Boundary layer structure near roughness in turbulent thermal convection

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Turbulent thermal convection is a very efficient thermal transfer process. Although it can be easily observed (atmosphere, oceans, ...), the understanding of the heat flux transport is still a challenge. The canonical laboratory experiment is the Rayleigh-Bénard convection cell. A fluid layer is confined between two horizontal plans. The bottom one is heated and the top one is cooled. Fluid density fluctuations generate a flow which can be turbulent with sufficient forcing. It is commonly accepted that heat flux is driven by thermal boundary layers close to plates where temperature gradients are confined.

We used a parallelepipedic cell (40x40x10 cm^3) filled with water, with controlled square-studs roughness placed on the bottom plate; the top plate is smooth. The cell is asymetric and allows for a direct comparison of smooth and rough boundary layers. We imposed thermal flux which leads to a Rayleigh number ($Ra = \frac{g\alpha\Delta T H^3}{\kappa\nu}$) of about 5.10^{10}. Roughness destabilize the boundary layer and enhance thermal flux beyond a transition Rayleigh number. We carried out local temperature measurements with micro-thermistors at various locations close to roughness (see Figure 1). A boundary layer thinner on the top of square-studs than on a smooth plate has been observed while calmer fluid is observed into the notch. We propose a phenomenological model to explain thermal transfer enhancement.

To supplement our measurements, we built into the Barrel of Ilmenau a scaled cell six times larger with proportional roughness and filled with air. We obtained similar Rayleigh numbers but with a boundary layer up to ten times larger. We performed PIV measurements close to roughness and observed some changes of the flow structure with the Rayleigh number, particularly into the notch (see Figure 1). Moreover, boundary layer thickness on a square-stud and into the groove are quite different which is consistent with our model.

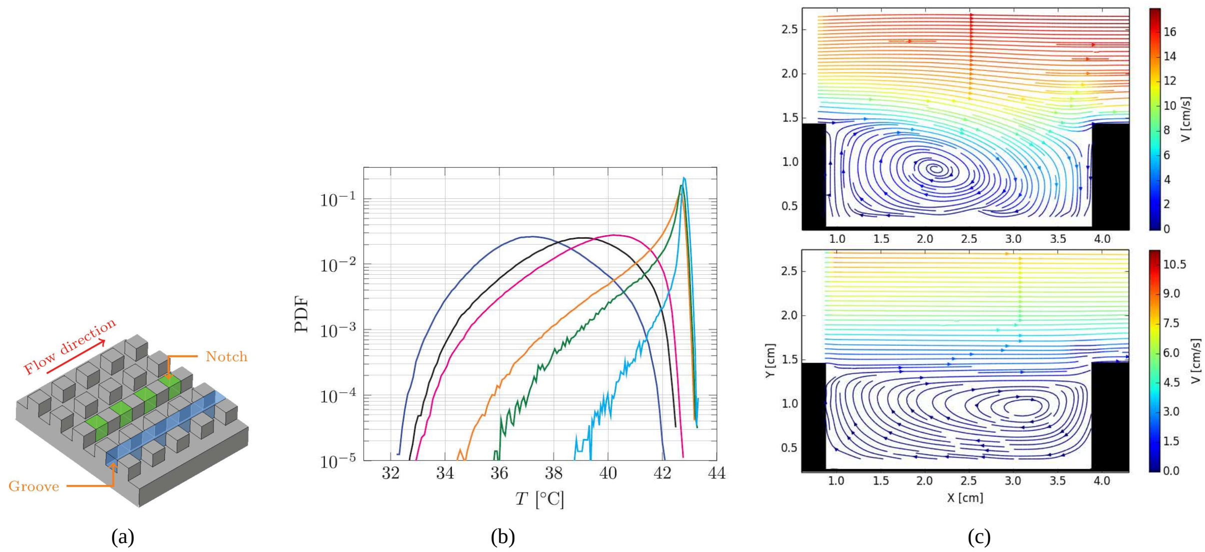

Figure 1: (a) Configuration of roughness, (b) example of temperature distributions on the square-studs, (c) flow streamlines into the notch at (up) $Ra = 2.8 \cdot 10^{10}$ and (down) $Ra = 4 \cdot 10^9$.

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