Boundary layer structure in turbulent Rayleigh-Bénard convection in air

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Abstract

We present Particle Image Velocimetry measurements in the boundary layer in turbulent Rayleigh-Bénard (RB) convection for the Rayleigh number $Ra = 1.4 \times 10^{10}$ and the Prandtl number $Pr = 0.7$. The measurements give detailed insight into the near-wall flow field in turbulent RB convection and provide experimental data to evaluate various competing theories on the heat transport which essentially based on the boundary layer. We found that the convective boundary layer becomes turbulent locally and temporarily although its shear Reynolds number $Re_s = U_\infty \delta / \nu \approx 265$ (U_∞ - outer velocity, δ - boundary layer thickness, ν- kinematic viscosity) is considerably smaller than the value 420 underlying existing phenomenological theories.

The measurements have been undertaken in a large-scale RB experiment, the "Barrel of Ilmenau". This RB cell with a diameter of $D = 7.15$ m and a maximum thickness of the fluid layer of $H = 6.30$ m is filled with air and currently the only one where Ra numbers up to $Ra = 10^{12}$ can be set and the boundary layer is sufficiently large (of the order of 10 mm) to probe the flow field with commercial measurement techniques. A detailed description of the facility can be found in [du Puits 2013]. We acquired PIV data in a rectangular box of the size 2.5 × 2.5 × 0.62 m³ (see Fig. 1). The box is made of transparent Perspex and was placed inside the large RB cell using its original heating and cooling plates as bottom and top walls. The temperature difference between the bottom and top wall is ΔT=10 K. In order to obtain more detailed information on the statistics and the temporal evolution of the boundary layer flow long PIV image sequences were recorded at various positions near the center line of the heated bottom plate (Fig. 1). Laser light sheet illumination was realized with a 2 W continuous wave laser. A smoke generator, based on an evaporation-condensation principle, was used to seed the flow with 1…2 µm droplets.

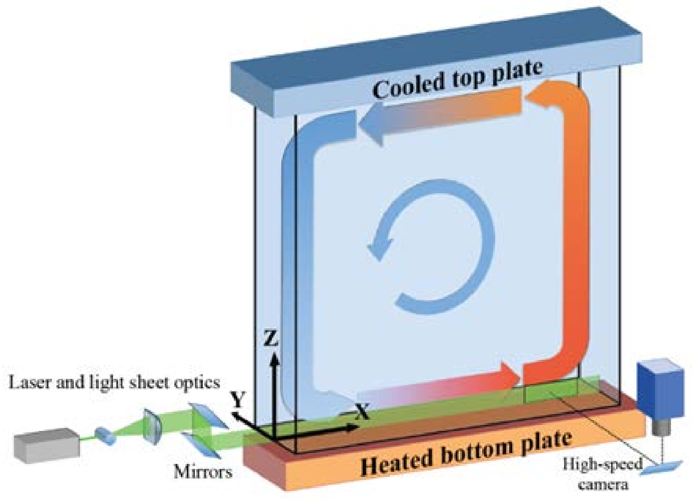

Figure 1: Rectangular test cell and set-up of the PIV measurements

Fig. 2 shows the essential finding of our work, two snapshots of the near-wall flow field at the position $= 1200$ mm, where the flow permanently alternates between a laminar and a fully turbulent states. The two plots in Fig. 2 demonstrate that even though both, Ra and shear Re numbers are below their critical thresholds of $Ra_c \approx 10^{14}$ and $Re_{s,c} = 420$, respectively, the boundary layer becomes turbulent locally and temporarily [du Puits 2014].

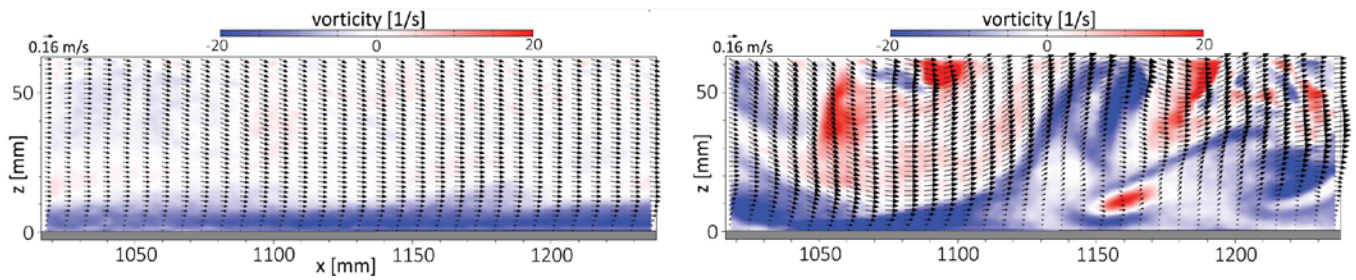

Figure 2: Contrasting flow states at position x=1200 mm separated by 1.7 seconds in time. Vectors are down-sampled by a factor of 8 horizontally and 2 vertically.

REFERENCES

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