Mitteilung

Fachgruppe: Experimentelle Aerodynamik

Experimental Study of Turbulent Boundary Layer Separation Induced by a Backward-Facing Ramp

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Introduction and experimental setup

The importance of turbulent separated flow is undoubted for a wide range of applications, and in particular at the borders of the aircraft flight envelope. At the same time, turbulence modeling in Reynolds-Averaged Navier-Stokes equations still requires improvements to correctly predict the shape and size of turbulent separation bubbles (TSBs). For reliable turbulence model validation and modeling extensions, high-quality experimental data are necessary. A new experiment, focusing on geometry-induced separation of a turbulent boundary layer at quasi-zero pressure gradient, was designed and conducted within the DLR project *ADaMant* [1] to provide such validation data.

The measurements were performed in the Large Water Tunnel of TU Braunschweig (GWB) on a flat-plate configuration featuring a 25° Backward-Facing Ramp (BFR). The model configuration is shown in Figure 1. The BFR had a height h = 8 mm and was located at a streamwise distance x_h = 1.134 m from the plate leading edge; it was designed to induce a TSB but no secondary recirculation, following the findings of a preliminary wind-tunnel experiment [2].

The measurements were conducted using Lagrangian Particle Tracking by Shake-The-Box (STB) [3] and Temperature-Sensitive Paint (TSP) [4]. The application of these measurement techniques was enabled by a modular model design: a module with a glass insert was used for the STB measurements (STB module in Figure 1, left), whereas a module with TSP coating and integrated electrical heating was used for the TSP measurements (TSP module in Figure 1, right). The glass in the STB module allowed a minimization of light reflections at the wall during the STB measurements, while the integrated heating in the TSP module enabled an enhancement of the flow-induced thermal signatures at the surface, which were captured via TSP. As can be seen in Figure 1, the flat plate was installed vertically in the GWB test section, spanning the whole test-section height. The laser-optical arrangement for the STB measurement system (5 high-speed cameras and a dual-head laser illuminating two measurement subvolumes) is sketched in Figure 1 (left). The high-speed camera for the TSP measurements was also mounted at the same position as the central STB camera, whereas the TSP was excited by three high-power LED systems.

Results

The experiments were conducted at four different freestream velocities (in the range U_∞ = 1.2–2.6 m/s), corresponding to Reynolds numbers $\mathrm{Re}_{xh} = x_h U_\infty / \nu$ = 1.2–2.7 · 10^6, where ν is the fluid viscosity. The present work focuses on the results obtained at the lowest Reynolds number (Re_{xh} = 1.2 · 10^6) in the region downstream of the BFR.

Figure 2 (left) shows instantaneous particle tracks over 10 time-steps reconstructed by STB, color-coded by the streamwise component of the velocity, for two wall-parallel slices at different distances from the surface downstream of the BFR. Figure 2 (right) shows an instantaneous temperature distribution (map of temperature fluctuations T' downstream of the BFR). Both STB and TSP results indicate recirculating flow characteristic of a TSB up to approximately $X = x - x_h$ = 40 mm from the BFR. Furthermore, a streaky pattern is visible in both datasets. These streamwise-oriented streaks are the focus of current analysis, aiming at the improvement of the understanding of the structure of a turbulent boundary layer in the presence of geometry-induced TSB.

