



1D NUMERICAL SIMULATIONS OF VARIOUS SELF SIMILAR ACCELERATED
TURBULENT MIXING LAYERS USING THE 2SFK MODEL.

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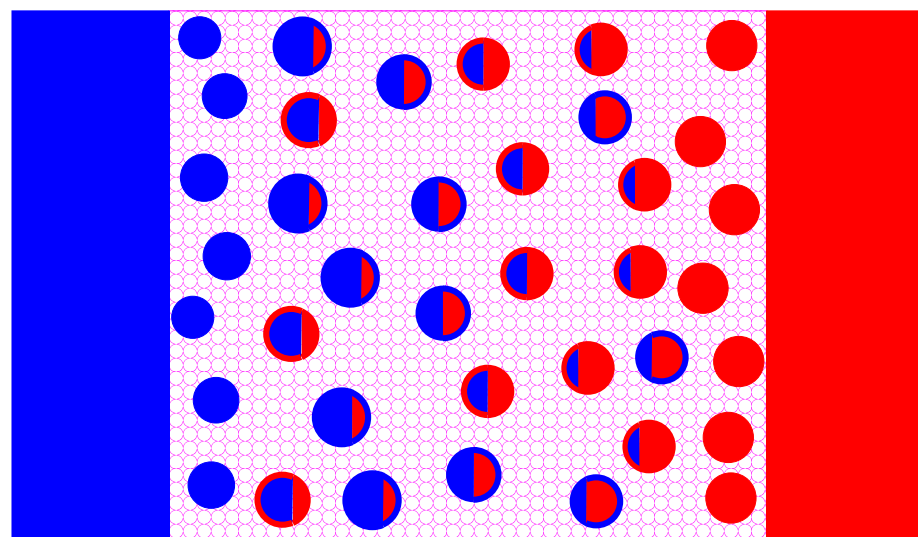
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Why introduce the idea of turbulent structure ?

MIXING ZONE

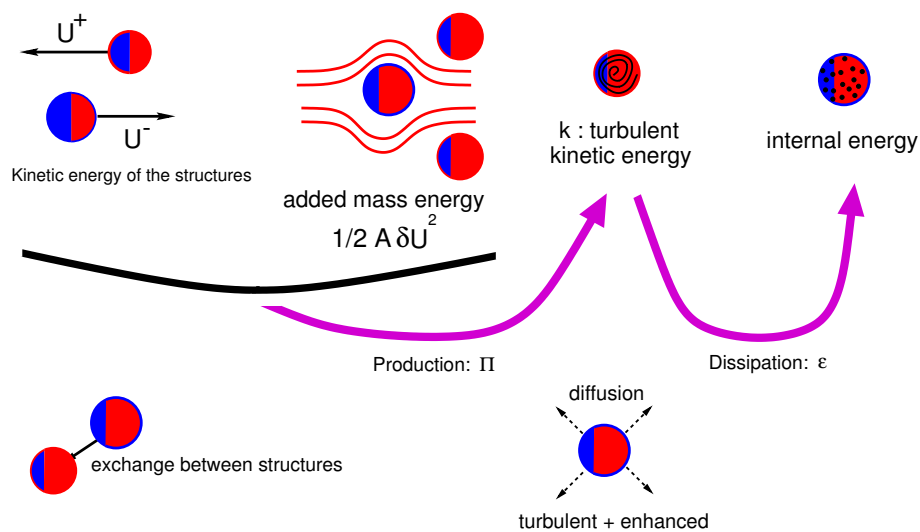


fluid B
 fluid R

Structure B
 Structure R

- For developed turbulent regime.
- Aimed at grasping features of the mixing.
- ☞ A fluid is a closed system:
no exchange possible.
- ☞ A structure is an open system:
exchange possible.
size of structure ~ turbulent length scale

Energy chart of 2SFK.



$$\Rightarrow KE_{\text{two}} = \frac{1}{2} \alpha^+ \rho^+ U^{+2} + \frac{1}{2} \alpha^- \rho^- U^{-2}$$

$$= \underbrace{\frac{1}{2} \bar{\rho} V^2}_{KE_{\text{single}}} + \underbrace{\frac{\alpha^+ \rho^+ \alpha^- \rho^-}{2 \bar{\rho}} \delta U^2}_{K_D}$$

KE : Kinetic Energy

K : Turbulent Kinetic Energy

K_D : Directed Energy

$$\Rightarrow KE_{\text{single}} + K_{\text{single}} = KE_{\text{two}} + K_{\text{two}}$$

$$\checkmark K_{\text{single}} = K_{\text{two}} + K_D$$

$$\leftarrow \text{RM: } K_D \ll K_{\text{two}}; \quad \text{RT: } K_D \sim K_{\text{two}}$$



Equations of 2SFK model.

