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Small scale entrainment characteristics in high Reynolds number jets and wakes

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Abstract —
The characteristics of the turbulent/non-turbulent interface (TNTI) that occurs at the edges of free shear layers such as mixing layers, jets and wakes, and also in boundary layers, is analysed through new high resolution direct numerical simulations (DNS) of planar turbulent jets and wakes (PJET and PWAKE). It is shown that provided the Reynolds number is above a certain threshold $Re_\lambda > 200$, thickness of the viscous dominated sublayer, known as viscous superlayer (VSL - δ_ν) as that of the entire turbulent/non-turbulent interface layer (TNTI - δ_ω) both scale with the Kolmogorov micro-scale. The diferences and similarities between the TNTIs from jets and wakes, as well how these affect the dynamics of the nearby vorticity, is discussed.

1. Introduction

The turbulent/non-turbulent interface layer (TNTI) is a sharp and highly contorted layer that exists in many turbulent flows such as mixing layer, jets, wakes and boundary layers. Across this layer important exchanges of mass, momentum and scalars take place in a process named as *turbulent entrainment*, whereby regions of non-turbulent or irrotational flow, acquire vorticity[1].

It has been established recently that the TNTI contains two sublayers within itself: a viscous superlayer (VSL) where viscous effects dominate, and a turbulent sublayer (TSL) where inertial effects dominate. These two sublayers have a small but finite thickness which when added gives the total thickness of the TNTI, with the VSL being the outer part of the TNTI, while the TSL is in contact with the turbulent core region of the flow.

An ongoing open question regarding these layers concerns their scaling of these layers, and in particular its thickness. In the present work direct numerical simulations (DNS) of planar turbulent jets and wakes have been carried out at higher Reynolds numbers than previously available, in order to assess the scaling and characteristics of these TNTI (sub)layers.

2. Simulations

Several direct numerical simulations (DNS) of planar turbulent jets and wakes were carried out using a very accurate pseudo-spectral methods solver [2]. The numerical simulations used were carried out with a Navier-Stokes solver that uses classical pseudo-spectral methods (collocation method) for spatial discretization, and a 3rd order, 3 steps Runge-Kutta scheme for temporal advancement.

In the far field fully developed turbulent region simulation the simulations attain a Reynolds number (based in the Taylor micro-scale) of the order of $Re_\lambda \approx 400$ which makes these simulations the ones presenting the highest Reynolds number in existence to study the dynamics of the TNTI. The biggest DNS uses $(4096 \times 4096 \times 1024)$ collocation points for a box size of $(10H \times 10H \times 2.5H)$.

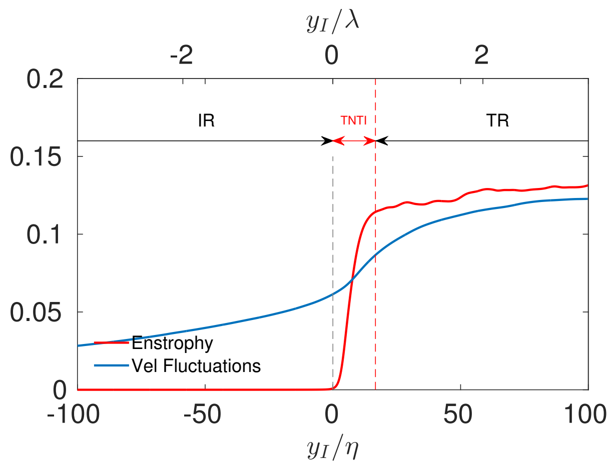

Figure 1: Conditional mean profiles of enstrophy and streamwise velocity fluctuations from one of the DNS of T. S. Silva *et al.* [2]. The turbulent/non-turbulent interface (TNTI) is a sharp layer separating non-turbulent or irrotational (IR) from turbulent (T) flow. The distance from the TNTI is normalised using the Kolmogorov and the Taylor micro-scale.

