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Two-dimensional shearless turbulent mixing: kinetic energy self diffusion, also in the presence of a stable stratification

F. De Santi[1], L. Ducasse[1], J. Riley[2], D. Tordella[1]
[1]Dipartimento di Ingegneria Aeronautica e Spaziale, Politecnico di Torino, Italy
[2]Mechanical Engineering Department, University of Washington, WA

Two-dimensional turbulence is important in many natural and engineering contexts. It presents some special and interesting phenomena that does not occur in three dimensional turbulence. Moreover, it also idealizes geophysical phenomena in the atmosphere, oceans and magnetosphere and provides a starting point for the modeling of these phenomena [1, 2, 3, 4]. In this contest, we would like to present new results concerning the turbulent energy transport in the simplest kind of two dimensional inhomogeneous flow, a turbulent shearless mixing process generated by the interaction of two isotropic turbulent fields with different kinetic energy but the same spectrum shape [5]. The self diffusion of kinetic energy is observed in two cases: with and without a stable density stratification.
In the unstratified case the simulations of mixing with different values of the energy ratio show that, asymptotically in time (in the limit of the observed range), the turbulent diffusion is much larger than the one measured in three dimensions[6, 7], see the full time history in the *movie*. The analysis of velocity third and fourth moments indicates that the flow is highly intermittent. Moreover, the temporal autocorrelation of the vorticity, at some fixed points, does not depend on the ratio of energy used and on the position. We can interpret this results in term of the existence of a long-range interaction.
In the stratified case the evolution of the flow changes significantly [8, 9]. The energy profile in the mixing region is lower than the minimum value imposed by the initial condition, which shows the effect of the buoyancy force work. Finally, the velocity skewness enlightens the generation of an inverse energy flow and intermittent penetration from the low to the high energy field even in the case of mild stratification.

In the following images, Fig. 1 e 2, we show a few results related to the stratified case.

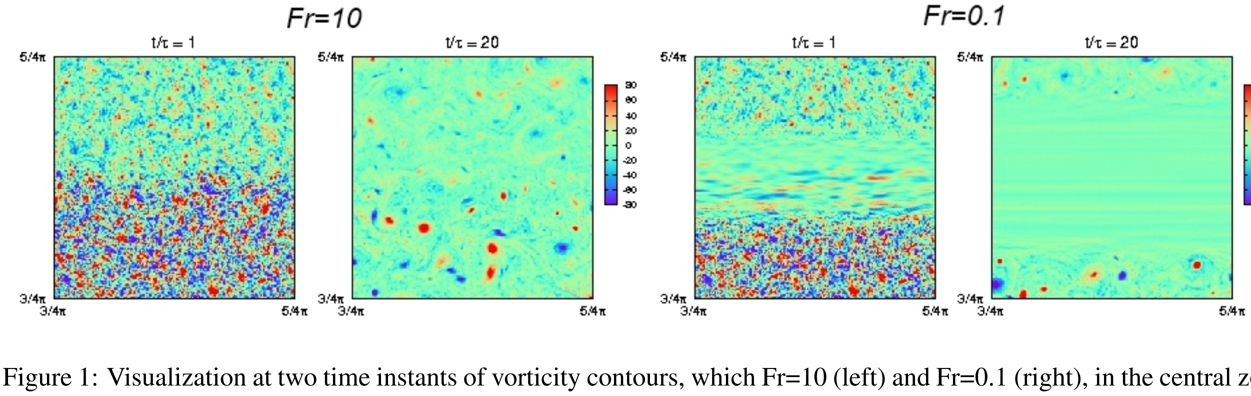

Figure 1: Visualization at two time instants of vorticity contours, which Fr=10 (left) and Fr=0.1 (right), in the central zone of the analytical domain. By increasing the stratification inhibition of vertical motion is prevalent enough, in respect to the turbulent diffusion, to lead to a layer of zero vorticity in the middle of the domain. See the full time history of the *vorticity* and the *density* at Fr=10 (low level of stratification). See also the full time history for the *vorticity* and the *density* at Fr=0.1 (high insensitive stratification). The simulations are carried out in a domain of 1024×1024 points, estimates Re_λ of order of 100.

