Dimensionality influence on the passive scalar transport observed through experiments on the turbulunce shearless mixing

S.Di Savino, M. Iovieno, L.Ducasse, D.Tordella,

Dipartimento di Ingegneria Aeronautica e Spaziale, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy

The transport of a passive substance by a turbulent flow is important in many natural and engineering contexts, e.g. turbulent mixing, combustion, pollution dispersal. The evolution of the scalar concentration is not only a footprint of the organized velocity structures, but the scalar statistics are in part decoupled from those in the velocity field, showing an intrinsic intermittency, with large fluctuations on small scales which dominate high moments [1, 2].

We would like to present new results concerning the passive scalar turbulent transport in two and three dimensions in a simple, but not trivial, inhomogeneous flow, see fig.1. The dimensionality of the field induces differences in the transport characteristic velocity, length scales, and temporal scaling, although qualitative similarity is retained in the general trend and in the shape of the the scalar flux and moment distributions. We go one step beyond the homogeneous isotropic turbulence and consider the simplest inhomogeneous and shearfree turbulent Navier-Stokes motion: the system where one energetic turbulent isotropic field is left to convectively diffuse into a low energy one. In this system the region where the two turbulences interact is associated to a high intermittent thin layer - where the energy flux is maximum - that propagates into the low energy region [4, 5]. The very presence of the interaction zone offers the way to carry out independent numerical measurements of the (long-term temporal) time dependent turbulent diffusivity. By means of Eulerian one-point statistics, we observed the turbulent energy interaction width and the passive scalar variance width. Spectra, probability density function, flux, variance, velocity derivative statistics have been obtained, a few of them are presented in this abstract.

In synthesis, we have seen that the diffusion in 2D is faster then in 3D. In particular the time scaling of the growth of the interaction width is superdiffusive in 2D ($\Delta \sim t^{0.68}$), while it is very slightly subdiffusive in 3D ($\Delta \sim t^{0.46}$), see fig.2. The time evolution of these interaction widths are equal to that observed for self-diffusion of the velocity field with the same dimensionality (that is, in the absence of the passive scalar, the turbulent diffusion associated to the mean flow of turbulent energy induced by the presence of a turbulent energy gradient, see again fig.2 and [4, 5, 8]). This seems to indicate that the passive scalar field follows the fluctuation velocity field. However, if we remove the turbulent energy gradient, the interaction widths remain unchanged, either in the 2D or 3D case. And this send back, on the one hand, to the decoupling of the velocity-scalar fields, and, on the other, to a possible universal growth of the turbulent diffusion layer across an interface. The presence of the turbulent energy gradient is instead felt on the distribution across the layer of local statistical quantities, as the skewness and kurtosis, see fig.3 (left and central parts, respectively). These depart from symmetry/antisymmetry with respect to the interface, respectively, when the energy gradient is absent. It should be noted that the passive scalar fields, differently from the velocity fields, present two intermittency layers released by the interface in opposite directions. In fig. 3, passive scalar and velocity spectra are shown on the right. In two dimensions, the passive scalar decay in the inertial range is less than that of the velocity field, while in three dimensions, the difference is very mild. The intermittency on the scalar fluctuations is not only limited to large scales but spreads also to the small

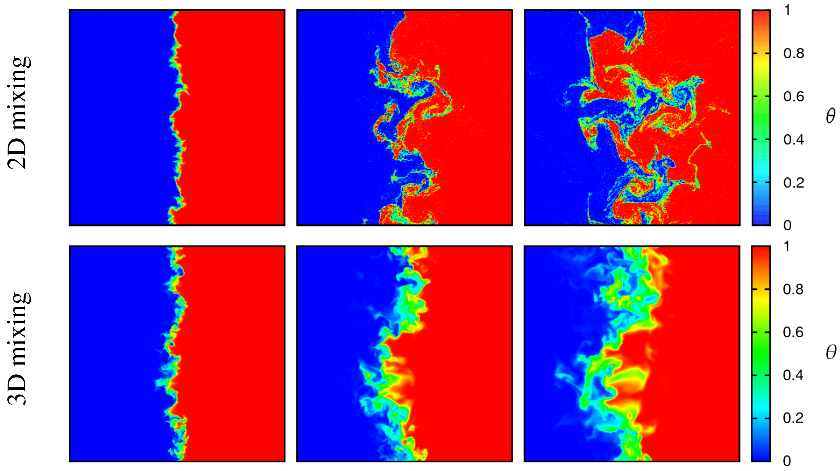

Figure 1: Visualization of the scalar field. The high turbulent energy velocity field is on the left of each image. The three different instants correspond from left to right to $t/\tau = 1, 5, 10$, respectively. The 3D simulation has an initial R_λ equal to 150 in the high energy isotropic region and 60 in the low energy region. [Full time history: *2D-movie*, *3D-movie*]

scale fluctuations, as can be seen in the derivative skewness and kurtosis in fig.4, where two distinct regions of high kurtosis can be observed at both edges of the mixing layer.

The results are obtained from direct numerical simulations of the diffusion of the passive scalar across the interface which separates the two isotropic decaying turbulent fields with different kinetic energy. The size of the computational domain is $4\pi \times (2\pi)^2$ (discretized with 1200×600^2 grid points) in the 3D simulations and $(2\pi)^2$ (discretized with 1024^2 grid points) in the 2D simulations [6, 7]. For details on the numerical technique, see [4, 5].

