NUMERICAL INVESTIGATION OF SELF-SIMILAR STATES OF UNSTABLY STRATIFIED HOMOGENEOUS TURBULENCE

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Abstract Numerical results of simulations of unstably stratified homogeneous turbulence are reported. The resolved equations correspond to the low Atwood number limit of incompressible binary mixtures, submitted to a gravity field, treated with the Boussinesq approximation. The dependence of asymptotic self-similar states to different dissipation processes is examined. The homogeneous configuration obtained is relevant to get insights in the Rayleight-Taylor induced turbulent mixing.

RAYLEIGH-TAYLOR MIXING AND UNSTABLY STRATIFIED HOMOGENEOUS TURBULENCE

Rayleigh-Taylor mixing appears when a heavy fluid is accelerated into a light one. It plays a significant role in a wide variety of applications ranging from atmospheric and oceanic flows to supernovae explosions and inertial confinement fusion experiments. Turbulent mixing zones encountered in such configurations raise challenging difficulties for one-point statistical models due to inhomogeneity, compressiblity and complicated mean flow sollicitations... As a result all terms involved in Reynolds average equations may simultaneously be at work but are not fully understood. To get clearer insights about buoyancy driven turbulent mixing zones, we want to get rid of some of these mechanisms by considering a much simpler flow configuration.

Namely we focus on the study of the low Atwood number limit of incompressible miscible binary mixtures treated with Boussinesq equations. The latter equations are used to investigate unstably stratified homogeneous flows. This configuration is a valuable tool for getting insights into the turbulence modelling of Rayleigh-Taylor flow[1]. Indeed, common features of both cases include the energy injection mechanism and the redistribution processes whereas the main differences lie in the inhomogeneity of Rayleigh-Taylor mixing.

EQUATIONS AND SIMULATIONS

Applying the Boussinesq approximation, around the one-dimensional basic density $\bar{\varrho}$, and the incompressible assumption to the Navier-Stokes equations in a gravity field of acceleration g along the z direction, we are left with equations

$$\begin{aligned}&(\partial_t + u_j\partial_j - \nu\Delta)u_i + \partial_i p = -\rho\delta_{iz}\\ &(\partial_t + u_j\partial_j - \kappa\Delta)\rho = -\mathcal{N}^2 u_z\\ &\partial_i u_i = 0\end{aligned} \tag{1}$$

where u_i is the fluctuating velocity, $\rho = (\varrho - \bar{\varrho})\ g/\bar{\varrho}$ is the fluctuating density (scaled by gravity and mean density), $\mathcal{N} = \sqrt{|\partial_z\bar{\varrho}\ g/\bar{\varrho}|}$ is the (uniform) Brunt-Väisälä frequency and ν, κ are kinematic viscosity and diffusion coefficients. Sign convention is chosen such that positive values of $\mathcal{N}^2$ lead to unstable configurations.

Imposing triply periodic boundary conditions, Sys.(1) describes unstably stratified homogeneous turbulence. Due to buoyancy drive, energy in the fluid increases endlessly. For constant value of the Brunt-Väisälä frequency, exponentially growing self-similar states are expected[1]. However, if $\mathcal{N}$ evolves itself according to the turbulent mass flux (which drives the mixing zone length in inhomogeneous Rayleigh-Taylor turbulence), the quadratic self-similar growth of Rayleigh-Taylor mixing is retrieved. That latter choice is therefore closer to our final goal so that we add the following temporal evolution equation for the uniform Brunt-Väisälä frequency, with $\langle . \rangle$ denoting spatial averaging :

$$d_t(\mathcal{N}^{-2}) = -8\langle\rho u_z\rangle \tag{2}$$

Simulations of Sys.(1) with Eq.(2) and periodic boundary conditions are performed here with simple and efficient spectral numerical methods. We focus on the self-similar regime of this buoyancy driven turbulent mixing and examine its dependence on the dissipation process. Four kinds of dissipation processes are tested: classical viscosity dissipation, hyper-viscosity dissipation, adaptive viscosity dissipation (designed to maintain the Kolmogorov scale at the resolution scale) and dissipation from an LES model[2].

References

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