COMPRESSIBLE RAYLEIGH-TAYLOR TURBULENT MIXING UNDER DIFFERENT ACCELERATION HISTORIES

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Abstract Compressible Rayleigh-Taylor turbulent mixing (CRTM) induced by Rayleigh-Taylor instability occurs when a compressible fluid of heavy density is accelerated or supported against gravity by a compressible fluid of light density, and is of fundamental importance in applications from combustion, to inertial confinement fusion, and to astrophysics. Traditionally, CRTFs are studied under constant acceleration histories. Due to the nature of the processes, however, it is necessary to study CRTF under general acceleration histories g(t). In this aspect, the evolution of Rayleigh-Taylor turbulent mixing under complex acceleration histories, including changes in signs, have been studied numerically[1] and experimentally[2] for incompressible flows, leaving an open question on that of compressible flows. In fact, most engineering problems are compressible. In addition, the available engineering turbulence models cannot capture the variation of mixing width for CRTM with complex acceleration histories, such as the gravity reversal. In order to better understanding the dynamic of CRTM under different variation histories, several DNS cases with different acceleration histories have been conducted and analyzed.

For CRTM under general acceleration histories, however, its time- and space- dependent open boundaries challenge the available boundary treatments and consequently the realization of numerical simulations. For example, when the approach of specifying the boundary values of primitive/conservative variables is used, besides the unknown of boundary values of some variables, the approach is found to be numerical instable, too. To overcome the difficulties, we extended the Navier-Stokes characteristic boundary conditions (NSCBC) to CRTM by combining CRTM's physical boundary conditions and NSCBC's idea, and by appending a dissipation region, where physics-consistent viscous terms are introduced to realize non-reflection without additional effect. Since this approach is derived from physical boundary conditions, we named this approach as physical-boundaries based characteristic boundary conditions (PBCBC). Numerical tests confirm the effectiveness and robustness of PBCBC (Fig.1).

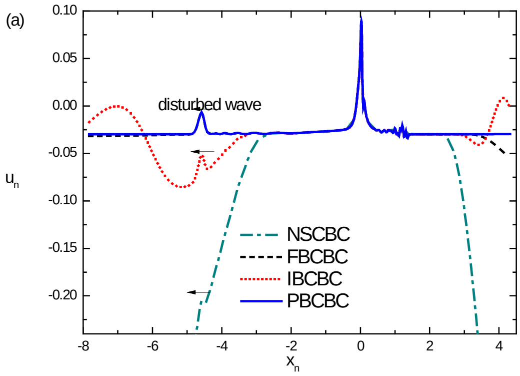

Figure 1. The normal velocity distributions in a line parallel to gravity direction for CRTM under variable acceleration histories and for different boundary treatments. NSCBC denotes the classical Navier-Stokes characteristic boundary conditions, FBCBC denotes the fluctuation-quantity based characteristic boundary conditions [3], IBCBC denotes the instantaneous-quantity based characteristic boundary conditions, and PBCBC denotes the physical-boundaries based characteristic boundary conditions. This comparison shows that only our methods capture the physics the CRTM under general acceleration histories.

To understood the variable acceleration effect on the mixing width and turbulence properties, we have proposed the following problems after the flows enter into turbulent stage (Fig.2) : (i) keep the acceleration be a constant; (ii) set the acceleration to zero; (iii) reverse the acceleration, and then to the initial value; (iv) impose variable acceleration histories as $g/\mathrm{g(t_0)} = [1+0.2\sin(2\pi kt)]^2$, where t changes from 0 to 1 and k=2. Note that the integral value of $S = \int\int_{t_0}^{t_1} g(\mathrm{t})dtdt$ equal with each other for problems of (i) and (iv), and problems of (ii) and (iii), thus we can use the results to check the dependence of mixing width on S. While the bulk of the results is still being analyzed, our preliminary results find that the acceleration histories has more significant effect on the small-scale mixing, compared with the mixing width. When the acceleration change its sign, the collisions of bubbles and spikes would enhance the structure breakdown and atomic mixing. To quantify the effect of variable acceleration histories, we will discuss a large number of metrics, including the mixing width, grow constants, molecular mixing parameters, anisotropy and high-order moments. These results will present as a resource to validate and refine the turbulent mixing models.

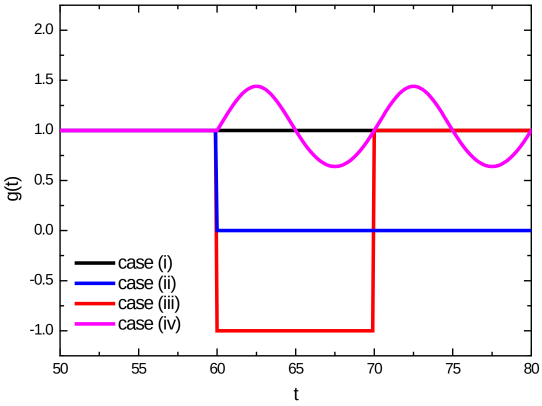

Figure 2. The different acceleration histories used in current DNS.

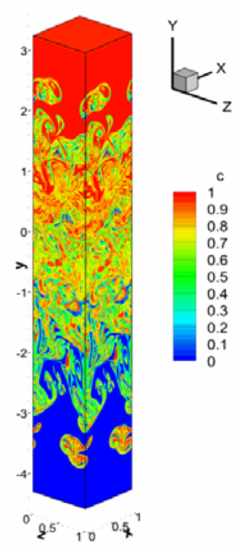

Figure 3. The concentration distribution at t=70 for problem (i)

References

[1] D. Livescu, T. Wei and M. R. Petersen, Direct Numerical Simulations of Rayleigh-Taylor instability. *Journal of Physics: Conference Series 318 (2011) 082007*,2011.
[2] G..Dimonte and M.Schneider, Density ratio dependence of Rayleigh-Taylor mixing for sustained and impulsive acceleration histories,Phys. Fluids,12(2),304-321,2000
[3] S. Reckinger, D. Livescu, O. Vasilyev, Adaptive wavelet collocation method simulations of Rayleigh–Taylor instability, Physica Scripta 2010 (T142) (2010) 014064.