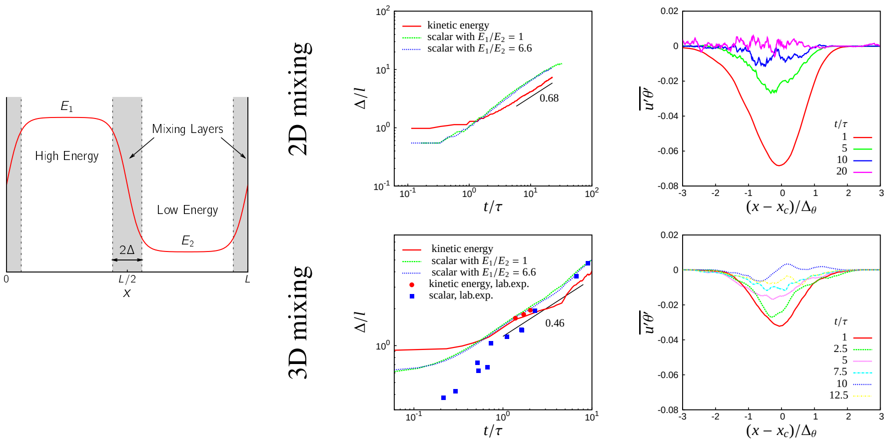

Figure 2: Left: Scheme of the numerical domain. Center and Right: Interaction layer thickness, normalized with the initial integral scale ℓ, and scalar flow $\overline{u'\theta'}$. The scalar layer thickness Δ_θ is defined as the distance between the points where $\overline{\theta}$ is equal to 0.25 and 0.75. The energy layer thickness is defined as the distance between the points where the normalized turbulent kinetic energy $(E-E_2)/(E_1-E_2)$ is equal to 0.25 and 0.75 as in [5]. Experimental data are from the wind tunnel experiments by Veeravalli and Warhaft [3] with $E_1/E_2 = 7$.

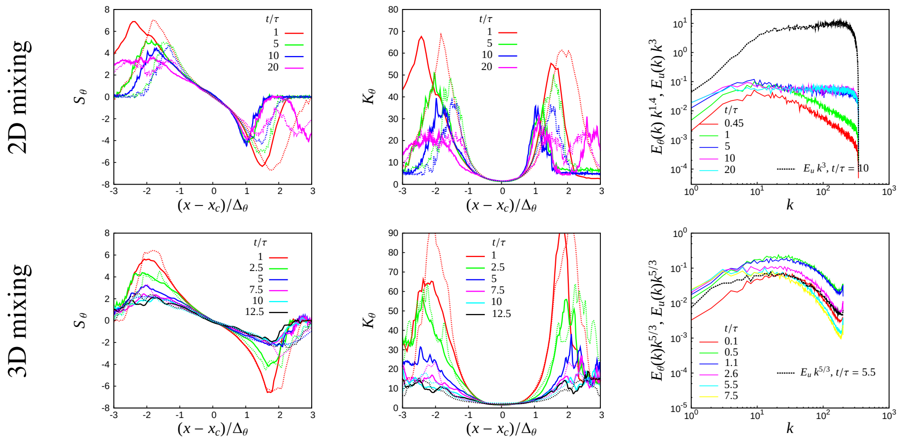

Figure 3: Scalar skewness and kurtosis distributions across the interaction layer (the full lines correspond to the case where the turbulent energy gradient is present, $E_1/E_2 = 6.6$, and the dashed lines to the case where $E_1/E_2 = 1$) and compensated one-dimensional scalar (full lines) and velocity (black dotted lines) spectra in the centre of the mixing layer. The spectra refer to simulations where the turbulent energy gradient is present.

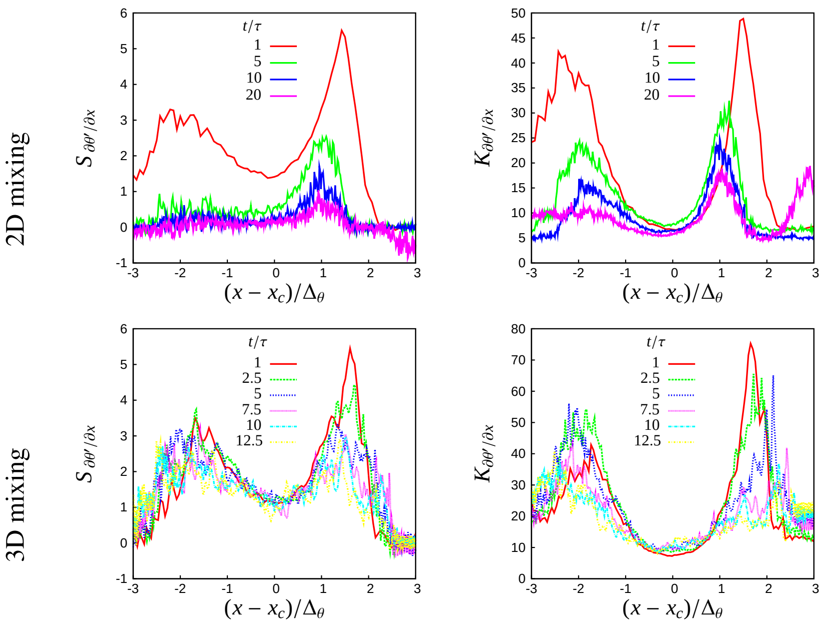

Figure 4: Scalar derivative in the inhomogeneous direction statistics across the mixing layer.

References

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