CHARACTERISTICS OF THE TURBULENT/NON-TURBULENT INTERFACE AND VISCOUS SUPERLAYER IN TURBULENT PLANAR JETS

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ABSTRACT

The viscous super-layer and the turbulent/non-turbulent interface (TNTI) in turbulent planar jets and in shear free turbulence are analysed by means of direct numerical simulations (DNS). For the range of Reynolds numbers considered in this study ($Re_\lambda \approx 115-160$) the mean thickness of the TNTI is of the order of the Taylor-scale for the planar jet and Kolmogorov micro-scale in shear free turbulence while in both flows the mean thickness of the VSL is of the order of the Kolmogorov micro-scale.

INTRODUCTION

Turbulent entrainment (TE) is a key mechanism occurring in a variety of shear flows *e.g.* mixing layers, wakes and jets, and also in boundary layers since it governs important exchanges of mass, momentum and passive or active scalar quantities across a thin boundary separating turbulent (T) from the irrotational (or non-turbulent - NT) flow region: the so called turbulent/nonturbulent interface (TNTI) Corrsin and Kistler (1955). Detailed analysis of this TNTI interface is crucial if one is to understand exactly what the entrainment mechanism consists of, since it has been shown in recent works that TE is primarily associated with small scale (”nibbling”) eddy motions taking place in the entire interface region Westerweel *et al.* (2005, 2009) and not with ”engulfing” induced by large scale vortices.

A long standing problem concerns the existence of a *viscous super-layer* (VSL) outside the T/NT interface, where vorticity from the interior of the turbulent flow region can be communicated into the surrounding irrotational flow through a mechanism of vorticity viscous diffusion. In contrast with the T/NT interface, for which some information *e.g.* regarding its scales already exists (da Silva and Taveira 2010), scarce information exists today regarding even the existence of this viscous super-layer. For instance, even the simple observation of the viscous super-layer has been elusive Westerweel *et al.* (2005, 2009) and very few of its characteristics are know *e.g.* what is its mean thickness and whether the super-layer is continuous or somehow connected with (or imposed by) the range of eddy structures existing inside the shear layer. It is important to stress that the viscous super-layer is not to be confused with the TNTI, which is a surface associated with a strong enstrophy gradient observed near the jet edges (see da Silva *et al.* 2014). The viscous super-layer, whatever its exact definition, must lay outside the T/NT interface since the flow inside the shear layer (after crossing the T/NT interface) is dominated by an intensification of small scale turbulence which turn quickly the enstrophy production the dominating mechanism once the T/NT interface is crossed.

The present work uses direct numerical simulations (DNS) of turbulent plane jets and shear free turbulence are used to study the characteristics of the T/NT interface and of the viscous superlayer(4). Specifically we analyse the statistics of the (local) thickness and length of these two layers as well as their relation with the presence of tube and sheet like structures, and the scalar interface.

DIRECT NUMERICAL SIMULATIONS

The present work uses direct numerical simulations (DNS) of turbulent plane jets and shear free turbulence are used to study the characteristics of the T/NT interface and of the viscous superlayer (4). The simulations are detailed in reference (8). Figures 1 and 2 show a detail of one of the DNS used in this work and of the geometry of the T/NT interface, respectively.

RESULTS

Detailed analysis of the local thickness of the T/NT interface δ_ω shows that in jets and in shear free turbulence the mean thickness is $\delta_\omega \sim \lambda$ and $\delta_\omega \sim \eta$, respectively. However the local value of δ_ω changes considerably in these flows: the probability density function (pdf) of δ_ω in a jet

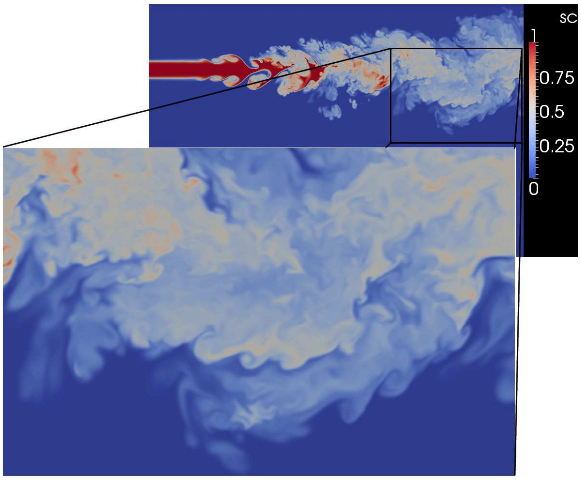

Figure 1. Side view of scalar contours in one of the DNS of turbulent planar jets used in the present work.

