The progressive suppression of Rayleigh-Taylor instability by stable stratification

- BIFD 2011 -

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ABSTRACT

This paper explores how regions of statically stable stratification progressively suppress the growth of Rayleigh-Taylor instability (RTI). In particular, we consider initial conditions comprising a single unstable density interface between layers in which the density stratification is (locally) statically stable.

This initial configuration contrasts with that of classical case in which RTI develops on an unstable density interface between two otherwise homogeneous layers. In this case at low Atwood number ($A = (\rho_1 - \rho_2)/(\rho_1 + \rho_2)$) the width of the mixing zone grows as $h \sim \alpha Agt^2$ (where g the acceleration due to gravity and α a dimensionless constant) until it is influenced by the size of the container. It feeds from the reservoir of potential energy in the initial conditions, ultimately half this energy being dissipated in the form of heat, and half going into producing mixed fluid with a final state of uniform density.

With our new configuration, the instability no longer grows as $h \sim \alpha Agt^2$ as it must penetrate into the stably stratified regions. Its initial acceleration driven by releasing potential energy from the unstable interface is progressively reversed as the overall stratification tends towards a stable form. Depending on the strength and form of the initial stratification, the growth of the mixing zone may be arrested before it reaches the upper and lower boundaries of the container. This raises the question of what controls the ultimate state: how far can the mixing zone penetrate the stable layers? Alongside this are the questions of how much of the initial potential energy can be released, and how much of the energy that is released can go into mixing the density stratification.

We present results for this new problem with a single Rayleigh-Taylor unstable interface bounded by stable stratifications with a range of linear and non-linear density profiles. We compare our experimental results with both simplified analytical models and three-dimensional numerical simulations, and reach some startling conclusions about the efficiency of this mixing process.