☛ 2SFK stands for 2-Structure, 2-Fluid and 2-K- ϵ

➡ Conservation per structure of ...

$$\begin{aligned}
 \text{[fluid mass]} \quad D_t^\pm(\alpha^\pm \rho^\pm C^{m\pm}) &= -\Phi_{j,j}^{m\pm} \mp \Psi^{m\pm} \\
 \text{[mass]} \quad D_t^\pm(\alpha^\pm \rho^\pm) &= \mp \Psi \\
 \text{[momentum]} \quad D_t^\pm(\alpha^\pm \rho^\pm U_i^\pm \pm \mathcal{A} \delta U_i) &= -\alpha^\pm \partial_i(P + P_t) + \mathcal{S}_i[\mathcal{A}] \\
 &\quad -\alpha^\pm Q_{ij,j} - \left(R_{ij} - \frac{2}{3} \alpha^\pm \rho^\pm k^\pm \delta_{ij} \right)_{,j} \mp (D_i + \Psi_i^H) \\
 \text{[internal energy]} \quad D_t^\pm(\alpha^\pm \rho^\pm E^\pm) &= -P(D_t^\pm(\alpha^\pm) \pm \Psi^\alpha) + \alpha^\pm \rho^\pm \Sigma^\pm + \alpha^\pm \rho^\pm \epsilon^\pm - \Phi_{j,j}^{E\pm} \mp \Psi^{E\pm} \\
 \text{[turbulence : k]} \quad D_t^\pm(\alpha^\pm \rho^\pm k^\pm) &= \frac{2}{3} \rho^\pm k^\pm (D_t^\pm(\alpha^\pm) \pm \Psi^\alpha) + \Pi^\pm - \alpha^\pm \rho^\pm \epsilon^\pm - \Phi_{j,j}^{k\pm} \mp \Psi^{k\pm} \\
 \text{[dissipation : } \epsilon] \quad D_t^\pm(\alpha^\pm \rho^\pm \epsilon^\pm) &= -\left(\frac{2}{3} C_{\epsilon 1} + C_{\epsilon 3} \right) \rho^\pm \epsilon^\pm (D_t^\pm(\alpha^\pm) \pm \Psi^\alpha) + C_{\epsilon 1} \frac{\epsilon^\pm}{k^\pm} \Pi^\pm - C_{\epsilon 2} \alpha^\pm \rho^\pm \frac{\epsilon^\pm{}^2}{k^\pm} \\
 &\quad - \Phi_{j,j}^{\epsilon\pm} \mp \Psi^{\epsilon\pm}
 \end{aligned}$$



Some closures of flux and exchange.

$$\lambda^\pm = \frac{k^\pm{}^{3/2}}{\epsilon^\pm} \text{ Turbulent length scale}$$

$$\nu^\pm = C_\mu \frac{k^\pm{}^2}{\epsilon^\pm} \text{ Turbulent viscosity } C_\mu = 0.09$$

$$\lambda = \frac{\lambda^{+4} + \lambda^{-4}}{\lambda^{+3} + \lambda^{-3}} \sim \max(\lambda^+, \lambda^-) \text{ Exchange length scale}$$

$$\omega_\Psi = \frac{1}{C_\mu} \frac{\nu^+ + \nu^-}{\lambda^2} \text{ Exchange time scale}$$

$$D_s^\pm = 4C_s \alpha^+ \alpha^- \lambda \|\delta\mathbf{U}\| \text{ Sifting diffusion}$$

$$D_i + \Psi_i^H = \frac{\alpha^- \rho^- H_i^+ + \alpha^+ \rho^+ H_i^-}{\alpha^+ \rho^+ + \alpha^- \rho^-} \Psi + C_d \alpha^+ \alpha^- \omega_\Psi \frac{(\alpha^+ \rho^+)^2 + (\alpha^- \rho^-)^2}{\alpha^+ \rho^+ + \alpha^- \rho^-} (\delta H_i - H_i^o) \text{ Drag}$$

$$H_i^o = - \left(1 + \frac{(\alpha^+ \rho^+ + \alpha^- \rho^-) \mathcal{A}}{\alpha^+ \rho^+ \alpha^- \rho^-} \right) \left[D_s^+ \frac{(\alpha^+ \rho^+),_i}{\alpha^+ \rho^+} - D_s^- \frac{(\alpha^- \rho^-),_i}{\alpha^- \rho^-} \right] \text{ Diffusive drift}$$

$$\Phi_i^{A\pm} = -\alpha^\pm \rho^\pm \left(\frac{\nu^\pm}{\sigma_A} + D^\pm \right) \left[A_{,i}^\pm - P_A \left(\frac{\rho_{,i}^\pm}{\rho^\pm{}^2} + \sum_m \frac{C_{,i}^{m\pm}}{\rho^{m\pm}} \right) \right] \text{ Flux of A}$$

