DYNAMICS OF SCALAR VARIANCE AND DISSIPATION AT THE T/NT INTERFACE OF A JET

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INTRODUCTION

In free shear flows, such as jets, a sharp and intricate layer separates the irrotational region from the turbulent core of the flow. This layer establishes an interface region - the *T/NT interface* - across which the exchanges of mass, energy and momentum take place. A considerable amount of effort has been put recently, into understanding the local dynamics that take place at such interface region. Recently it was hinted that the main entrainment mechanism is *"nibbling"* acting at the smallest scales [1], rather than engulfing promoted by the large eddies [2].
The analysis of the geometric properties of both the T/NT interface and its neighbour vorticity structures has shown that the interface is *"made of"* these turbulent structures, whose radius is seen to be of the order of the Taylor micro-scale in the case of shear flows [3]. More recently the role of the intense vorticity structures (IVS) at the T/NT interface was also analysed [4] leading to similar conclusions. The developments in the methods used to study the local dynamics also allowed a detailed study of the exchanges in the kinetic energy between the turbulent and irrotational regions of the flow hinting that non-viscous mechanisms play a central role in the entrainment process [5].
Numerous studies showed that chemical reactive flows can be quite satisfactorily modelled using flamelet models, assuming a thin reaction zone and sufficiently fast chemistry [6]. This models assume flames to be an ensemble of laminar flames, where the thermochemical properties can be described as a function of a scalar, or set of scalars, whose transport equations have to be resolved. Namely, the simplest models describe such properties as a function of the mixture fraction, that can be treated as a passive scalar. Thus a passive scalar, and its dissipation, play a major role since small errors in its prediction may lead to very large errors in the prediction using flamelet models [7]. Moreover, taking into account not only the average value but also the fluctuations of the mixture fraction allows LES for more accurate predictions of combustion, in particular for secondary species of interest for pollutant dispersion analysis [6].

NUMERICAL METHOD

The present work focuses on the study of the dynamics of the mixing of a passive scalar across the T/NT interface, which is important for subjects such as pollutant dispersion, combustion and other reactive flows. The study uses data from a direct numerical simulation of a turbulent plane jet at Reynolds number of $Re_\lambda = 140$ (Fig. 1), and the Schmidt number is 0.7. Specifically we analyse locally the properties of the *"scalar interface"* and establish a comparison with the T/NT interface defined by the vorticity field. An extensive set of conditional statistics in relation to the distance to the *"scalar"* and T/NT interfaces is used to shed light on the ruling mechanisms in the scalar gradient (therein scalar dissipation) and scalar variance (*fluctuations intensity*) transport equations.

RESULTS AND DISCUSSION

Figure 2(a) shows the conditional profiles of the mean scalar field, $\langle\theta\rangle_I$, and scalar variance, $\langle\theta'^2\rangle_I$, as function of the distance from the T/NT interface. At the " scalar interface" the observed jump, in the scalar averaged profile, is much stronger than the one observed for the velocity field, however both have a width of the order of the Taylor Scale. Figure 2(a) shows also that conditional statistics relative to the T/NT and "scalar" interfaces are qualitatively and quantitatively similar, despite a small offset of a couple Kolmogorov Scales. Such offset can be explained by a faster scalar diffusive spread than vorticity, for $Sc < 1$, which means that the "scalar interface" is outside the turbulent region.
For the scalar gradient the observed jump , fig. 2(b), has a thickness of the order of the Kolmogorov scale. It is also clear that this jump is wider and its limits harder to define when using statistics conditioned to the distance from the T/NT interface" than when using the ones conditioned to the distance from the "scalar interface". In the latter it is clear that the jump has a width of $\approx 7\eta$, or $\approx 5.5\eta_B$.
Figure 2(c) shows the conditional profile of the scalar gradient, where the distance from the interface is non-dimensionalized by a "scalar Taylor scale", $\lambda_\theta = [(\theta'\theta')/(\partial\theta'/\partial x)^2]^{1/2}$. When using either its value at the "scalar interface" or at the jet core, the width of the jump is of the order of λ_θ. Instantaneous fields and local profiles (figs. 1(c), 2(d)) show evidences of a continuous "scalar interface" made of intense gradient (intense scalar dissipation) sheets wrapped around the structures defining the T/NT interface. Moreover, local profiles show that the thickness of these sheets and therefore of the "scalar interface" is of the order of the Kolmogorov scale ($\approx 8\eta$). The scalar gradient and variance transport equations were also investigated to study the ruling mechanisms of scalar mixing at the edge of the jet.
Figure 3 shows that all mechanisms are more important close to the interface and that at the turbulent core the scalar gradient budget reduces to a near perfect balance between production and dissipation. Comparing the conditional results

in relation to the T/NT and "scalar" interfaces one observes similar evolutions and a reasonable agreement in the acting width, however the levels obtained vary at some extent. At the interface vicinity, molecular diffusion takes an important role, from $-1.5\frac{y_I}{\eta}$ to $5.5\frac{y_I}{\eta}$, diffusing gradients from the production (higher strain) region towards the interface, softening the strong inhomogeneities that exist at the "scalar interface". However advection still is the local dominant mechanism for the scalar gradient transport.

