ODAS-MOTAR 2021 – Joint ONERA-DLR Symposium

June 14-16, 2021

TITLE:
Multi-resolution, Time-Resolved Particle Image Velocimetry of a Turbulent Boundary Layer Approaching Separation

NAME & First name of main author:
WILLERT, Christian

NAME & First name of co-authors:
- SCHRÖDER, Andreas
- SCHANZ, Daniel
- NOVARA, Matteo
- SCHROLL, Michael
- GEISLER, Reinhard
- RIBERGÅRD, Simon

Address (Department/Institute):
DLR Institute of Propulsion Technology (Köln)
DLR Institute of Aerodynamics & Flow Technology (Göttingen)

Abstract

The evolution and characteristics of turbulent boundary layers subjected to a positive pressure gradient are common in many flows of industrial relevance and appear, for instance, on the suction side of high-lift wing sections or turbomachinery blading. The pressure gradient is associated with a deceleration of the external flow which results in a thickening of the boundary layer and reduction of the wall friction. Under strong adverse pressure gradient conditions, the wall friction reduces to zero as the flow begins to separate. From a numerical perspective these flows are difficult to model with methods of engineering relevance, such as Reynolds averaged Navier-Stokes simulations (RANS) and motivate experiments such as the one presented here to provide relevant validation data.

The measurements presented herein were performed in an Eiffel type wind tunnel with a cross section of 1.8 x 1.8 m^2 into which a ramp model of about 7 m length is mounted. Figure 1 shows a cross section of the installed ramp model used for the generation of adverse pressure gradient flow conditions. Extensive measurements have already been performed on this configuration to globally characterize the flow at Reynolds numbers of up to $Re_\theta = 40000$ (Schroeder et al. 2018, Knopp et al. 2020). The emphasis of this contribution is on the comparison of the temporally evolving velocity profile close to the wall under zero pressure gradient (ZPG) and adverse pressure gradient (APG) conditions near the point of flow separation.

The time-evolving velocity profiles, for which a sample is shown in Figure 2, were acquired using high-speed PIV at sampling frequencies up to 50 kHz and high image magnifications near unity to resolve the fine scales in the turbulent boundary layer (Willert 2015). To simultaneously capture the dynamics of the outer flow, the measurements in the APG region were performed with two cameras with differing magnification. The acquired PIV image data, about 25 TB in total, was processed using a pyramid correlation scheme and provided optimal, noise-minimized velocity estimates by considering up to 7 consecutive image frames. The image data was also processed using a 2D-2C LPT (Lagrangian particle tracking) algorithm, derived from the 3D-3C "Shake-the-Box" (STB) LPT method by Schanz et al. (2016), which allows for even higher spatial resolution and avoids spatial filtering artefacts associated with the PIV analysis.

As highlighted in Figure 2, the highly dynamic near-wall flow fluctuates around a mean near zero (cyan color) which is due to the APG induced deceleration of the external flow, that is, the flow is on the verge of separation. This data forms the basis for the further statistical and spectral analysis yielding mean and higher order moments, spatially resolved velocity spectra as well as space-time correlations. The proposed contribution will provide further details on the employed PIV instrumentation and processing approaches along with some initial results on the spectral behavior of the turbulent boundary layer subjected to two different pressure gradient conditions.