3. Results

In order to asses the local dynamics of turbulence near the interface, conditional statistics of various quantities (vorticity, dissipation, ...) were done as a function of the distance from a referential positioned within the TNTI envelope - usually the irrotational boundary (IB) - which is the surface delimiting the outer boundary of the TNTI. Figure 1 shows typical conditional mean profiles of vorticity magnitude and streamwise velocity fluctuations across the TNTI layer. The vorticity exhibits a sharp jump at the TNTI while the turbulence kinetic energy (and its componentes) displays a smooth evolution.

The mean thickness of the TNTI $\langle \delta_\omega \rangle$ was studied by measuring the length scale of a characteristic vorticity jump observed at the TNTI through conditional statistics of enstrophy. To analyze the thickness scaling at different Reynolds number Re_λ it was normalized by both the Kolmogorov micro-scale η and the Taylor micro-scale λ. For sufficiently high Reynolds numbers ($Re_\lambda > 200$) it has been found that the thickness of the TNTI and its sublayer scales with the Kolmogorv micro-scale i.e. $\delta_\omega \sim \eta$ [2].

Figures 2 (a) and (b) show the probability density functions (PDFs) of the viscous superlayer (VSL) thickness δ_ν and of the turbulent sublayer (TSL) thickness δ_ω, for the planar jet configuration for several Reynolds numbers. It is clear that only above a 'critical' Reynolds number do the PDFs become 'self-similar' for all the cases, again attesting the need for a sufficiently high Reynolds number to attest the scaling of the TNTI layer, which has eluded previous works.

The presentation will also discuss similar results for the planar wake.

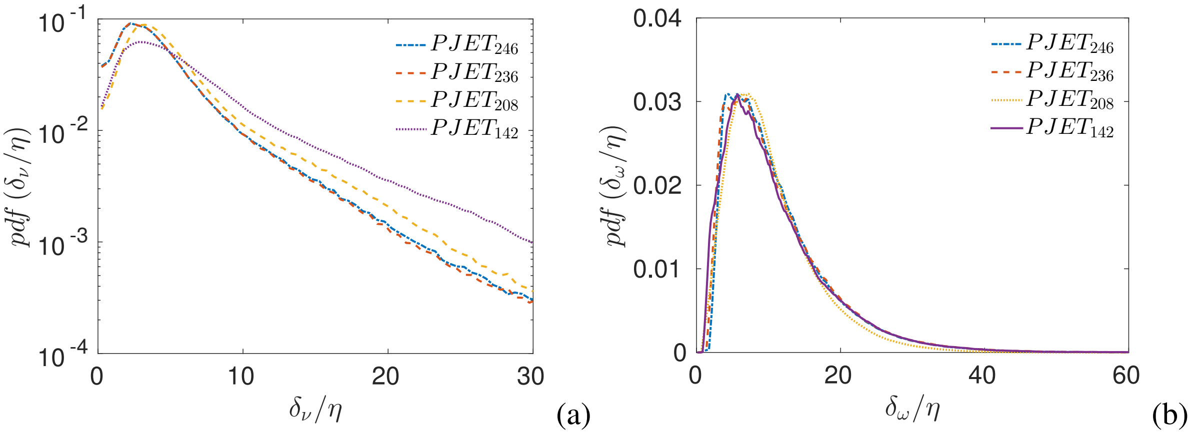

Figure 2: Probability density functions of the viscous superlayer (VSL) thickness δ_ν and of the turbulent sublayer (TSL) thickness δ_ω, for the planar jet configuration for several Reynolds numbers.

References

1. C. B. da Silva and J.C.R. Hunt and I. Eames and J. Westerweel. Interfacial layers between regions of different turbulent intensity, *Annual Review of Fluid Mechanics*, 567-590, **46**, 2014
2. T. S. Silva, M. Zecchetto and C. B. da Silva. The scaling of the turbulent/non-turbulent interface at high Reynolds numbers *J. Fluid Mech. (in press)*.