Large and small scale aspects of the turbulent entrainment in jets

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Abstract

This work analysis several large and small scale aspects of the turbulent entrainment mechanism that exists in mixing layers, wakes, and jets. In these flows flow field can be divided into two regions. In one region the flow is turbulent (T) and its vorticity content is high, while in the other region the flow consists of largely irrotational (nonturbulent - NT) flow. The two flow regions are divided by the turbulent/nonturbulent (T/NT) interface where the turbulent entrainment mechanism takes place.The physical mechanisms taking place at the T/NT interface is important in many natural and engineering flows since important exchanges of mass, momentum and passive or active scalar quantities take place across the T/NT interface. It was assumed in the past that the turbulent entrainment mechanism is mainly driven by "engulfing" motions caused by the large scale flow vortices, but recent experimental and numerical works give more support to the original model of Corrsin and Kistler [1] where the entrainment is primarily associated with small scale ("nibbling") eddy motions (Mathew and Basu [2], Bisset *et al.*[3], Westerweel *et al.*[4], Holzner *et al.* [5]). However, it is assumed that the entrainment and mixing rates are largely determined by the large scales of motion.

The present work uses a direct numerical simulation (DNS) of a turbulent plane jet at $Re_\lambda \approx 120$ in order to analyze several large and small scale aspects of the turbulent entrainment and particularly their interplay. Figure 1 shows contours of vorticity modulus for this simulation. The T/NT interface is detected using a similar procedure than the one described in previous works (figure 2). Conditional statistics of the vorticity norm and vorticity components in relation to the distance to the T/NT interface are given in figure 3. The vorticity is zero in the irrotational flow region, rises steeply across the T/NT interface, and is more or less constant inside the turbulent region.

Recently da Silva and Pereira [6] analyzed the invariants of the velocity-gradient, rate-of-strain, and rate-of-rotation tensors across the T/NT interface in order to characterize several aspects of the small scale dynamics near the T/NT interface. In the present work

we focus on the intense vorticity structures (IVS) from the flow, as defined by Jiménez [7], in order to analyze the interplay between the large and small scales of the flow during the turbulent entrainment. Notice that right at the T/NT interface the flow lacks these large scale structures, in agreement with the analysis from da Silva and Pereira [6] (see figure 4). An interesting result is the existence of non negligible viscous dissipation rate outside the turbulent region. It turns out that this interesting phenomena is caused the the presence of IVS near the T/NT interface (Fig. 5). The presentation will focus on how the presence of these IVS commands the evolution of many small scale quantities and ultimately imposes the entrainment rate.

Keywords: Turbulent entrainment, intense vorticity structures, kinetic energy and enstrophy dynamics, invariants of the velocity-gradient, rate-of-strain, and rate-of-rotation tensors.

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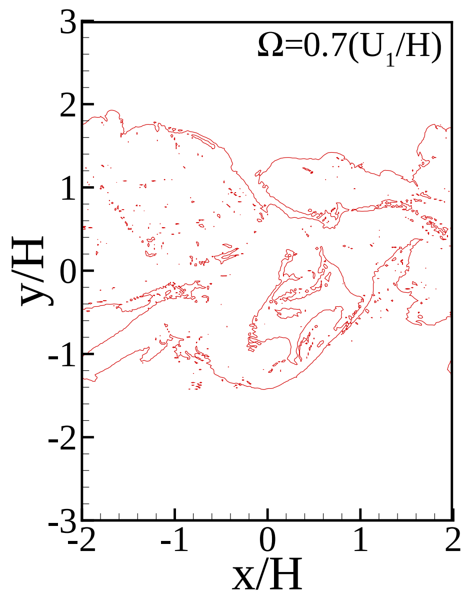

Figure 1: *Contours of vorticity modulus corresponding to $\Omega = 0.7U_1/H$ in a (x, y) plane of the jet at $T/T_{ref} = 27$*

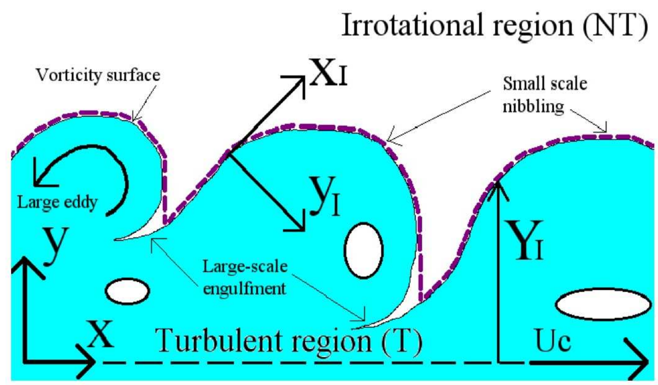

Figure 2: *Sketch of the T/NT interface for the plane jet indicating the vorticity surface (solid line) and the interface envelope (grey dashed lines). The sketch shows also the coordinate system used in the computation of the plane jet (x, y) and the one used to analyse the T/NT interface (x_I, y_I).*

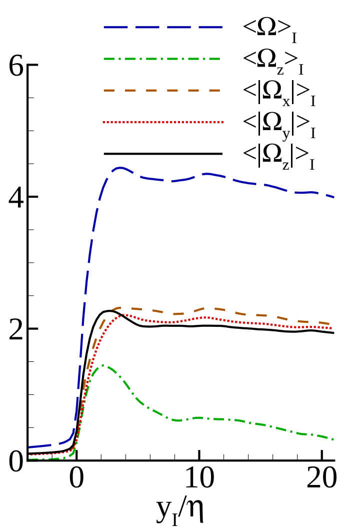

Figure 3: *Conditional mean profiles of the vorticity norm and its components in relation to the distance from the T/NT interface.*