Transport mechanisms dominate also the growth of scalar variance to entrained fluid, despite turbulent diffusion playing the dominant role close to the interface. Within the turbulent core, production and dissipation maintain the expected balance, but near the interface dissipation displays a negative peak close to the width of the scalar interface. From this location inwards, production assumes the dominant role, until a distance from the T/NT interface of the order of λ. The results observed suggest that the mixing of the scalar fluctuations takes place at very small scales, which creates new challenges for the subgrid-scale modelling in the context of LES, as suggested by da Silva[8].

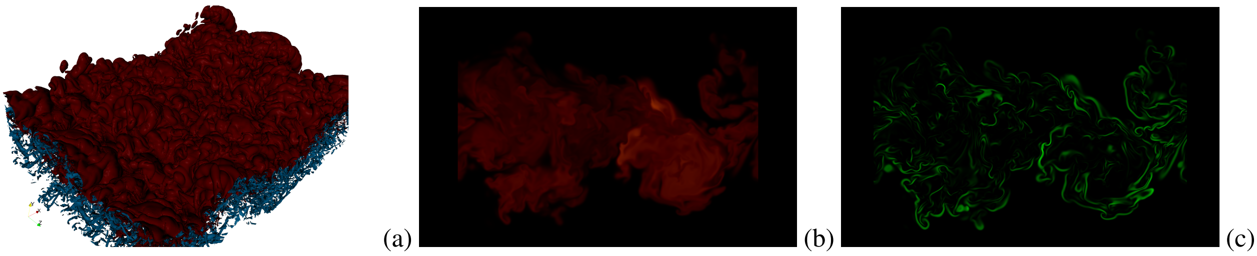

Figure 1. (a) Visualization of the T/NT interface (red) and Intense Vorticity Structures, IVS, (blue). (b) Visualization of the jet scalar field ((x,y) plane). (c) Visualization of the scalar gradient sheet structure ((x,y) plane).

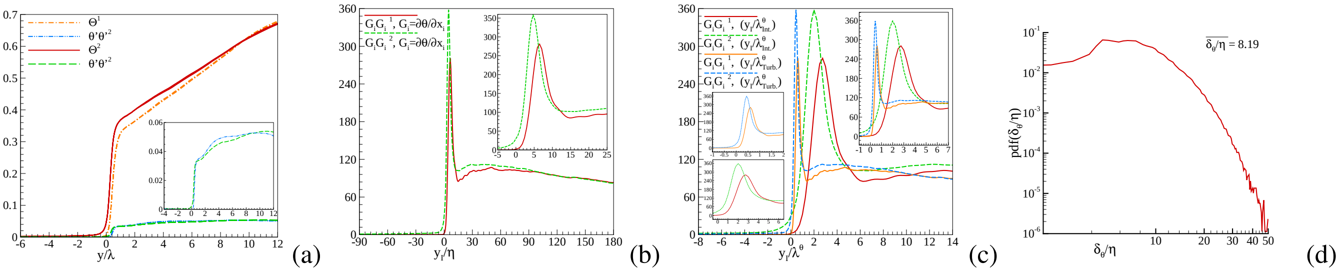

Figure 2. (a) Conditional profile of mean scalar and scalar variance. (b) Conditional profile of scalar gradient norm. (c) Conditional profile of scalar gradient norm. Note: Conditional distance to the "scalar interface" [1] and to the T/NT interface [2]. (d) Pdf of the "scalar interface" thickness.

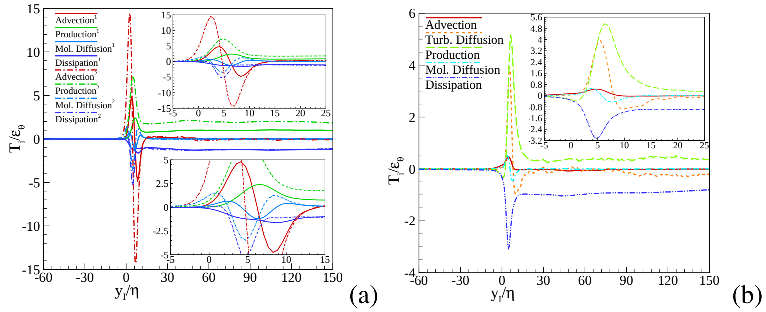

Figure 3. (a) Conditional budget of the Scalar gradient norm. (b) Conditional budget of the Scalar variance. Note: Conditional distance to the "scalar interface" [1] and to the T/NT interface [2].

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