
SCALE INTERACTION IN A MIXING LAYER. THE ROLE OF THE LARGE-SCALE GRADIENTS.

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Abstract The interaction between scales is investigated in a turbulent mixing layer. The large-scale amplitude modulation of the small scales already observed in other works depends on the crosswise location. Large-scale positive fluctuations correlate with a stronger activity of the small scales on the low speed-side of the mixing layer, and a reduced activity on the high speed-side. However, from physical considerations we would expect the scales to interact in a qualitatively similar way within the flow and across different turbulent flows. Therefore, instead of the large-scale fluctuations, the large-scale gradients modulation of the small scales has been additionally investigated.

INTRODUCTION AND MOTIVATION

In the present work the interaction between turbulence scales in a mixing layer is investigated at relatively high Reynolds number [1]. The interaction between the large and the small scales has been the topic of several studies. Recent investigations showed that in a boundary layer the large scales of turbulence modulate the small-scale motions [2] [3]. Close to the wall, large-scale positive fluctuations are associated with a stronger activity of the small-scale motions, whereas they are related with reduced small-scale activity in the outer region. The top-down interaction between large and small scales presents an important phase delay, and therefore it is not concurrent [4]. These findings were based on time series from hot-wire anemometry.

The interaction between scales was studied experimentally in a jet by Fiscaletti *et al.* [5], using hot-wire anemometry, and PIV. It was found that the small-scale signal is stronger in amplitude if it is conditioned on positive large-scale fluctuations. Surprisingly, the strength of the small-scale amplitude modulation in the spatial signal obtained with PIV was only 25% of the value obtained from the time signal from hot-wire anemometry. The elevated level of the amplitude modulation from hot-wire anemometry was attributed to the fixed spectral band filter used to obtain the large- and the small-scale signals, which does not consider the local convection velocity. Moreover, the inhomogeneous distribution of the structures of vorticity, and their preferential location in high velocity regions of the flow could explain the spatial amplitude modulation.

Buxton & Ganapathisubramani (2014) [6] investigated experimentally the fully developed region of a mixing layer. They found that negative large-scale fluctuations coincide with regions characterized by a high amplitude of the small-scale signal. Large and small scales appear therefore to interact similarly to the outer region of the turbulent boundary layer. The work did not consider different crosswise locations within the mixing layer. Therefore, the first goal of the present study is the investigation of the interaction between the large and the small scales of turbulence at different crosswise locations in the mixing layer.

A strong flow dependency with respect to the nature of the scale interaction, i.e. increased vs decreased small activity with positive large scale fluctuations, has been observed (Bandyopadhyay & Hussein 1984, [2]). In addition, the location within the same flow seems to affect large-scale amplitude modulation. On the other hand, this appears at conflict with the classical theories of turbulence, according to which the transfer of turbulent kinetic energy across the scales is a universal process. Then, we would expect the scale interactions to be qualitatively similar across flows. Recent findings have related the activity of the viscous scales to the large-scale shear layers within the flow ([7], [8]). Large-scale shear layers, characterized by strong velocity gradients are expected to play an important role in the cascade of turbulent kinetic energy. As a second goal of this work, we intend to examine possible interactions between the large-scale gradients (rather than the large-scale velocity used before) and the small scales of turbulence, by determining the correlation between the large-scale gradients and the local activity of the small scales (local enstrophy).

METHODS

The results from an existing DNS of a spatially developing mixing layer with initial vorticity thickness Reynolds number $Re_\omega = 600$ are analyzed. The Reynolds number based on the Taylor length scale of the flow is 250. Technical details concerning the simulation and the main relevant turbulent scales can be found in Attili & Bisetti (2012) [1]. Twenty three-dimensional sub-domains taken at different downstream distances are examined. The size of these domains is $16.7\lambda \times 13.3\lambda \times 68.3\lambda$. The spatial resolution in the data is 2η . A coordinate system is introduced, centred at the inlet

of the mixing layer, with x representing the streamwise direction, y the crosswise direction, and z the spanwise direction. The procedure applied to examine the large-scale amplitude modulation of the small scales is similar to Fiscaletti *et al.* (2015), and is explained as it follows:

- i. The 3D spatial domains is divided into boxes of one Taylor length scale, λ .
- ii. The mean streamwise velocity is calculated inside each box, U_L . From that, the strength of the local non-dimensional large-scale fluctuation is determined as $u_L^* = \frac{U_L - U_c}{U_c}$, where U_c is the average streamwise velocity at the crosswise location of interest.
- iii. The enstrophy is computed inside each box, and non-dimensionalized with the total enstrophy computed at the crosswise location of interest, which is used as a measure of the small-scale activity.
- iv. Equally spaced u_L^* bins with a spacing of 0.05 ranging from $u_L^* = -0.2$ to $u_L^* = 0.2$ are created.
- v. The average enstrophy conditioned on the strength of the local large-scale fluctuation ω_L^2/ω^2 is calculated, depending on the strength of u_L^* .

FIRST RESULTS

Preliminary results of the aforementioned procedure are shown in Fig 1. It is clearly observed that the large-scale amplitude modulation in a mixing layer depends strongly on the cross-wise location. On the high-speed side of the layer (positive values of y) there is a negative large-scale amplitude modulation (analogously to the outer region of the boundary layers), whereas on the low-speed side of the layer (negative values of y) there is a positive large-scale amplitude modulation (analogously to the outer region of the boundary layers). This is consistent with Buxton *et al.* [9], in which the authors found that the convection of the small scales is on average larger than the mean on the low speed side, and smaller than the mean on the high speed side.

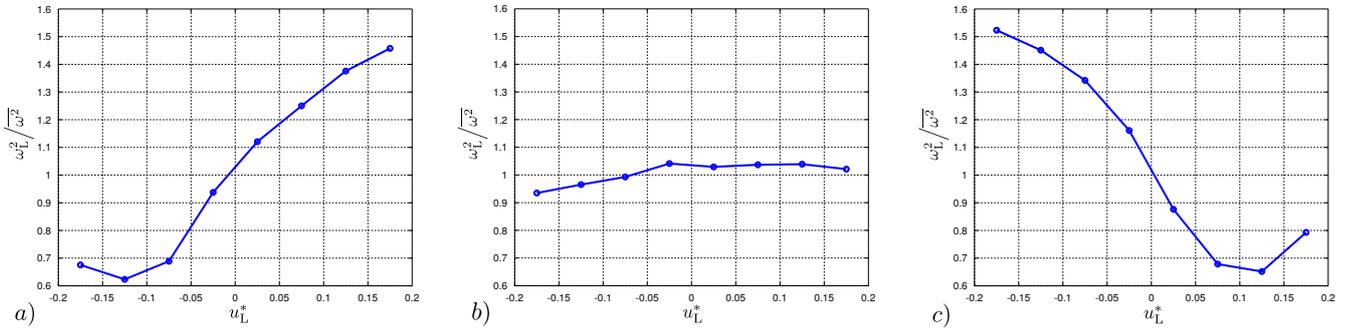


Figure 1. Local enstrophy of the small scales conditioned on the strength of the large-scale fluctuation u_L^* , at three different crosswise locations, a) $y = -16.67$, b) $y = -2.13$, and c) $y = +2.87$. The Taylor length scale of the flow is used to non-dimensionalize the crosswise locations.

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