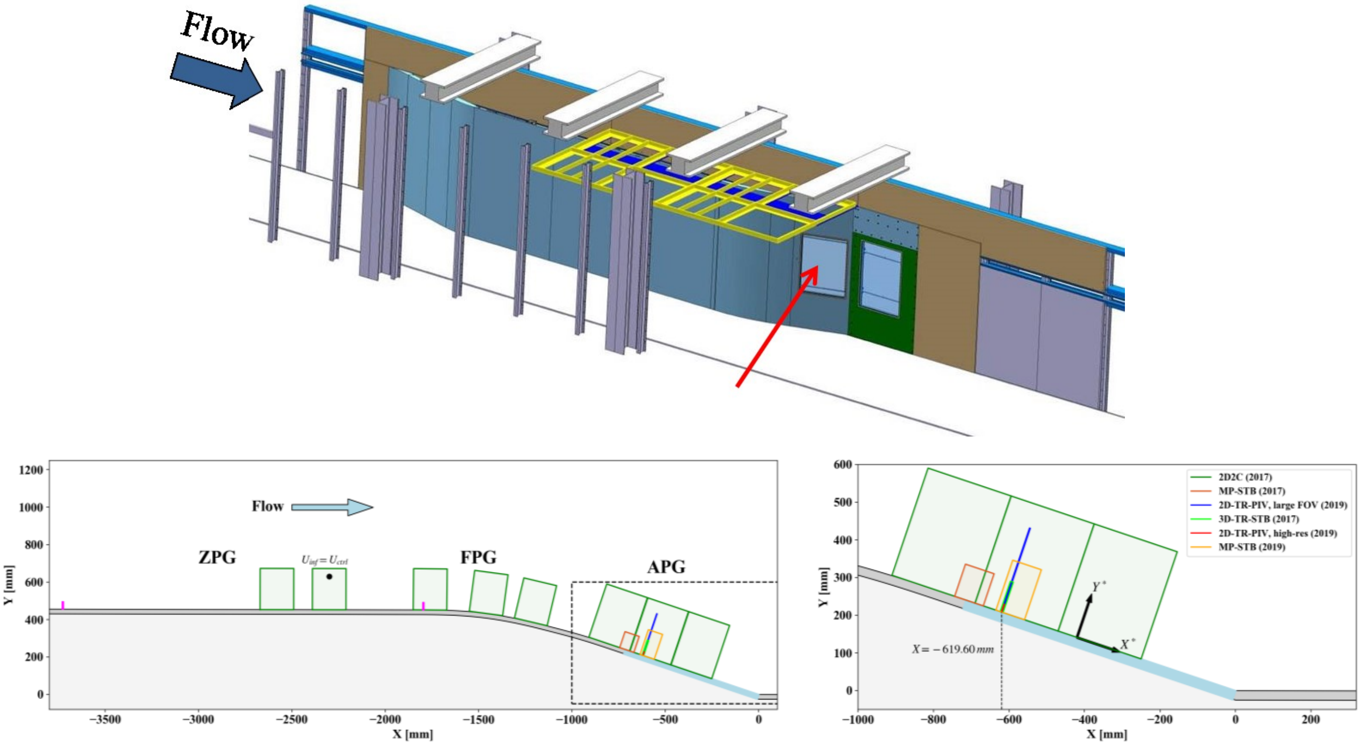

Figure 1: Top: Schematic of wind tunnel test section with installed ramp model. Bottom, left: Cross section of the ramp model used for the generation of adverse pressure gradient (APG) flow conditions with indication of measurement locations, with detail shown on the bottom, right. Presented measurements are performed in the ZPG domain near $X = -3.7$ mm and in APG near $X = -0.62$ m

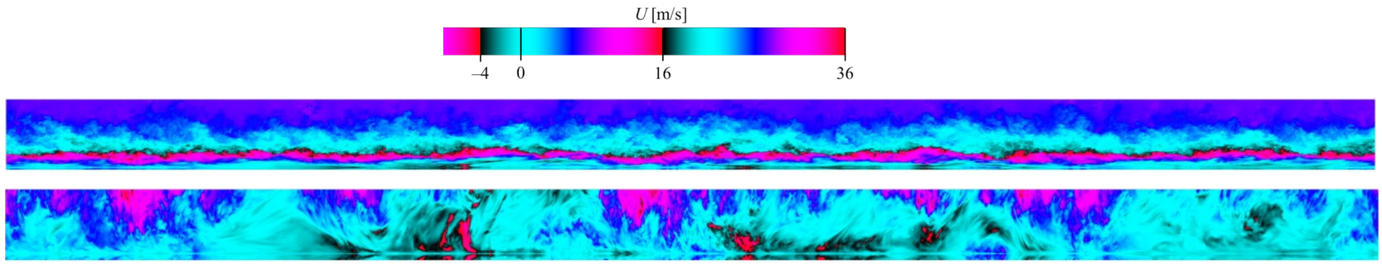

Figure 2: Time-records obtained at the point of flow separation in the APG covering 0.2 s (10000 samples) visualising the stream-wise velocity profile U for Camera 2 (top) spanning a wall-normal distance of $Y^* = 245$ mm and Camera 1 (bottom) spanning $Y^* = 24.5$ mm at $U_\infty = 28.7$ m/s.

References

Knopp T, Novara M, Schanz D, Geisler R, Philipp F, Schroll M, Willert C & Schröder A (2020) Modification of the SSG/LRR-ω RSM for turbulent boundary layers at adverse pressure gradient with separation using the new DLR VicToria experiment. In Dillmann A, Heller G, Krämer E, Wagner C, Tropea C& Jakirlic S, (editors), New Results in Numerical and Experimental Fluid Mechanics XII, pp. 80-89. Springer International Publishing, Cham.

Schanz D, Gesemann S & Schröder A (2016) Shake-The-Box: Lagrangian particle tracking at high particle image densities. Experiments in Fluids, 57(5), 70.

Schröder A, Schanz D, Novara M, Philipp F, Geisler R, Agocs J, Knopp T, Schroll M & Willert C E (2018) Investigation of a high Reynolds number turbulent boundary layer flow with adverse pressure gradients using PIV and 2d- and 3d- Shake-The-Box. In 19th Intern. Symp. Applications of Lasers and Imaging Techniques to Fluid Mechanics, Lisbon, Portugal.

Willert CE (2015): High-speed particle image velocimetry for the efficient measurement of turbulent statistics. Exp Fluids 56:17. DOI 10.1007/s00348-014-1892-4