NEGATIVE STREAMWISE SKIN-FRICTION IN NEAR-WALL TURBULENCE

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Abstract The recent discovery of rare backflow events in turbulent boundary layer flows based on the analysis of DNS data has raised again the need of experimental visualizations of wall-shear stress (WSS) fields in such unsteady flows. Of importance is the localization of critical points which are thought to strongly correlate with large-scale events in the log-layer. Up to now there is no experimental prove of these rare events and their topological patterns in the skin-friction field. Their existence in a turbulent boundary-layer flow is shown herein by means of imaging with 2D arrays of flexible micropillars attached at the wall.

EXTENDED ABSTRACT

The recent discovery of rare backflow events in turbulent boundary layer flows based on the analysis of DNS data (Lanears et al. 2012, [1]) has raised again the unmet need of accurate near-wall measurements to detect such events. It has further been shown that there is a strong correlation between the appearance of critical points (zero WSS) and their relation to large-scale events in the log-layer. Only recently, such data were gained from highly resolved DNS data which allowed to analyze the topology around these critical points (Cardesa et al. 2014, [2]). Up to now there is no experimental prove of the topological pattern and the behavior of such critical points. As discussed in Lanears et al. (2012), the discovered rare events have been so far not been detected using state-of-the art techniques to measure the velocity close to the wall such as hot-wire or LDA probes. This is because the sensing volume needs to be located away from the wall, and the frequency of occurrence drastically reduces with distance from the wall. Second, in order to capture the strong velocity gradients within the viscous sublayer, the diameter of the measurement volumes has to be as small as the viscous length scale, which brings along a drastic reduction of the sampling rate. The present paper shows results of 2D micropillar array wall-shear measurements according the method described in Brücker et al. (2005) which have been recorded in an oil flow tunnel in a turbulent boundary layer flow at $Re = 7\times10^5$ [3]. Figure 1 shows such an event where a critical point and negative streamwise skin-friction is seen immediately from the raw visualization pictures taken from the micropillar array recordings.

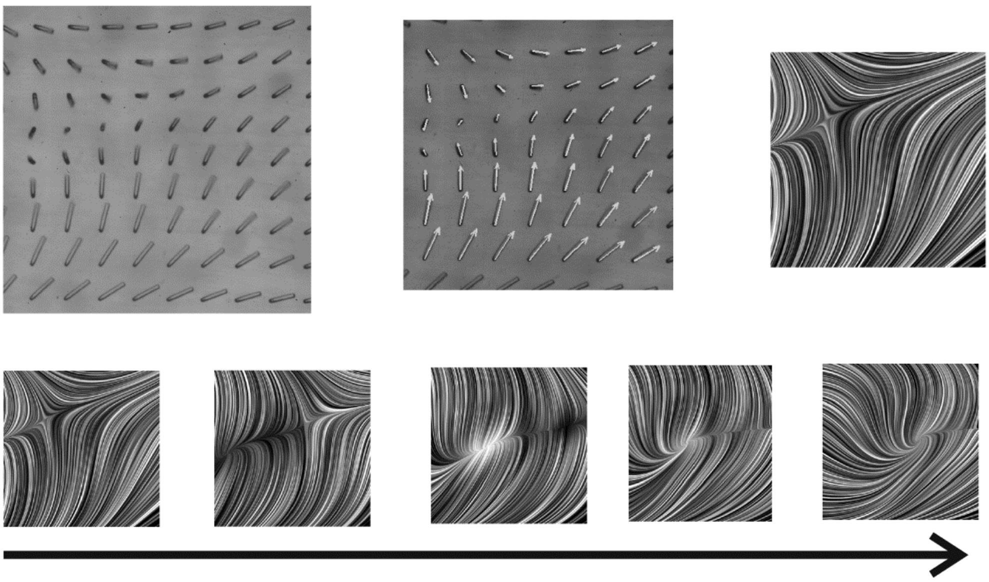

Figure 1: Evolution of a saddle- node pair (flow is from left to right). Top row, left: original raw image, middle: vectorization of the inner part (7×7 vectors), right: LIC picture generated from the vectorization with cubic interpolation. Bottom row: evolution of topology over 5 successive pictures ($\Delta t^+ = 2.93$).

A necessary condition for the detection of such events in the experiments is the tailored sensitivity of the pillars and measuring system skewed towards low WSS values, thus the structures were made soft for the disadvantage of low accuracy in peak values at high bending, which however was not of focus herein. Those backflow events occur at about 0.05% of the recorded images and are always linked to critical points, see Figure 2. However, there is a preference of these backflow regions with non-zero WSS vectors that are curled to angles between 90°-115° against the mean flow direction. Since the DNS data reported in [2] have shown a strong link of the critical points with intense large-scale structures in the outer layer as shown, these near-wall signals might be useful for flow-control, too.

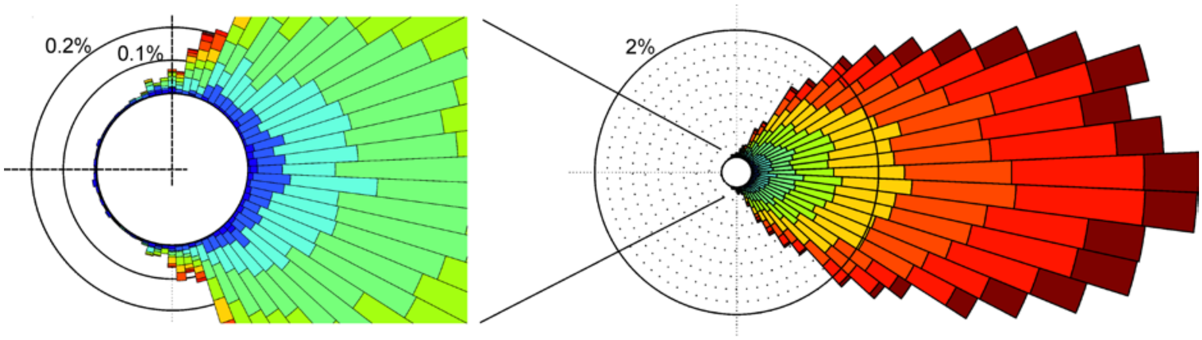

Figure 2: Probability distribution of orientation vector ***Q*** of the micropillars in the x-y-plane (flow is from left to right). The left figure shows a zoom-in into the data given on the right. Angular steps are in 5°.

References

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[2] J. Cardesa, J. Monty, J. Soria, M. Chong “Skin-friction critical points in wall-bounded flows”. 1st Multiflow Summer Workshop, IOP Publishing, Journal of Physics: Conference Series 506 (2014), 01200

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