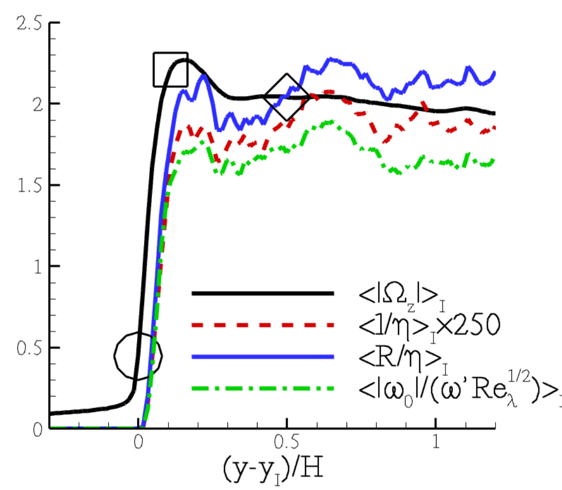

Figure 4: *Conditional mean profiles of radius, lenght, and vorticity of the intense vorticity structures (IVS) in relation to the distance from the T/NT interface.*

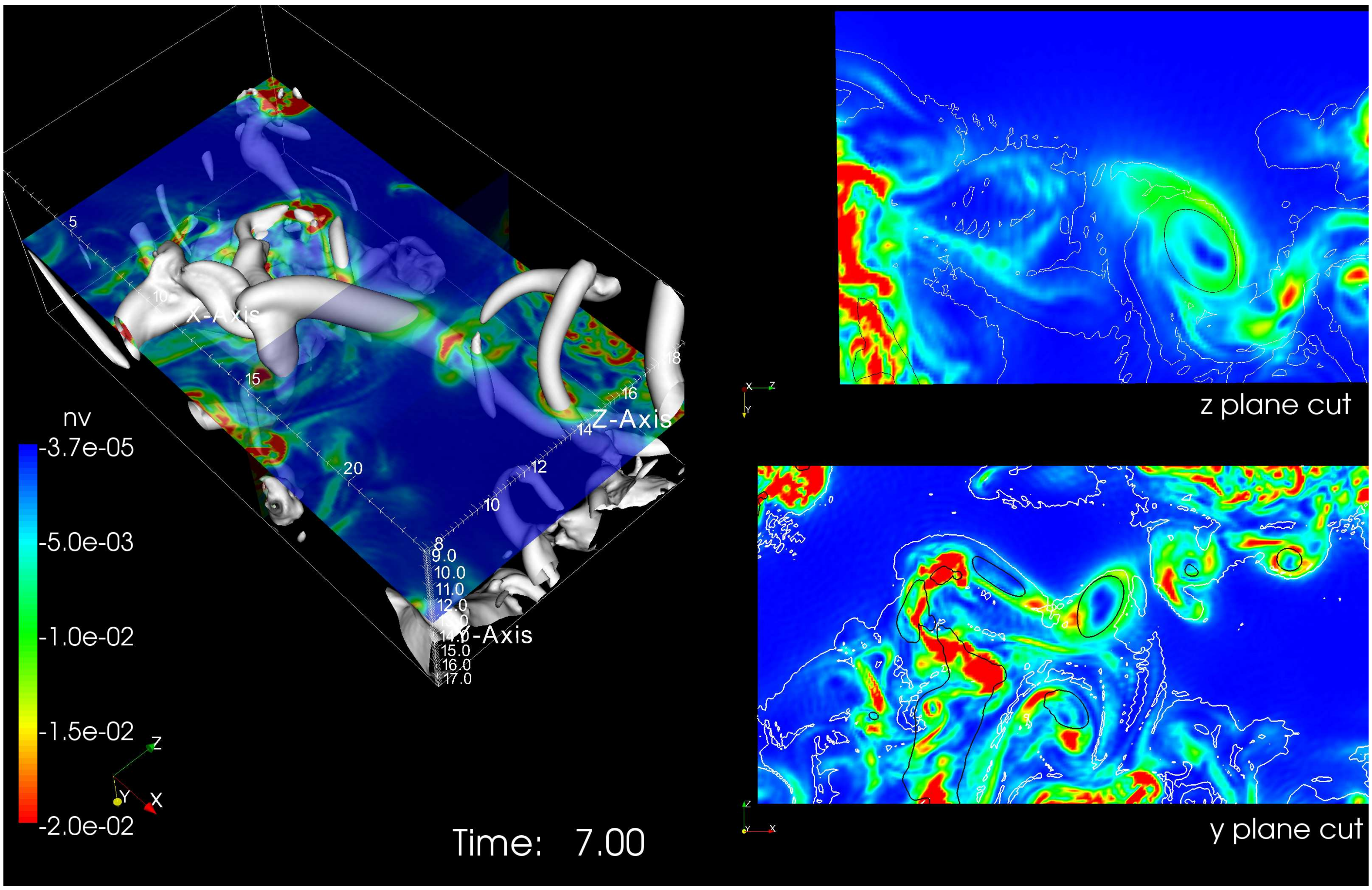

Figure 5: The role of the intense vorticity structures (grey) on the generation of irrotational viscous dissipation (contours) outside the turbulent region, near the T/NT interface (white). The plot shows only a small subdomain of the computation.