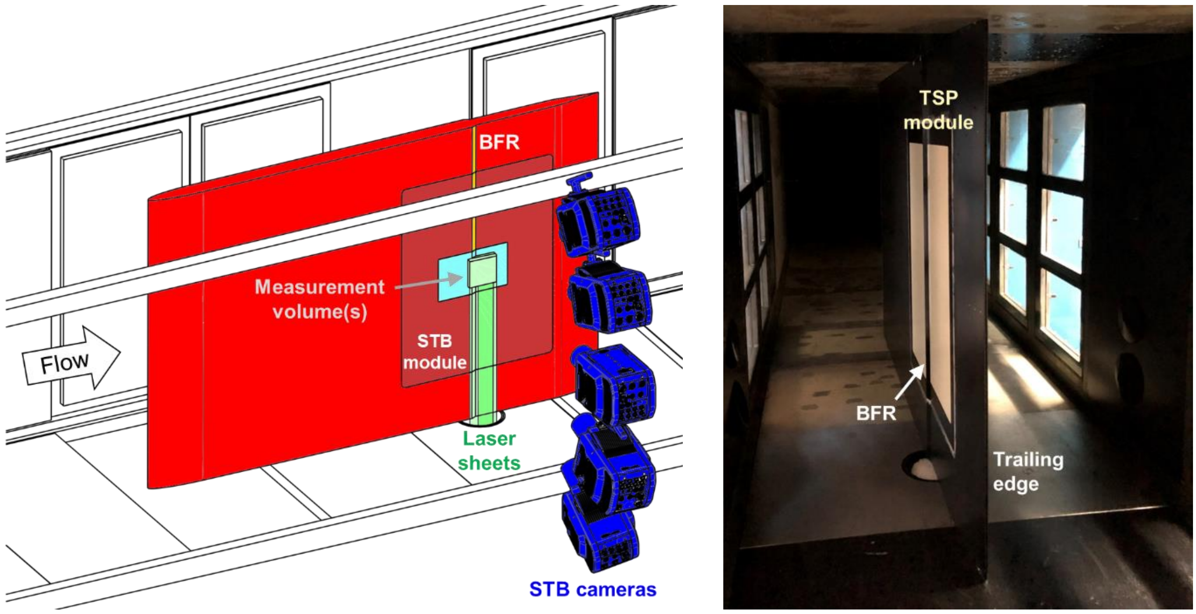

Figure 1. Left: sketch of the experimental setup for the STB measurements. Right: picture of the flat-plate model with TSP module installed in the GWB test section, as seen from a downstream location.

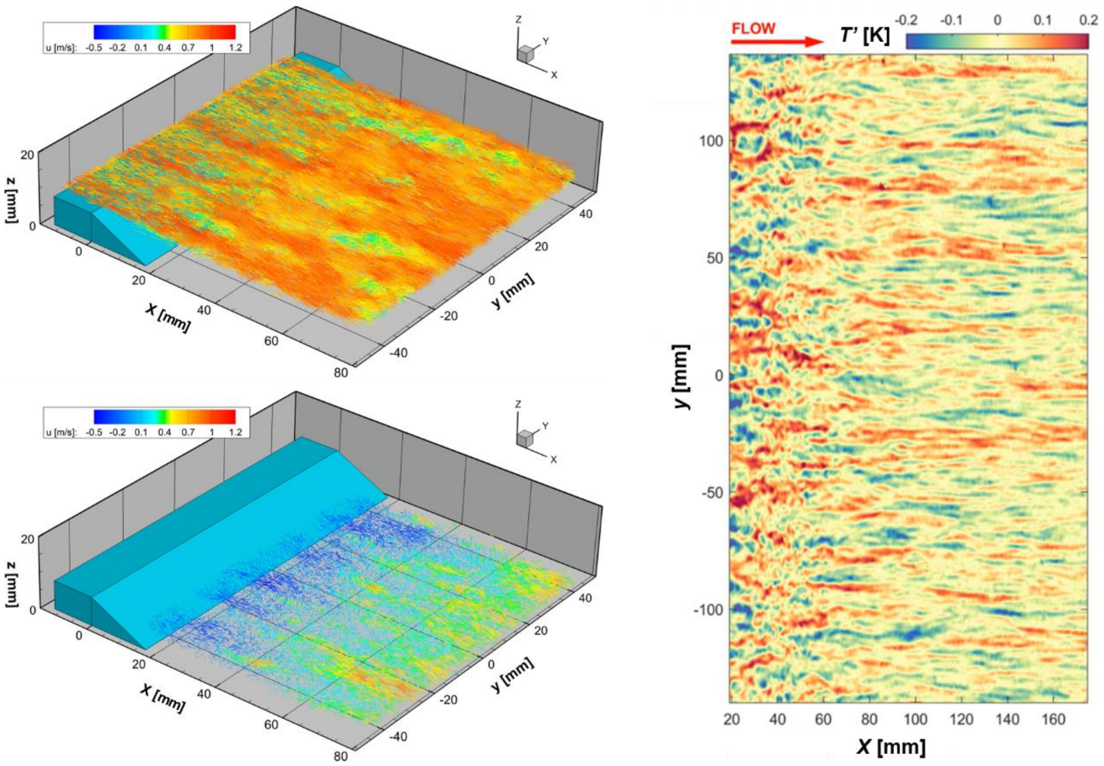

Figure 2. Results obtained at Re_{xh} = 1.2 · 10^6, where X = 0 corresponds to the BFR location x_h, y = 0 to the mid-span location, and z = 0 to the vertical location of the plate surface downstream of the BFR. Left: particle tracks reconstructed by STB, color-coded by the streamwise component of the velocity u, for wall-parallel slices close to the model surfaces upstream (top, left) and downstream (bottom, left) of the BFR. Right: instantaneous distribution of the surface temperature fluctuations, obtained from the TSP data downstream of the BFR.

References

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