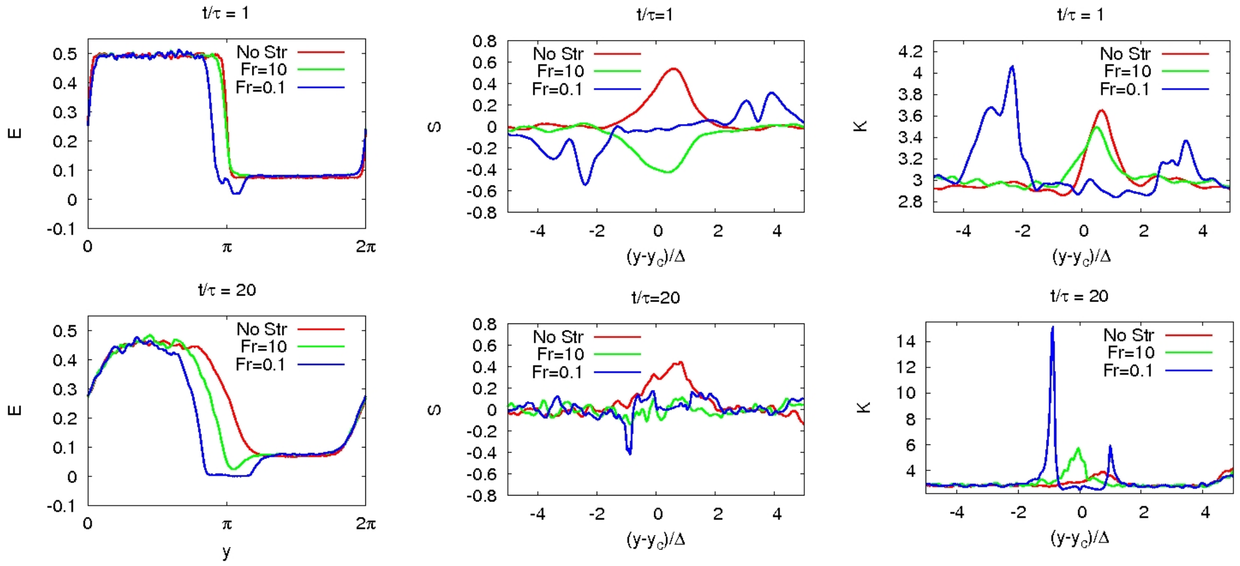

Figure 2: Visualization at the same two time instants considered above of the kinetic energy profile (on the left), the skewness (in the center) and the kurtosis (on the right) of the velocity component in the inhomogeneous direction. Here x_c indicates the mixing layer center and Δ the mixing layer thickness. By the profile of kinetic energy we observe a sharp decrease of energy in the mixing interface: closer to the interface, the work done by buoyancy forces reaches its maximum value and the interface behaves like an energy hole. For stratification very strong, at initial times the skewness presents almost symmetry: in the high energy field it is negative, in the low one it is positive and it is zero in the separation layer. This trend is preserved in time but the peaks lower and the central area shrinks. After 20 time scales the skewness zero zone disappears and a peak is predominant at the interface between zone of high energy and separation layer. Conversely, the intermediate case, Fr=10, presents a nearly symmetrical distribution of the third moment when compared with the unstratified case. Evolving over time, the peaks moves increasingly to high energy field zone (inverse energy flux). The intermittent behavior of these flows can be analyzed even looking at the fourth moment of velocity in the inhomogeneous direction. For Fr=0.1 there are two peaks: one at the interface between the high energy zone and the middle layer, and a smaller one at the other interface. These peaks are getting higher and more distant in time. For Fr=10 kurtosis evolves not so far from what occurs in the non stratified case, but the peak is slightly lower and moving to the high energy field.

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