A measure of turbulent diffusion in two and three dimensions

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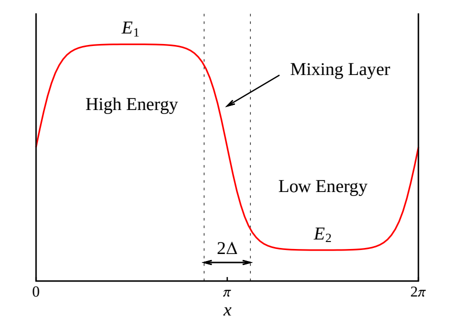
Presentation of the problem

2 turbulent flows put aside with different kinetic energies :

- a high energy field on the left of energy E_1
- a low energy field on the right of energy E_2



Mixing layer thickness : $\Delta(t)$

$\Delta(0) \approx l$ (integral scale)

$l \approx D/80$

Periodic boundary conditions : 2 mixing layers in the simulation

Presentation of the problem

Main goals :

- Study the turbulent diffusion through the evolution in time of the mixing layer
- Compare 2D and 3D cases

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Shearless mixing layers show the following properties:

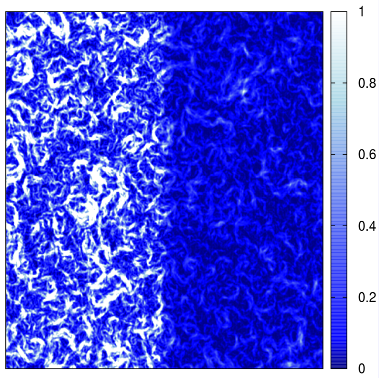
- No gradient of mean velocity → no kinetic energy production
- Mixing generated by the inhomogeneity in the turbulent kinetic energy
- Intermittent behavior at both large and small scales (EC-512, 2009)
- Gradient of energy : sufficient condition for the onset of intermittency (Phys.Rev.E, 2008)
- 2D and 3D mixings → show a very different behaviour

A visualisation

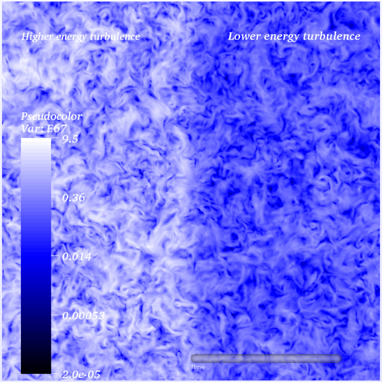
Kinetic energy : evolution in time

Initial energy ratio : $E_1/E_2 = 6.6$

2 D



3 D



Important remarks

Main parameter : Initial energy ratio E_1/E_2

The system has been studied using the values :
$E_1/E_2 = 6.6, 40, 300, 10^4, 10^6$

In the Navier Stokes equation :

$$\partial_t \mathbf{u} + (\mathbf{u} \cdot \nabla)\mathbf{u} = \frac{1}{\rho}\nabla p + (-1)^{p+1}\nu_n \Delta^{2n}\mathbf{u}$$

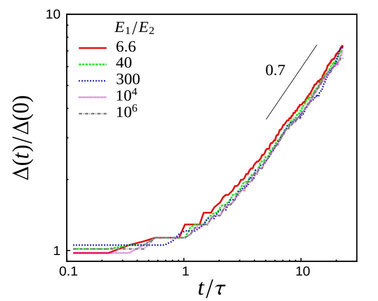
2D : An hyperviscous coefficient ($n = 2$) has been used

3D : The total energy decays faster than in 2D

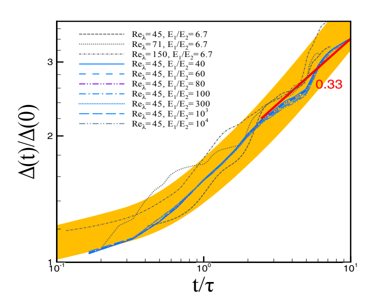
Evolution of the mixing layer

Time evolution of the mixing layer thickness $\Delta(t)$:

2 D



3 D

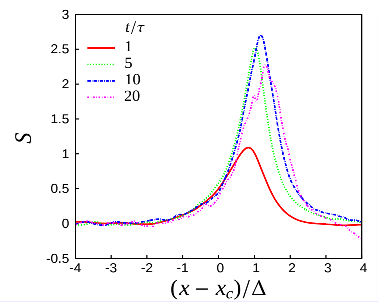


$\Rightarrow$ 2D mixes faster !

