# TOWARDS THE NUMERICAL INVESTIGATION OF ROUGH SURFACES IN QUASI TWO-DIMENSIONAL RAYLEIGH-BÉNARD CONVECTION

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*Abstract* The aim of the present work is to investigate numerically the influence of roughness on Rayleigh-Bénard convection in three-dimensional rectangular containers in Direct Numerical Simulations (DNS). We seek for a domain that allows a quasi two-dimensional flow even for small Rayleigh numbers, which are preferable due to lower computational costs. It turns out that the influence of the vertical walls is not negligible and leads even to stationary flows at rather large Rayleigh numbers. Therefore, a free-slip condition has been prescribed on two nearby walls and the differences to the no-slip case with increasing *Ra* are studied. The main idea is, that for low Rayleigh numbers the free-slip walls lead to an already quasi two-dimensional flow, while for very large Rayleigh numbers (as they occur in experiments in similar containers) the differences in the boundary conditions are negligible when investigating global quantities like the mean heat flux, since the flow is bulk dominated. The DNS results for no-slip and free-slip boundary conditions are compared with those in the two-dimensional case.

Rayleigh-Bénard convection (RBC) is a model system for many flows in nature and technology. Usually smooth walls, and in particular smooth heating and cooling plates are considered for simplicity. But in many realistic flows (e.g. cooling devices) the roughness of the walls, realized by periodic obstacles, is used to enhance the heat transfer efficiency.

As a consequence, many experimental studies have been performed over the last years to study the influence of rough heating and cooling plates (e.g. [1, 8]). The latter have the disadvantage that parameter studies for different configurations of the roughness are very difficult and expensive, since every configuration requires a new set of heating and cooling plates. Furthermore, in experiments a uniform heating and cooling of the roughness elements is more complicated than in case of a smooth plate, which might lead to non-isothermal heating and cooling.

From this point of view Direct Numerical Simulations (DNS) are the proper tool to investigate different configurations of roughness in a reproducible manner. They are of course limited in the range of considerable Rayleigh numbers *Ra* due to a strongly increasing computational effort for larger *Ra* [6, 10]. Therefore in the first step two-dimensional simulations have been performed and a model for the integral heat transport (Nusselt number *Nu*) in dependence of the roughness configuration was developed [7]. In Figure 1 the influence of different configurations of roughness on the global flow structure is depicted. Since it is well known that for a small Prandtl number *Pr* the dynamics of RBC in two and three

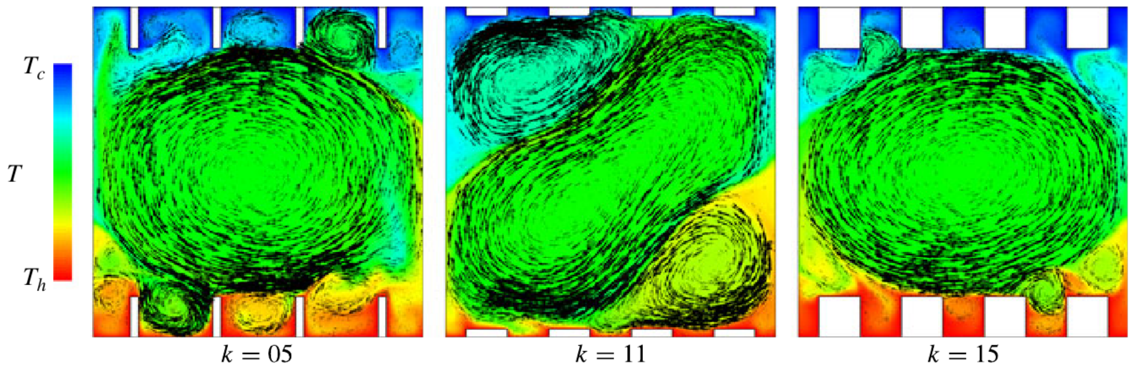


**Figure 1.** Instantaneous temperature field in two-dimensional DNS for different configurations ($k$) of roughness, $Ra = 10^8$, $Pr = 1$ (adopted from [7]).

dimensions differs considerably [4], the model needs to be tested and extended for the three-dimensional case.

