A New Look into the Self-Similar RT α_b Discrepancy

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Introduction

The non-linear growth of a Rayleigh-Taylor unstable mixing regions under multimode perturbation is usually described by:

(1) $h_b(t)=\alpha_b gAt^2$ - where h_b is bubbles height, g is the acceleration, A is Atwood's number and α_b is assumed to be a universal constant. Experimental, theoretical and numerical attempts to estimate α_b yield a wide range (0.02 to 0.08). Many of the results were summarized by the Alpha-Group (α-G) [1]: the experimental value is 0.057 ± 0.008 while intense numerical investigation, using 7 different codes, fit a value of 0.025 ± 0.003. Other theoretical studies predict α_b to be 0.05[2,4].

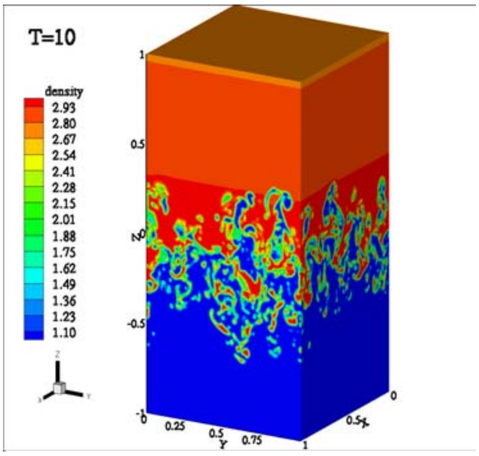

Fig. 1: Density colormap at T=10 s

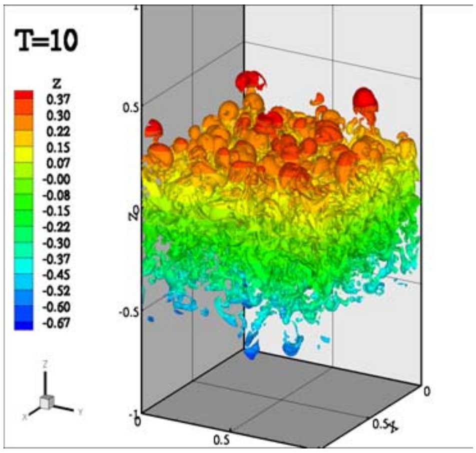

Fig. 2: Interface at T=10 s
Colors represent height (z)

New Simulations

Using the code VULCAN/3D[3] and different initial conditions (IC) we performed several numerical experiments. We used 128*128*256 cells (see [3] for more code and simulation details). Gross patterns of the flow fields are displayed in fig. 1 & 2 .

In a first experiment (case A) we have perturbed the hydrostatic equilibrium by a divergence free velocity field, hereafter ICA. We estimate a value of 0.058 for α_b, in agreement with experiments and other simulations[4]. These initial conditions however are different from the IC used by the α-G : a perturbation of the initial interface, hereafter ICB. In a second numerical experiment (case B) we repeat the simulation using ICB. In this case the resulting value of α_b is 0.034. The graphs $h_b(t)$ for both cases are displayed in fig. 3. While case A fits the experimental value, case B is much closer to the Alpha-Group results. One may conclude that initial conditions affect the value of α.

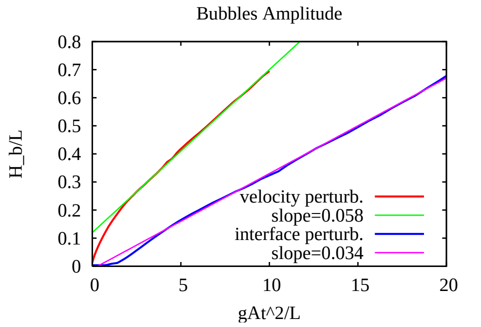

Fig. 3: Mixing zone upper boundary Different initial conditions simulations

Discussion

The graphs in figure 3 (and similar ones produced by (1) and (5)) show that the t^2 behavior starts after a finite incubation time, which is shorter in case A than in Case B. Only after that time the flow becomes nonlinear and self-similar. Thus one would expect a scaling law of the form:

$h_b(t) = h_b(t_0) + v_b(t_0)\,(t-t_0) + \alpha_b gA(t-t_0)^2$ - where t_0 is the incubation time and $h_b(t_0), v_b(t_0)$ are the bubbles height and velocity at that time (see (5) and (6) for different formulas). A fit according to this law is presented in fig. 4 where we used $\alpha_b=0.045$ **for both simulations.** When we shift the h_b and the gAt^2 coordinates so that the minima of the parabolas coincide, both simulations lie on the same 0.045 slope (fig. 5).

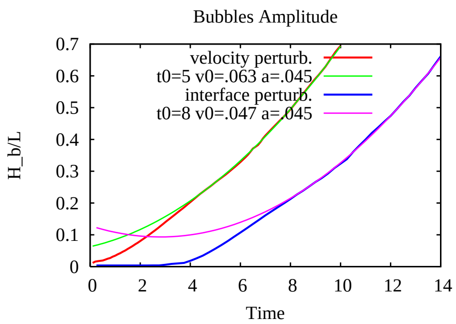

Fig. 4: Mixing zone upper boundary Different initial conditions simulations

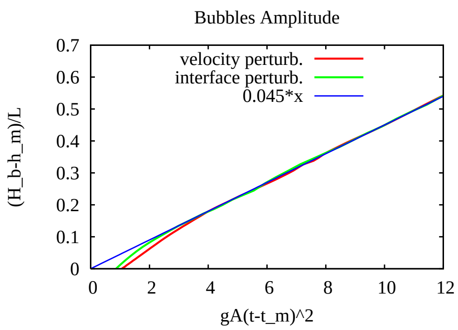

Fig. 5: Mixing zone upper boundary Plotted in h_b-h_{min}, $gA(t-t_{min})^2$ plane

Additional analysis reveals that because the simulation final time is not much larger than the incubation time, a good fit could be made for parabolas with α_b in the range of 0.040 ± 0.015.

In our previous analysis[3] we determined α_b by the slope at h_b-gAt^2 plane (see fig. 3), while in the α-G paper [1] α_b is measured by the derivative $dh_b/d(gAt^2)$ (see [5]) . Both these predictions yield a false value when t/t_0 is not large enough. To demonstrate these false measurements we applied both these methods to the analytic parabolas that were fitted to the simulations results in fig. 4. These parabolas have quadratic term with α_b=0.045,

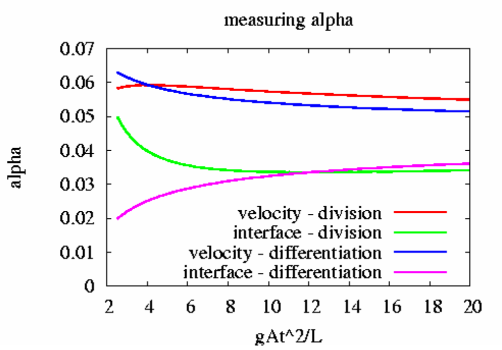

Fig. 6: Different methods for measuring α_b applied to the two simulations

but as can be seen in fig. 6, the measured α_b of the parabola that was fitted to ICA results is larger than 0.05 while the measured α_b of the parabola that was fitted to ICB results is smaller than 0.04.

Conclusion

The sensitivity of the estimated value of α_b , using eq.(1) , to initial conditions is large. However, the initial conditions affect mainly the incubation time in which the flow is not yet self-similar. When this incubation time is taken into account the diversity of the value of α_b is removed. In order to determine the value of α_b one needs a large inertial range that will allow larger simulation time. We note that even in the most resolved simulations performed so far the inertial range is small and as a result, the incubation time is not short compared to the total simulation time. Therefore, a precise estimate of α_b is still beyond the capability of our current simulations.

References

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