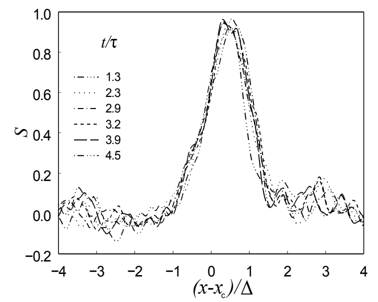
Velocity statistics

Skewness (computed along the homogeneous y direction)

2 D



3 D

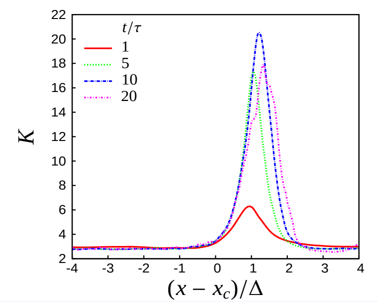


$E_1/E_2 = 10^4$

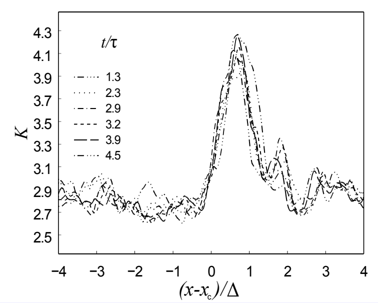
Velocity statistics

Kurtosis (computed along the homogeneous y direction)

2 D



3 D

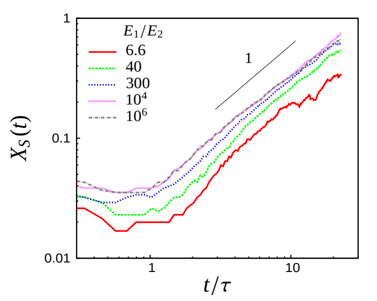


$E_1/E_2 = 10^4$

Velocity statistics

Position of the maximum of skewness X_S

2 D

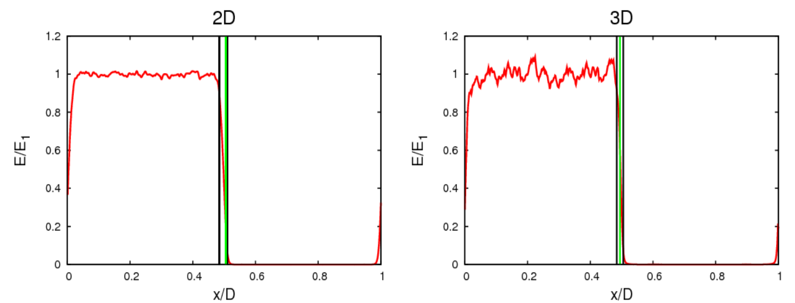


2D $\Rightarrow X_S(t) \propto t$ evolves faster than $\Delta(t) \propto t^{0.7}$

3D $\Rightarrow X_S(t) \propto \Delta(t) \propto t^{0.33}$

Time evolution

Time evolution of the energy profile :



—— Mixing layer
—— Position of the maximum of skewness

Total time in both cases : $\sim 22\ \tau$

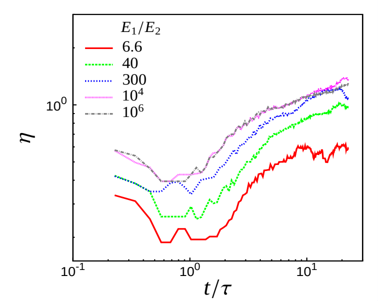
Velocity statistics

Evolution of the penetration $\eta = X_S/\Delta$

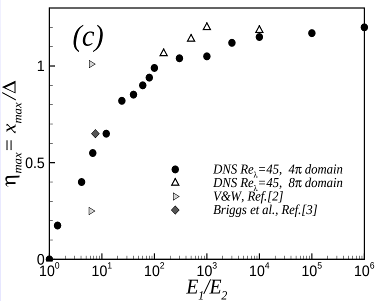
$2D \Rightarrow \eta(t)$ diverges

$3D \Rightarrow \eta(t)$ reaches a constant value : η_{max}

2 D



3 D



Memory

Proposal of a memory measure **as a global quantity referred to its own time derivative**, for example

$$MEM = \frac{\Delta}{\Delta'}$$

2D : $\frac{\mathrm{d}\Delta(\mathrm{t})}{\mathrm{d}t} \sim t^{-0.3}$, 3D : $\frac{\mathrm{d}\Delta(\mathrm{t})}{\mathrm{d}t} \sim t^{-0.67}$

2D : $\mathbf{MEM} = \frac{\mathbf{\Delta(t)}}{\mathbf{\Delta(t)_t}} \sim \mathbf{1.4t}$, 3D : $\mathbf{MEM} = \frac{\mathbf{\Delta(t)}}{\mathbf{\Delta(t)_t}} \sim \mathbf{3t}$

different dimensionality, same trend (qualitative universality?), with a different coefficient

3D has a slightly longer memory than 2D

Conclusions

Comparison between the 2D and 3D situation :

Similarities :

- $\Delta(t)$ evolves asymptotically in time as a power law
- A strong intermittency $\rightarrow$ visible on the high order moments

Differences :

- Mixing is faster in 2D
- No autosimilarity in time in the 2D case

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Possible explanation :

The evolution of $\Delta(t)$ is essentially led by the large scales
2D→ energy tends to concentrate to the large scales (inverse cascade)