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Spectral assessment of the turbulent convection velocity in a spatially developing flat plate turbulent boundary layer at Reynolds numbers up to $Re_0 = 13000$

Nicolas Renard^{1*}, Sébastien Deck¹, Pierre Sagaut²

A Wall-Resolved Large Eddy Simulation of a spatially developing flat plate turbulent boundary layer has been performed using the ZDES mode 3 technique ($\Delta x^+ = 50$, $\Delta z^+ = 12$), covering a wide Reynolds number range $3060 \leq Re_0 \leq 13650$ ([1]). The flow visualisation near the $Re_0 = 13000$ station reveals the presence of packets of hairpins (fig. 1) and of Very Large Scale Motions (fig. 2).

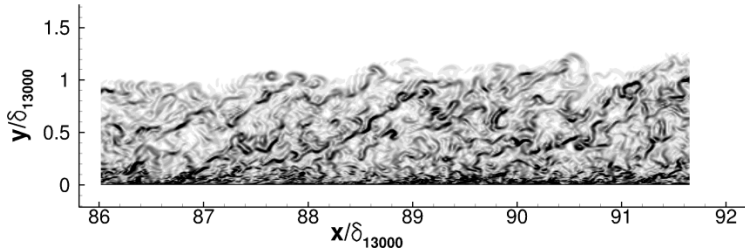


Figure 1: Numerical Schlieren near the $Re_0 = 13000$ station

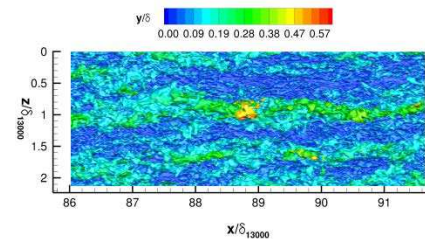


Figure 2: $u^+ = 20$ isosurface coloured by wall-distance near the $Re_0 = 13000$ station

A spectral analysis of the streamwise velocity fluctuations is performed, providing a mapping of the streamwise turbulent intensity as a function of wall distance and streamwise wavelength (fig. 3). Besides the inner site associated to near-wall turbulence, two outer sites may be seen: one around 2 to 3δ (where δ is the boundary layer thickness at $Re_0 = 13000$), which corresponds to the hairpin packets seen in fig. 1, and one around 10δ which matches the features of the VLSMs seen in fig. 2.

The present study is devoted to the assessment of the convection velocity of the streamwise velocity fluctuations as a function of their streamwise wavelength, which is related to the advection velocity of the coherent motions. This has been done in the case of a lower Reynolds number channel flow by [2] using the instantaneous spatial signal and its time derivative. In the present spatially developing boundary layer, the data available is on the contrary the local time signal and its spatial derivative. A method dual to the one presented in [2] is derived and applied to the present simulations, providing the advection velocity as a function of the wall distance and the wavelength (fig. 4). This estimation of the convection velocity will be shown to be related to the 2-point 2-time correlation method.

Fig.4 shows that the foot of the VLSMs is convected faster than the smaller-scale motions while their top is slower than the surrounding structures, so that the convection velocity is roughly uniform over the whole coherent VLSM and in agreement with experimental observations ([3]).

The computed convection velocity is finally used together with Taylor's hypothesis in the spirit of [2] to recover spatial spectra such as fig. 3 from time spectra computed from the time signals.

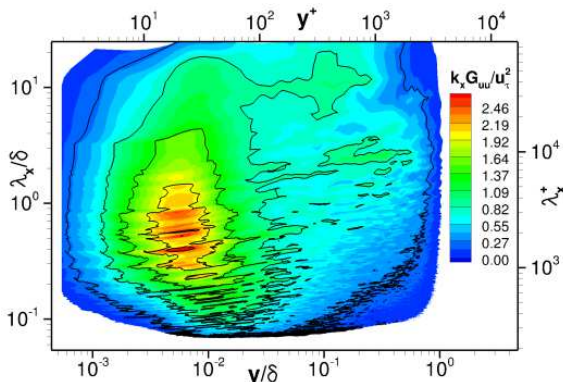


Figure 3: Premultiplied streamwise velocity spectrum at $Re_0 = 13000$ as a function of wall-distance and streamwise wavelength

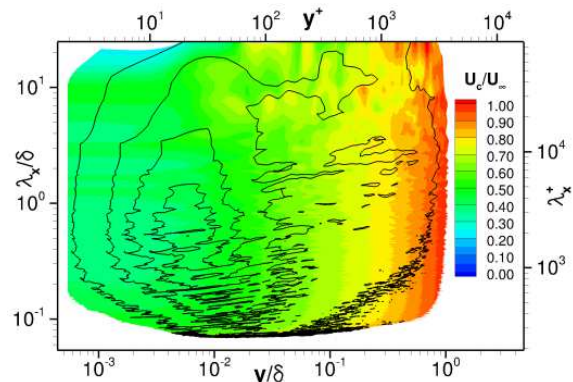


Figure 4: Advection velocity of the streamwise velocity fluctuations at $Re_0 = 13000$ as a function of wall-distance and streamwise wavelength (colours). Isolines: streamwise velocity spectrum

References

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- [3] N. Hutchins, J. P. Monty, B. Ganapathisubramani, H. C. H. Ng and I. Marusic, Three-dimensional conditional structure of a high-Reynolds-number turbulent boundary layer. *Journal of Fluid Mechanics*, 2011, 673, 255–285.

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