High-accuracy turbulence statistics from particle images using a deep optical flow neural network

E. Lagemann*, W. Schröder* and C. Lagemann*

It is well known that classical particle-image velocimetry (PIV) measurements typically do not provide the spatial resolution required to precisely study turbulence statistics in the inner layer of turbulent wall-bounded flows. This issue arises from the fact that the viscous sublayer and the buffer layer are hardly resolved in standard setups covering the complete boundary layer due to the inherent velocity averaging across the finite-size interrogation windows. However, recent advances in processing particle images with a deep recurrent optical flow estimator called RAFT-PIV[1] allow for a pixel-wise resolution of the measured velocity fields at a spatial resolution going far beyond the current gold-standard of classical evaluation routines.

In this context, we will evidence that this outstanding property of RAFT-PIV enables a precise resolution of the turbulence statistics close to the wall. Exemplary results based on synthetic particle images of a turbulent channel flow at a friction Reynolds number $Re_\tau \approx 1000$ are shown in Figure 1 comparing the distributions obtained by a state-of-the-art classical PIV technique (Pascal-PIV), RAFT-PIV, the ground truth data, and DNS data. The standard evaluation (Pascal-PIV) strongly underestimates the shown stresses due to its inherent spatial averaging. In contrast, the distributions of RAFT-PIV match the ground truth and the DNS data very well with a significantly higher resolution. The viscous sublayer and the buffer layer appear well resolved such that, e.g., the inner peak of the streamwise stresses is captured adequately. Consequently, RAFT-PIV shows how to exploit the available pixel-wise information to more accurately determine turbulence statistics in near-wall regions from experimental PIV data. In the final contribution, we will provide further evidence of RAFT-PIV's outstanding capabilities and present detailed analyses of experimental and synthetic PIV images of turbulent channel and turbulent boundary layer flows at varying Reynolds numbers. This includes relevant statistics such as energy spectra and wall-shear stress distributions.

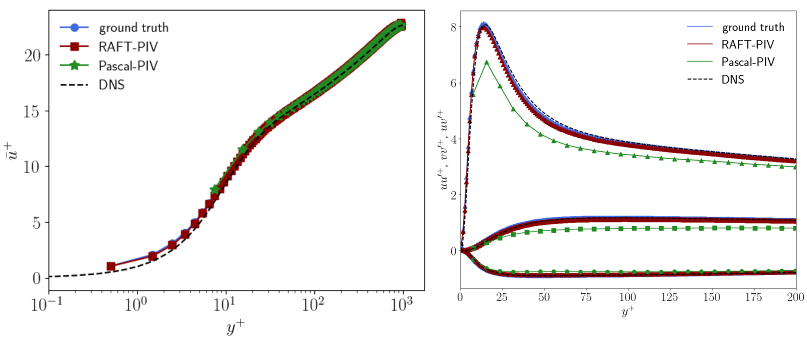

Figure 1: Inner-scaled streamwise velocity profile (left), normal and shear stresses (right).

*RWTH Aachen University, Chair of Fluid Mechanics and Institute of Aerodynamics, Wüllnerstrasse 5a, 52062 Aachen, Germany

[1]Lagemann et al., *Nat. Mach. Intell.* **3:641–651** (2021).