It is thereby rather difficult to find a proper three-dimensional domain in which the global flow is still quasi two-dimensional. For example in a cube the global flow organises in a diagonal manner [9] if a certain *Ra* is reached. In some experiments in which the flow structure is investigated, a rectangular quasi two-dimensional box is used [11]. It usually has a similar height and length but a rather short depth, e.g. depth/height$= 1/4$. In very recent experiments also the influence of roughness is investigated in such a container [3]. In Figure 2(a) a sketch of such a domain with roughness elements is depicted. Also a recent numerical study (with smooth walls) exists [2] which treats similar *Ra* as in most of the experiments.

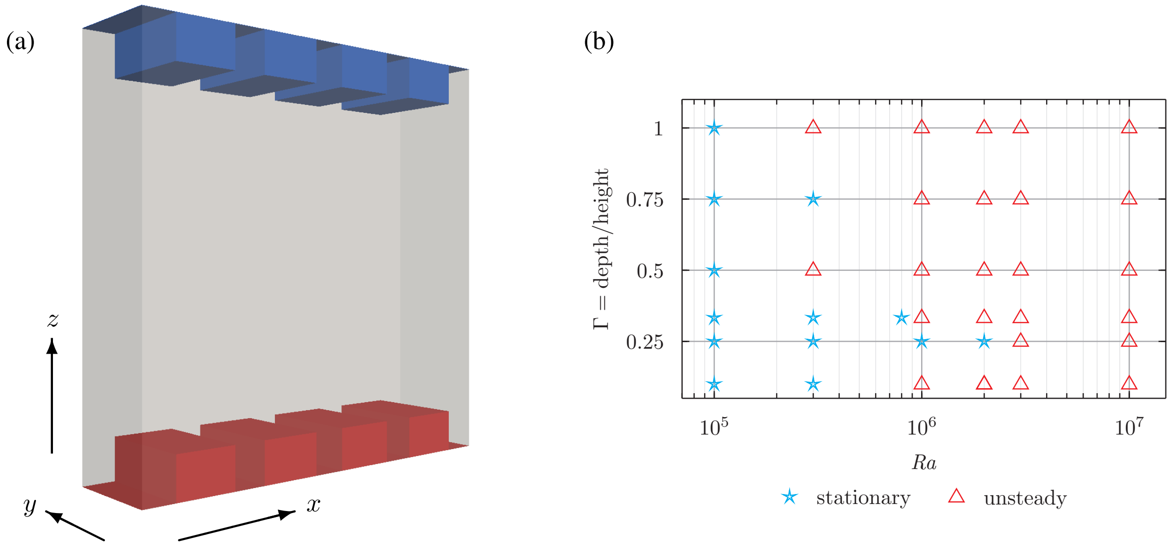


**Figure 2.** (a) Sketch of the considered quasi two-dimensional geometry for investigating the influence of roughness. The quantity of the heated/cooled obstacles on the bottom/top plate and their size may vary. (b) Influence of the aspect ratio $\Gamma$ =depth/height on the state of the equilibrium for smooth no-slip walls, $Pr = 0.786$.

The main difficulty is, that in DNS with roughness the Rayleigh number needs to be much smaller than in the mentioned experiments and consequently the flow is strongly influenced by the nearby walls. This is not only manifested in the heat transfer and the mean kinetic energy but also in the equilibrium state as it is shown in Figure 2(b). For small ratio $\Gamma$ =depth/height the flow stays stationary up to quite large *Ra*. In addition, due to changes in the global flow structure, in the transition region an increase of the depth might lead again to a stationary equilibrium (cf. Figure 2(b) $Ra = 10^6, \Gamma \approx 1/4$).
To overcome this, simulations with free-slip boundary condition on vertical walls $y$ =const. (see Figure 2(a)) and $\Gamma = 1/4$ are performed using a finite volume method [5]. It is expected that the influence of the walls for rather low *Ra* is decreased while for larger *Ra* (e.g. in experiments) the flow is bulk dominated and consequently global quantities like the Nusselt number should not be influenced much. The results of these simulations are compared with the no-slip case for different *Ra*. Furthermore, first results with surface roughness in a quasi two-dimensional domain will be presented.

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