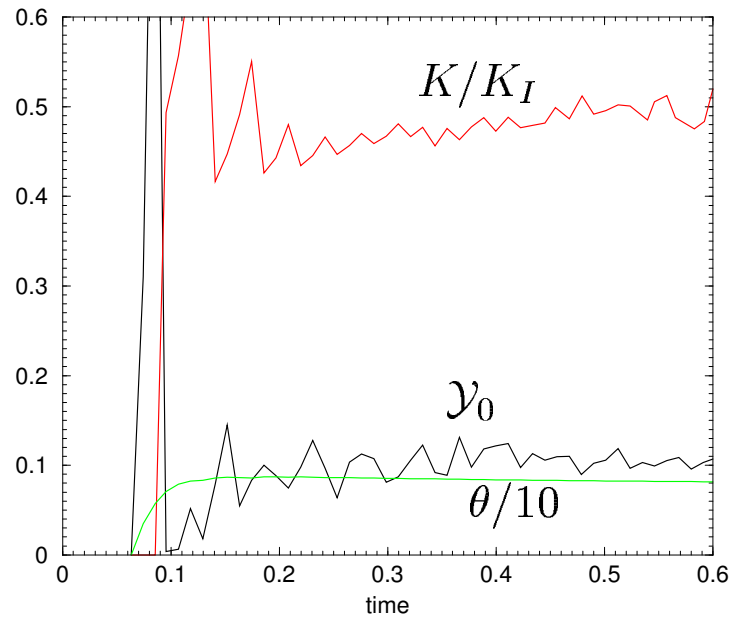
$$\Psi^A = \frac{1}{2} C_{\epsilon c} \alpha^+ \alpha^- \omega_\Psi (\alpha^+ \rho^+ A^+ - \alpha^- \rho^- A^-) \text{ Exchange of A}$$



Growth rate, mixing rate, level of dissipation ($A_t = 0.2$).

Rayleigh Taylor
Atwood 0.2

reference:
(α -group results)
 $K/K_I \sim 0.46$
 $\mathcal{Y}_0 \sim 0.12$
 $\theta \sim 0.8$

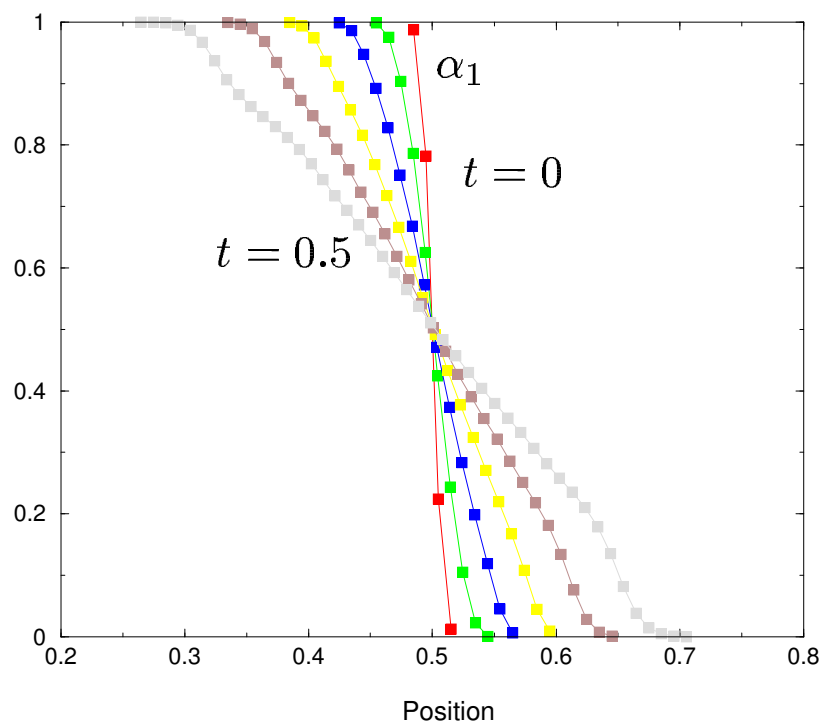


- ✓ K is the single-fluid turbulent kinetic energy.
- ✓ K_I is the gravitational energy input.
- ✓ \mathcal{Y}_0 is the growth rate.
- $L(t) = \mathcal{Y}_0 A_t g t^2$
- ✓ θ is the molecular mixing rate.