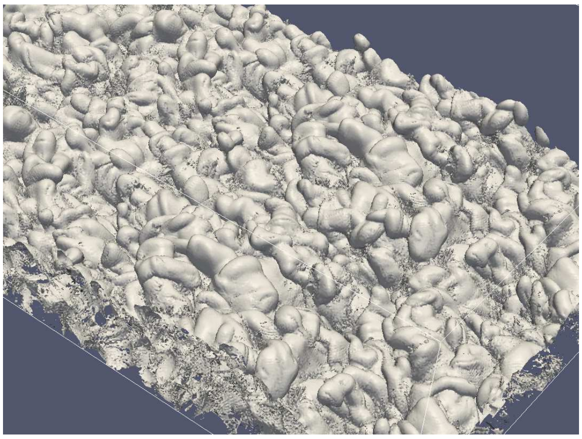

Figure 2. Detail of the Turbulent/non-turbulent interface defined through iso-surfaces of vorticity corresponding to the detection threshold in the turbulent planar jet.

shows that a plateau exists from about $3\eta < \delta_\omega < 6\eta$ showing the imprint of the intense vorticity structures in the definition of the T/NT interface in jets (da Silva *et al.* 2011).

If one defines, as originally postulated by Corsin and Kistler (1955), that the viscous superlayer is a region of ”dominating enstrophy diffusion and negligible enstrophy production” one can ’see’ that such a layer does exist. A conditional profile of the enstrophy budget as a function of the distance from the T/NT interface allows one to see the ’mean’ superlayer thickness (Fig. 3). This layer is however completely outside the T/NT interface (and is not part of it as the original sketches from Corsin and Kistler (1955) seem to imply). The superlayer is not continuos and seems to be continuous only around half circular stretches of fluid with mean length of the order of the Taylor micro-scale in jets. In contrast to what happens for the T/NT interface, the local thickness of the superlayer δ_v is of the order of the Kolmogorov micro scale $\delta_v \sim \eta$ be it in either jets or shear free turbulence (T/NT interface without mean shear). This layer can only be observed in extremely fine DNS which maybe explains why it was so difficult to see before.

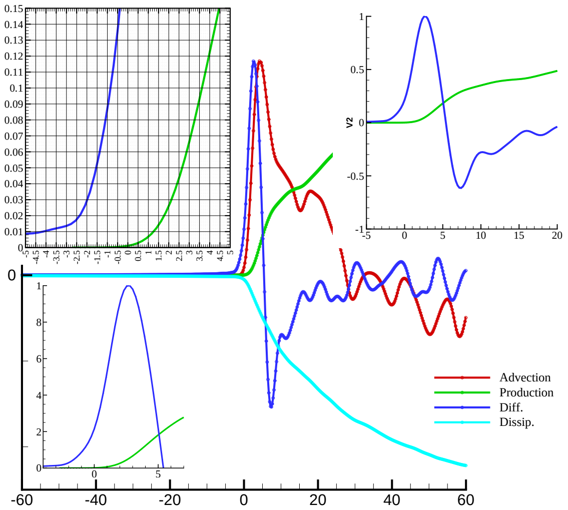

Figure 3. Conditional mean profiles (in relation to the distance from the T/NT interface) of the enstrophy transport equation (advection, production, viscous diffusion, and viscous dissipation). The horizontal axis (x) represents the distance from the T/NT interface which is at $x = 0$. $x < 0$ is the irrotational region while $x > 0$ is the turbulent region (distances are normalised by the Kolmogorov micro-scale).

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