete mixing of the fluids. In fact, the turbulence fragments one fluid into the other, generating an emulsion-like state where the characteristic droplet size (the Hinze scale) decreases in time, resulting from a balance between the kinetic and the interfacial energy density. In our work we study the properties of this emulsion-like state, and in particular the causal relation between the self-similar turbulence state and the emulsion properties represented by the Hinze scale, the interface surface area and the velocity pair-correlation function.

To this purpose, we compare physical experiments (Figure 1) and direct numerical simulations to a self-consistent phenomenological theory designed to describe the underlying phenomenon [3]. With their phenomenology, Chertkov and co-authors speculate that the Hinze scale passively adapts to the large scales of the flow. The bubble generation is therefore considered to be a consequence of the large-scales, and is believed to not produce any back-reaction on the global features of the mixing.

Our experiments and simulations reveal that the convergence of the α coefficient is slowed down by the interfacial tension; more in detail, the stronger the interfacial tension, the later the turbulence reaches its self-similar state for which α is constant. Nevertheless, whether this correlation implies causality is not yet clear. Indeed, the delay in reaching the self-similar state could be due to the bubbles at the Hinze scale, that are originated not only from the interfacial tension but also from the kinetic energy cascade. If the bubbles delay the self-similar state, this means that they back-react on the large scales for some time. If this is the case, the assumption under which the emulsion properties can be considered a consequence of the large scale evolution breaks down, and a new phenomenology has to be derived.

To clarify the relation between the large scales and the bubble production, we aim to control independently each of the governing parameters. That is, we will keep the Hinze scale evolution unchanged and modify the interfacial tension at the same time. This can be done by decreasing the Atwood number and the interfacial tension together. We expect that this will provide a clear picture on the causal relations underpinning the evolution of immiscible RT turbulence that is potentially relevant for a broader class of turbulent flows with unsteady forcing mechanisms.

Figure 1. Snapshots of a laser induced fluorescence RT turbulence experiment (time interval between the images: $0.1\,s$, scale bar: $14\,mm$). The experiment is conducted using hexane as light fluid and a mixture of water and glycerol (37% in weight) as heavy fluid.

References

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