Viscous effects on the Rayleigh-Taylor instability with background temperature gradient

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The growth rate of the compressible Rayleigh-Taylor instability (RTI) has been studied in the presence of a background temperature gradient, Θ, using a normal mode analysis [1]. The effect of Θ variation has been examined for three interface types corresponding to combinations of the viscous properties of the fluids (inviscid-inviscid, viscous-viscous and viscous-inviscid) at different Atwood numbers, At, and, when at least one of the fluids' viscosity is non-zero, as a function of the Grashof number, Gr. The results have been applied to two practical examples, using sets of parameters relevant to Inertial Confinement Fusion (ICF) coasting stage and solar corona plumes. The role of viscosity on the growth rate reduction is discussed together with highlighting the range of wavenumbers most affected by viscosity.

Background and Motivation

Temperature differences are often present across the Rayleigh-Taylor (RT) unstable layers and can modify the instability growth compared to layers of constant temperature. For example, in the solar corona prominences, the temperature difference can reach $10^5 K$ and during the ICF coasting or deceleration stage up to $10^7 K$. However, there has been no systematic study of the effects of temperature differences on RTI. Moreover, in applications such as ICF, RTI can develop between fluids with vastly different viscosities. Thus, the limiting case in which one of the fluids is viscous and the other is inviscid, is practically important. Nevertheless, even when viscous effects were considered in previous studies, the viscosities of the two fluids were commensurate. Thus, the stability of viscous-inviscid interfaces has not been studied for RTI.

Description/Impact

This work investigates the general viscous, compressible case, in which the background temperature varies linearly in the direction perpendicular to the interface, using a normal mode approach. In order to address practical cases with large viscosity differences between the two fluids, the viscous-inviscid interface has been examined for the first time in the context of RTI. For the general case, the resulting ordinary differential equations are solved numerically; however, dispersion relations for the growth rate are presented for several limiting cases. An analytical solution is found for the inviscid-inviscid interface and the corresponding dispersion equation for the growth rate is obtained in the limit of large Θ. For the viscous-inviscid case, a dispersion relation is derived in the incompressible limit and $\Theta = 0$. In general, for all cases, the effect of $\Theta < 0$, corresponding to hotter light fluid, is destabilizing and that of $\Theta > 0$ (colder light fluid) stabilizing, compared to the background state with $\Theta = 0$. Compared to the viscous-viscous case, there are noticeable differences for the viscous-inviscid case results at all At values. The results are applied to two practical examples displaying RTI – coasting phase in ICF and solar corona plumes – and demonstrate the importance of inclusion of viscosity, which can significantly damp the growth rates starting from wave numbers as small as $\hat{k} \approx 0.5\mu m^{-1}$ for ICF and $\hat{k} \approx 0.02 km^{-1}$ for solar corona.

Acknowledgements

This work was carried out under the auspices of the National Nuclear Security Administration of the U.S. Department of Energy at Los Alamos National Laboratory under Contract No. DE-AC52-06NA25396, and supported by the Laboratory Directed Research and Development Program.

References

[1] Gerashchencko S and D. Livescu. Viscous effects on the rayleigh-taylor instability with background temperature gradient. *Phys. Plasmas*, 23:072121, 2016.