Volume fraction of light fluid (various times).

self similar evolution
developed turbulence
in the TMZ)

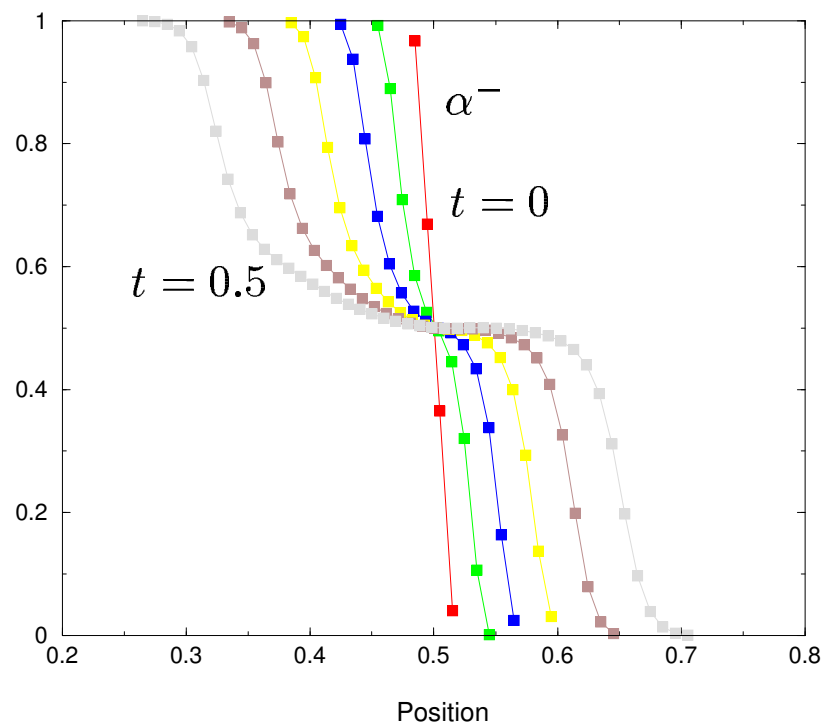


Volume fractions of fluids
are linear over the TMZ
for low Atwood 0.2.
In agreement with EXP
and DNS



Volume fraction of light structure (various times).

self similar evolution
developed turbulence
in the TMZ)

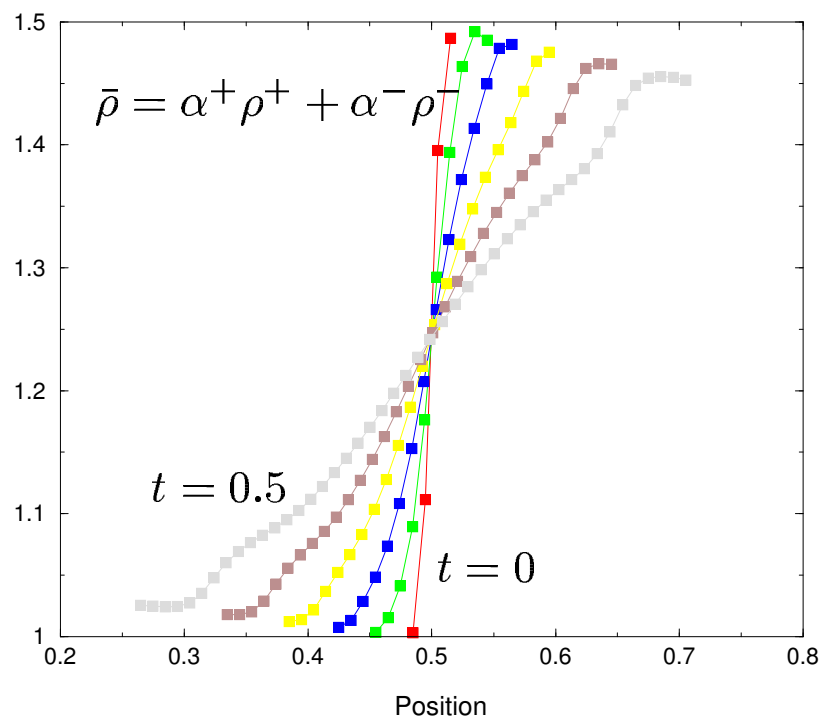


- There is a significant part of the TMZ where $\alpha^+ \approx \alpha^-$
- DNS simulation would allow to verify these profiles



Density profile (various times).

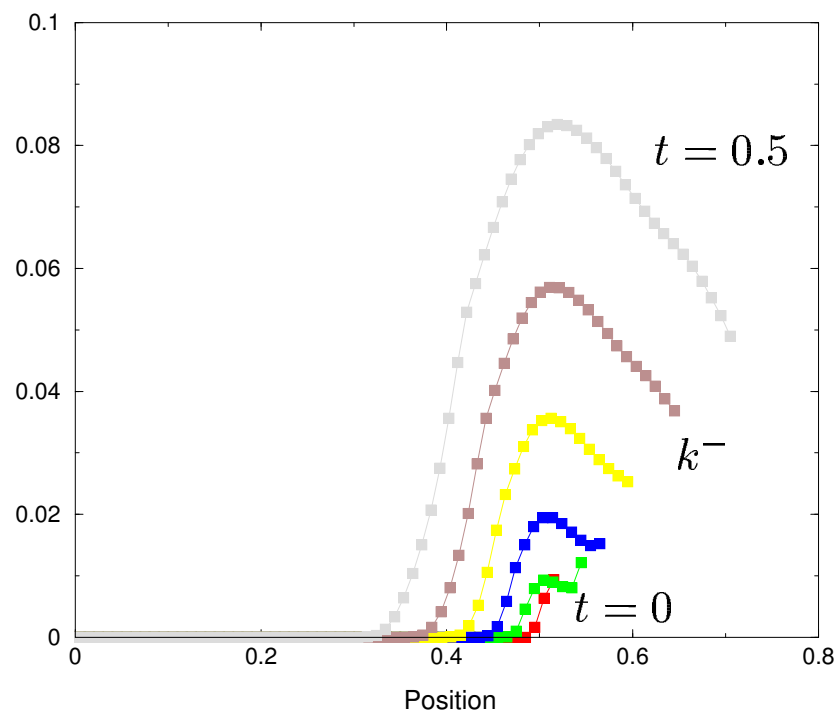
is also equal
 $\rho = \alpha_1 \rho_1 + \alpha_2 \rho_2$.
 If two fluids are
 incompressible and since
 α_1 and α_2 have
 linear profiles in the TMZ
 → $\bar{\rho}$ linear profile



