Flow Reversal in Turbulent Boundary Layers with Varying Pressure Gradients

C. Willert[1,*], J. Soria[2], C. Cuvier[3], J.M. Foucaut[3], J.P. Laval[3]

1: DLR Institute of Propulsion Technology, German Aerospace Center, Germany
2: Department of Mechanical and Aerospace Engineering, Monash University (Clayton Campus), VIC 3800, Australia
3: LMFL FRE3723, Univ. Lille, Centrale Lille, CNRS, Villeneuve d'Ascq, France

* Correspondent author: chris.willert@dlr.de

Keywords: turbulent boundary layer, PIV processing, long-range micro PIV, wall shear stress

HIGHLIGHTS

- High-speed, high magnification PIV was applied in a turbulent boundary layer at zero and adverse (positive) pressure gradient using image magnifications above unity and frame rates up to 25 kHz.
- Shear Reynolds numbers were varied from $\mathrm{Re}_\tau = 1840$ to $\mathrm{Re}_\tau = 5600$ ($\mathrm{Re}_\theta = 5600 - 18360$)
- Viscous scales ranged from 44 µm to 82 µm, depending on Reynolds number and pressure gradient.
- Rarely occurring reverse flow events (Fig. 1, left) with probabilities in the range $3 \cdots 5x10^{-4}$ could be captured in sufficient numbers by acquiring very long time series of PIV images of nearly 10^5 samples each.
- The shape of enclosing streamline of the reverse flow events (c.f. Fig. 1, left) was found to be self-similar throughout all studied conditions showing a blunt leading edge and tapered trailing end.
- Single line correlation of image data in the viscous sublayer provides reliable estimates of the unsteady wall shear rate from which probability density functions of the wall shear stress can be determined (Fig. 1, right).
- The presence of reverse flow events can be clearly identified in particle tracing images compiled from the sequences by extracting wall-parallel lines of image data.
- The probability of reverse flow events shows only a small dependence of Reynolds number.
- Compared to ZPG conditions the reverse flow probability roughly doubles in the studied APG cases.

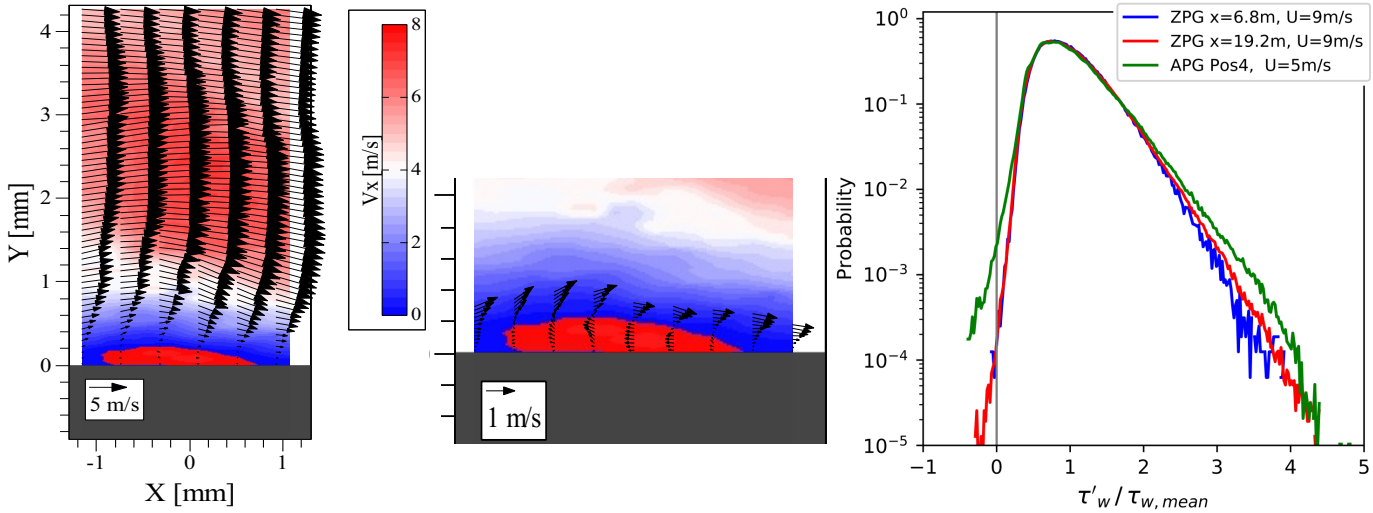

Fig. 1, Left & middle: Single reverse flow event, indicated by the red patch above the wall at $y = 0$ captured in the APGTBL at $U_\infty = 9$ m/s. PIV processing with sampling windows of 24 × 8 pixel ($6.1^+ \times 2.0^+$) with vertical vector spacing of $\delta x = 0.5^+$. The length of the structure is $x = 35^+$, its height $y = 4.5^+$. **Right:** Probability density functions (PDF) of the normalized wall shear stress at $\mathrm{Re}_\tau = 2360$ (blue), $\mathrm{Re}_\tau = 5600$ (red) and in the APG region (green). Values to left of the vertical line at $\tau'_w = 0$ indicate negative shear stress events in the form of flow reversals.