ROUGHNESS-TRIGGERED TURBULENT BOUNDARY LAYERS IN RAYLEIGH-BÉNARD CONVECTION

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Abstract We present measurements carried out inside the Barrel of Ilmenau as part of the European EuHIT transnational infrastructure access program. The Barrel of Ilmenau is the worldwide largest experiment to study highly turbulent convection in air. A rectangular cell, with proportions strictly identical to the water cell in Lyon [4], but six times larger, has been inserted inside the Barrel. The top plate is smooth, and the bottom plate is rough. The roughness are also similar to the one in Lyon, but six times larger. We have obtained velocity fields using PIV near the obstacles, as well as the local heat-flux on the bottom plate. This has allowed us to test and improve our previous interpretation of the roughness-induced heat transfer enhancement mechanisms.

EXPERIMENTAL SETUP

A 0.60 m-thick 2.50 m × 2.50 m rectangular cell was inserted inside the Barrel of Ilmenau. The bottom and top plates of this convection cell are directly those of the Barrel itself and are described in more details in [2]. The controlled roughness consists in an array of 1.2 cm-high 3 cm × 3 cm aluminum square obstacles, evenly glued on the bottom plate. Because these obstacles are aligned with the walls, it is possible to distinguish between "grooves", washed by the mean wind and "notches" between obstacles where the fluid is confined. The working fluid is air. The Prandtl number is 0.71. The experimental mean temperatures, and the corresponding Rayleigh numbers are summarized in table 1.

T_h	T_c	T_m	P	Ra
23 °C	20 °C	22 °C	200 W	4.66×10^9
35 °C	15 °C	27 °C	1700 W	2.8×10^{10}
55 °C	20 °C	41 °C	4090 W	4.04×10^{10}

Table 1. Experimental conditions in the experiment.

VELOCITY FIELDS

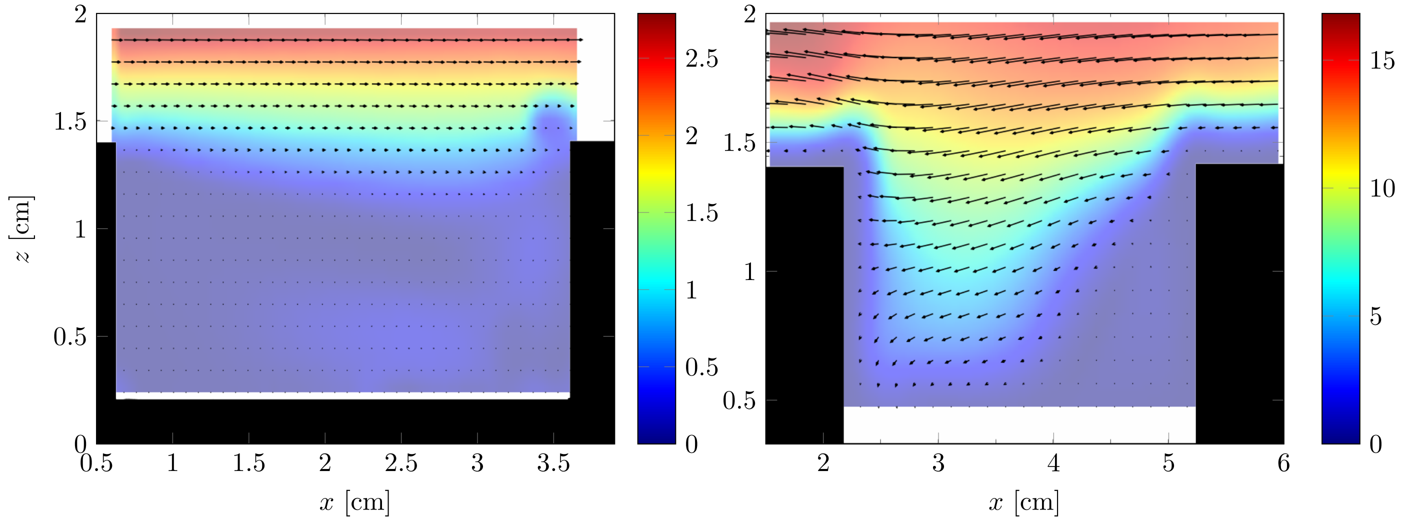

Figure 1. Velocity field inside a notch, at $Ra = 4.66 \times 10^9$ (left figure) and $Ra = 4.04 \times 10^{10}$ (right figure). The color code is the velocity modulus in cm/s.

The flow was seeded with cold-atomized oil droplets with a typical size of 1 µm, identical to those used previously by [1]. Their size is sufficiently small to behave as tracers. These particles were illuminated with either a horizontal (for visualization in the groove and on the top of the obstacles) or vertical (for visualization in the notch) laser light sheet of about 70 mm height and 2 mm thickness, generated by a 2 W cw laser in combination with a beam expander.

The velocity fields are computed using a cross-correlation *Particle-Image-Velocimetry* algorithm implemented in the CIVx software suite [3]. From these fields, it is possible to obtain statistical quantities, such as velocity profiles and the velocity boundary layer thickess δ_v, both on the top of the obstacles, in the groove or inside the notch.

As shown in figure 1, the flow characteristics are quite different inside a notch, at low Rayleigh number, where there is no heat-transfer enhancement, at and high Rayleigh number where there is a heat transfer enhancement due to the roughness. Below the transition, the fluid inside the notch is essentially at rest (though it is slowly recirculating), while above the transition, we observe large incursions of the bulk inside the notch.

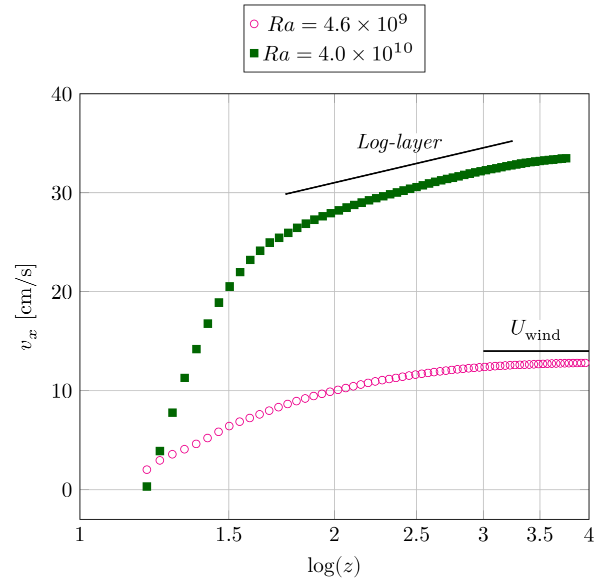

Figure 2. Velocity profile on the top of an obstacle at the center of the cell, above and below the transition.

The velocity profile on the top of the obstacle are also quite different above and below the transition. Below the transition, the profile is fairly compatible with profiles obtained in the smooth case, such as those in [5]. Above the transition, the velocity profile is closer to a logarithmic profile that one would expect in the case of a turbulent boundary layer (see figure 2).

References

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