STRUCTURE DETECTION IN A RT TURBULENT MIXING LAYER

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The last three decades have seen a significant improvement in the understanding of the physical processes which control the growth of gravitationnally driven turbulent layers, such as Rayleigh–Taylor flows. Central to this insight is the buoyancy–drag equation[4] $L'' = -C_d \frac{L'^2}{L} + C_b\, A\, g$, which relates the growth of the mixing layer width $L(t)$ to two opposed "forces" in the system (buoyancy and drag), A and g being respectively the Atwood number and the gravity. This description actually presumes the existence of "material elements" on which these "forces" apply and whose displacement produces the observed transport and growth.

This interpretation is supported by a simple visual inspection of density and velocity fields from Direct and Large Eddies simulations of RT flows (see for instance fig. 24 in the Alpha-Group publication[5]), which shows the presence of counter-flowing lumps of fluid in the mixing layer. However, as previously shown in simulations and modelling studies by Youngs[6], fluid conditional averages are not sufficient in order to connect observations with the buoyancy-drag equation. There is a mutual entrainment and mixing of fluids at small scales due to turbulence producing effective "lumps" of mixed fluids, here designated as "structures".

Despite its importance in order to validate and calibrate 2-fluid–2-structure models such as Youngs'[6] or the 2SFK[7], no systematic approach to detect the contours of structures in simulations has been produced so far. We present here preliminary results on structure detection in DNS by filtering with the vertical velocity field. A new equation for improved structure determination is then proposed.

In RT flows, due to the buoyancy term, the mixing layer develops essentialy in the gravitation's direction (vertical here). In this case, using the contrast of vertical velocity is a simple and efficient approach to detect structures. We define the structure presence function $b^-(t,x,y,z)$ and $b^+(t,x,y,z)$ as :

$$b^-(t,x,y,z) = \begin{cases} 1 & \text{if} \quad u_z(t,x,y,z) > s\, L'(t)\, \dfrac{z}{L(t)} \\ 0 & \text{if} \quad u_z(t,x,y,z) < s\, L'(t)\, \dfrac{z}{L(t)} \end{cases} \qquad ; \qquad b^+ = 1 - b^-$$

where s is a predefined coefficient. As a first approach, one could think that a zero velocity threshold (or $s = 0$) could perform a proper separation between downward and upward moving structures, but fluctuations that appear in the outer laminar regions make necessary to shift the threshold in opposite directions on each side. Here we retain a value of $s = 1/3$. Figure 1(a) shows the vertical profiles of the average structure and fluid volume fractions α_{b^-} and α_{c^-} obtained by DNS, defined as $\alpha_\phi = \int_{xy} \phi(x,y,z)dxdy / \int_{xy} dxdy$. Prediction of the 2SFK model[7] (figure 1(b)) shows a satisfactory agreement.

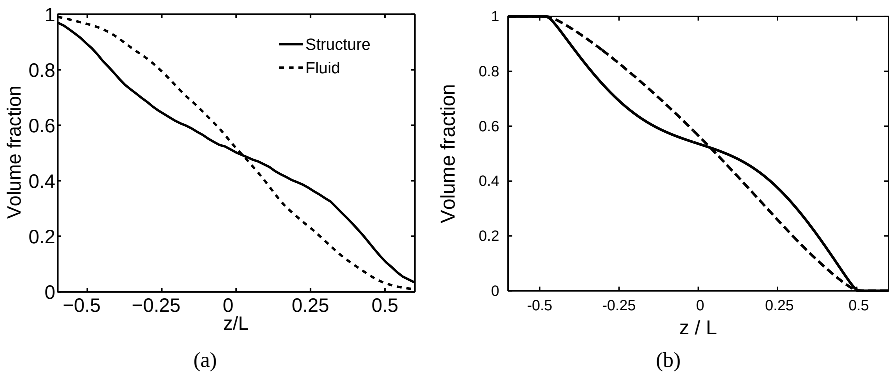

Figure 1. Profiles of the structure and fluid volume fractions α_{b^-} and α_{c^-} along the mixing zone; (a) Numerical results using the procedure given in text on a $128^2 \times 256$ 3D-simulation; (b) 2SFK model.

Although this method gives apparently good results with RT flows, it is difficult to extend it to Richtmyer–Meshkov or Kelvin–Helmholtz instabilities where the mixing layer does not evolve in a predominant direction anymore. As said before, the mixing process at small scales entails high turbulent kinetic energy that is first responsible for producing structures. Thus, the contrast of vertical velocity ought to be replaced by some type of contrast based on turbulence. Including a memory effect in order to filter small scale intermittency effects, we propose the following evolution equation for $b^\pm$:

$$\partial_t b^\pm + \left(u_i - \sigma_f (rl)^{4/3} \left(\varepsilon^{1/3}\right)_{,i}\right) b^\pm_{,i} = \sigma_s\, r^{4/3}\, \tilde{\nu}\, b_{,ii} + \sigma_s\, r^{-2/3}\, \tilde{\omega}\, 4\, b^+\, b^-\, (2b^\pm - 1)$$

where u_i is the local material velocity, ε the local kinetic energy dissipation, $\tilde{\nu} = \tilde{k}^2/\tilde{\varepsilon}$ the mean turbulent viscosity over the mixing zone, $\tilde{\omega} = \tilde{\varepsilon}/\tilde{k}$ the mean turbulent turnover frequency, $l = \tilde{k}^{3/2}/\tilde{\varepsilon}$ the mean integral length scale, σ_f and σ_s are predefined coefficients of the slow and fast processes and, r is a predefined space and time resolution scale relative to integral scales.

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