→ $\bar{\rho}$ roughly linear
 ρ_1 and ρ_2 are not
 strictly incompressible here
 (value of $\bar{\rho}$ at the edge)

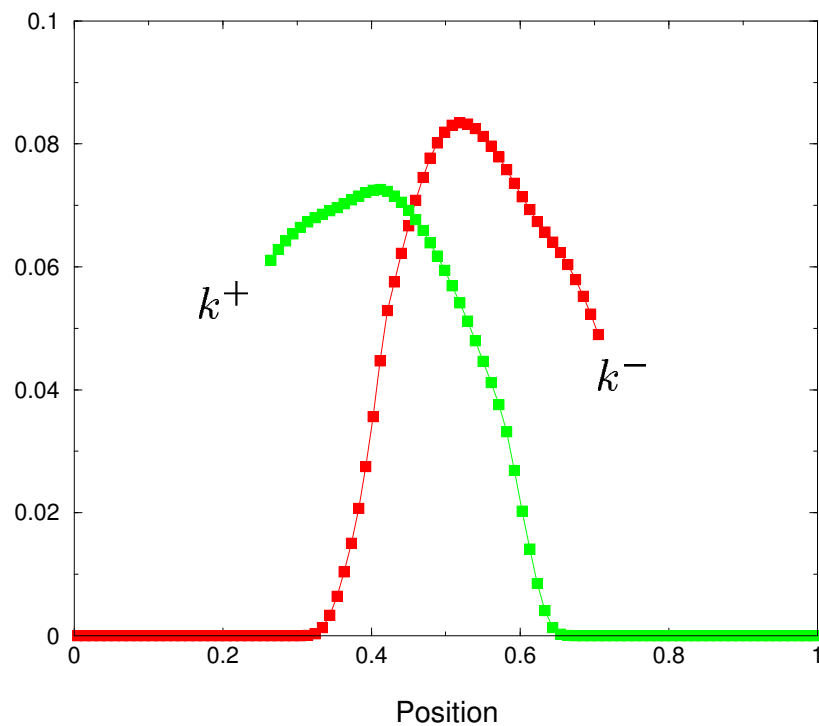


Per mass turbulent kinetic energy (various times).



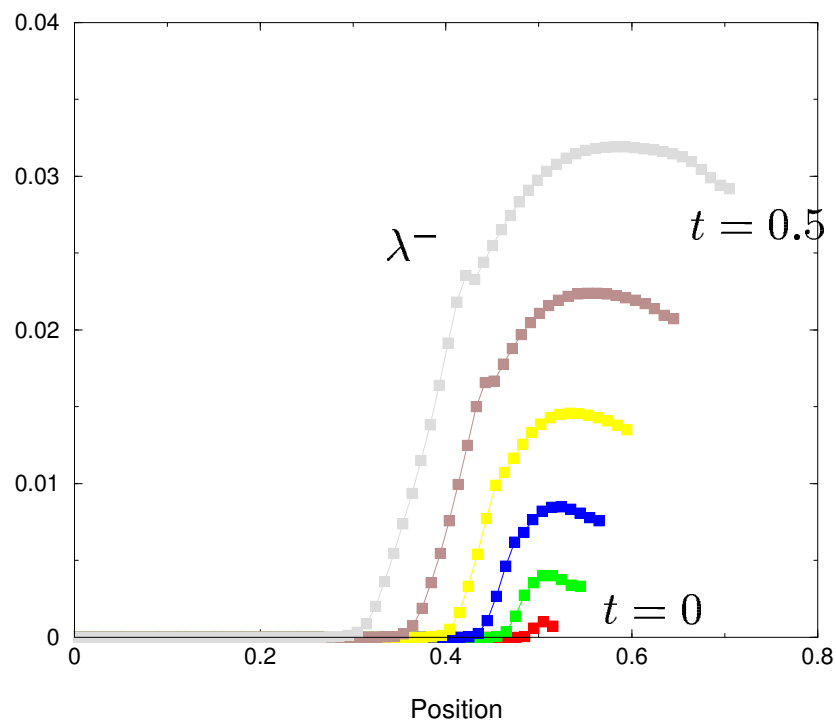


Per mass turbulent kinetic energies (same time).



