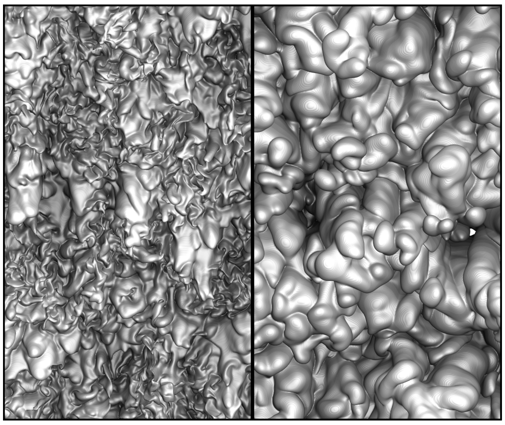
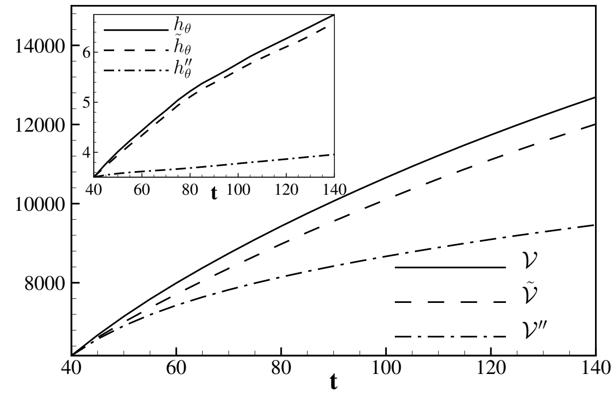
CAUSALITY IN TURBULENT ENTRAINMENT OF A PASSIVE SCALAR IN FREE-SHEAR FLOWS

G. Boga, E. Stalio and A. Cimarelli
DIEF, University of Modena and Reggio Emilia, 41125 Modena, Italy.
E-mail: gabriele.boga@unimore.it; enrico.stalio@unimore.it; andrea.cimarelli@unimore.it

Numerical experiments on the turbulent entrainment and mixing of scalars in an incompressible temporal planar jet flow [1] have been performed [2]. These simulations are based on a scale decomposition of the velocity field, thus allowing the establishment from a dynamic point of view of the evolution of different scalar fields under the separate action of large-scale coherent motions and small-scale fluctuations, see Figure 1(a). This is the main novelty that differentiates the present work from other studies dealing with the analysis of flow realization snapshots, e.g. [3], [4] and [5]. The turbulent spectrum can be split into active and inactive flow structures. The large-scale engulfment phenomena actively prescribe the mixing velocity by amplifying inertial fluxes and by setting the area and the fluctuating geometry of the scalar interface [6]. On the contrary, small-scale isotropic nibbling phenomena are essentially inactive in the mixing process. It is found that the inertial mechanisms initiate the process of entrainment at large scales to be finally processed by scalar diffusion at the molecular level. This last stage does not prescribe the amount of mixing but adapts itself to the conditions imposed by the coherent anisotropic motion at large scales. The effectiveness of the large-scale motions in prescribing a large scalar interface area and in maintaining steep scalar gradients resulted in a faster growth in entrained volume with respect to the one induced by small-scale fluctuations, as shown in Figure 1(b). Additionally, the presence of protruding bulges on the scalar interface generated by large-scale motions resulted in a faster growth of the jet width with respect to the small-scale case, as can be seen in the inset of Figure 1(b). The present results may have strong repercussions for the theoretical approach to scalar mixing, as anticipated here by simple heuristic arguments which are shown able to reveal the rich dynamics of the process. Interesting repercussion are also envisaged for turbulence closures, in particular for large-eddy simulation approaches where only the large scales of the velocity field are resolved.


(a)



(b)

Figure 1. (a) Instantaneous scalar interface ($\theta_{th} = 0.02\Theta_{cl}$) in the two experiments at time $t = 120$: small-scale driven scalar field (left) and large-scale driven scalar field (right). (b) Temporal evolution of the entrained volume $\mathcal{V}$ and of the position of the interface h_θ (inset) for the scalar field driven by the unfiltered velocity field $\mathcal{V}$ and h_θ (solid line), by the large-scale velocity field $\tilde{\mathcal{V}}$ and $\tilde{h_\theta}$ (dashed line) and by the small-scale velocity field $\mathcal{V}''$ and h''_θ (dashed-dotted line).

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