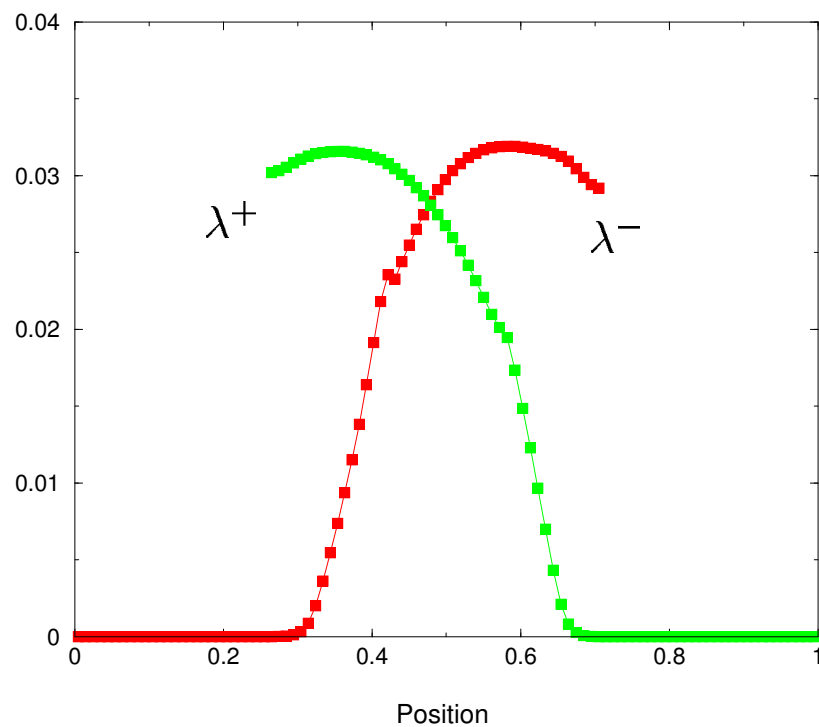


Turbulent length scale (various times).





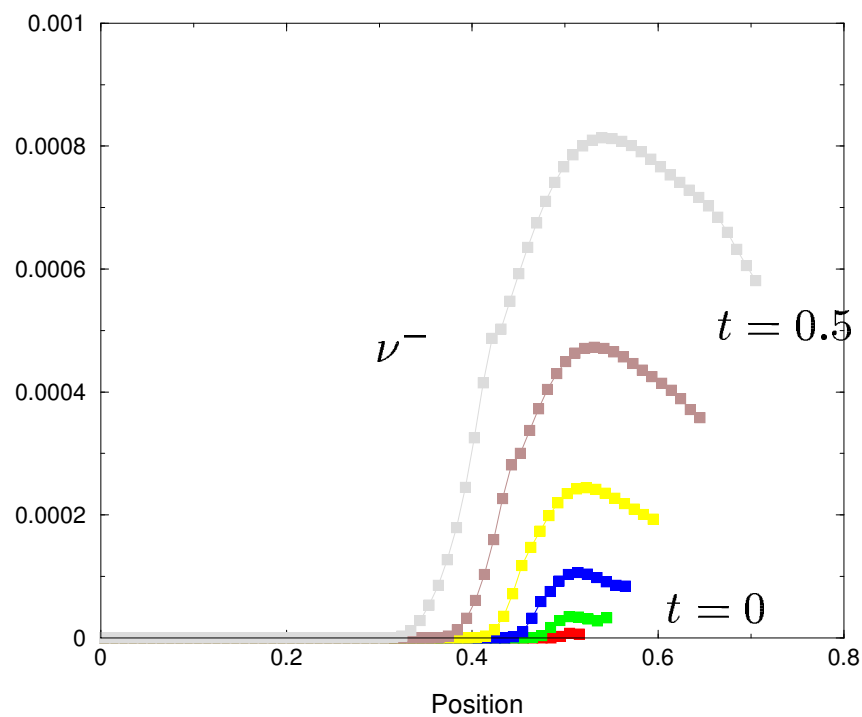
Turbulent length scale (same time).



➤ in this example:
 $\lambda_{\max} \approx 0.03$
 $L_{\text{TMZ}} \approx 0.4$
turbulent Knudsen number :0.075

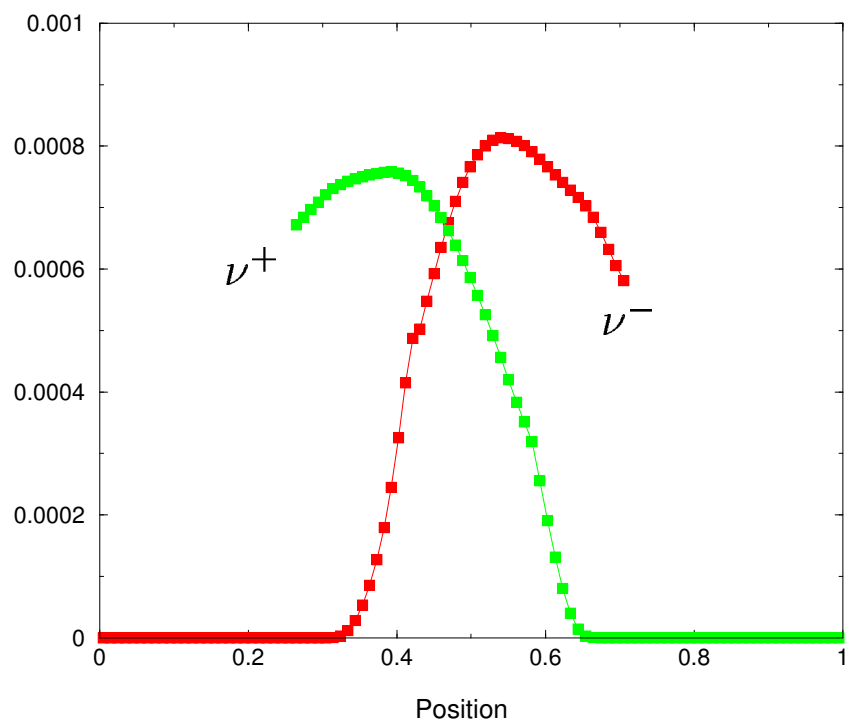


Turbulent viscosity (various times).



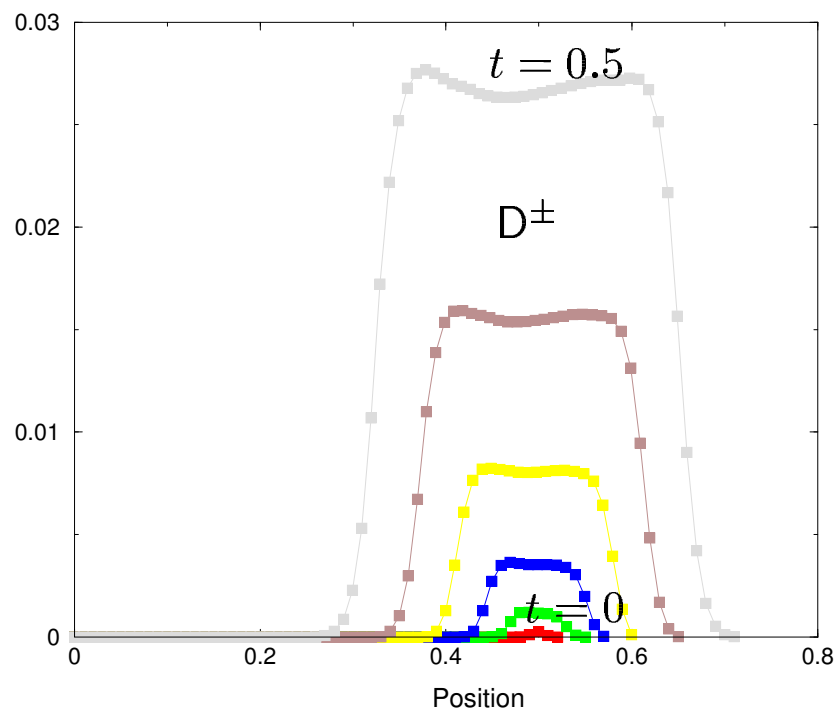


Turbulent viscosity (same time).





Diffusion (various times).



☛ in this example:

$$D_{\max}(t = 0.5) \approx 0.03$$

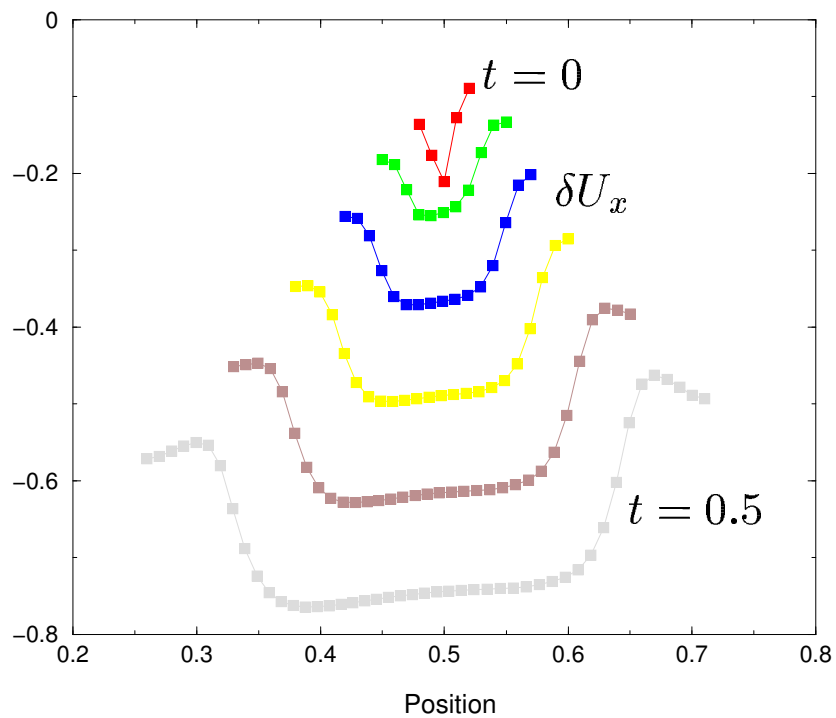
$$L_{\text{TMZ}}(t = 0.5) \approx 0.4$$

$$\dot{L}_{\text{TMZ}}(t = 0.5) \approx 1.6$$

normalized D_{\max} : 0.05

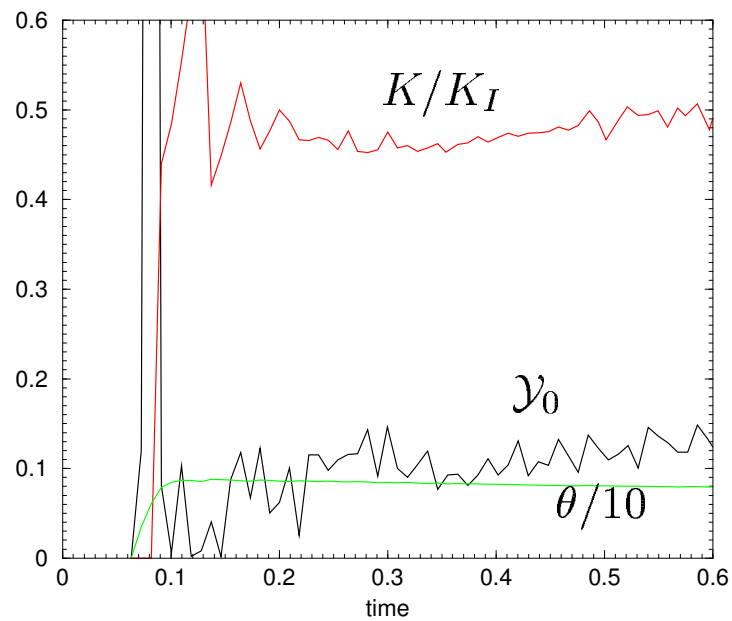


δU (various times).





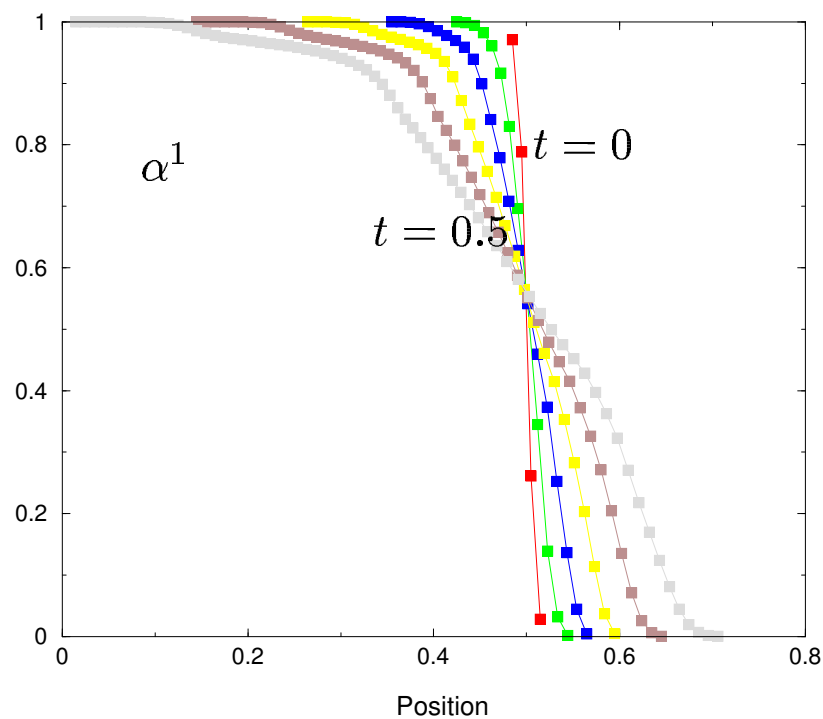
Growth rate, mixing rate, level of dissipation ($A_t = 0.8$).





Volume fraction of light fluid (various times).

self similar evolution
developed turbulence
in the TMZ)



Volume fractions of fluids
are not linear over the TMZ
for high Atwood 0.8.
In agreement with EXP
and DNS