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DNS of an air-filled differentially heated cavity of aspect ratio 4 at Ra-numbers 6.4×10^8, 2×10^9, 10^{10}, 3×10^{10} and 10^{11}

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ABSTRACT

Natural convection in differentially heated cavities (DHC) has been the subject of numerous studies over the past decades. This configuration models many engineering applications such as ventilation of rooms, cooling of electronics devices or air flow in buildings. Simultaneously, this configuration has served as prototype for the development of numerical algorithms. However, concerning the turbulent regime, the state-of-the-art is not satisfactory yet (for a review the reader is referred to [1]). Therefore, an accurate prediction of the flow structure and the heat transfer in such configuration at high Rayleigh numbers is of great interest.

The main goal of the present work is to improve our understanding of the dynamics of turbulent convection in a differentially heated cavity up to Ra-number 10^{11} (*i.e.* three orders of magnitude higher than the critical Ra-number). To do so, a set of five direct numerical simulations (DNS) of a DHC of aspect ratio 4 (Rayleigh number based on the cavity height 6.4×10^8, 2×10^9, 10^{10}, 3×10^{10} and 10^{11}, $\mathrm{Pr} = 0.71$) are presented and analysed. They cover a relatively wide range of Ra-numbers from weak to fully developed turbulence. These configurations have been selected as an extension of our previous work [1] where 2D and 3D results for the three lowest Ra-numbers were presented and compared.

Despite the geometric simplicity of this configuration a complex behaviour is exhibited (see figure 1). The vertical boundary layers remain laminar in their upstream part up to the point where the waves travelling downstream grow up enough to disrupt the boundary layers ejecting large unsteady eddies to the core of the cavity. The mixing effect of these eddies, that throw hot and cold fluid respectively, tends to result in almost isothermal hot upper and cold lower regions. This mixing effect at the top and bottom areas of the cavity, force the temperature drop in the core of the cavity occurs in a smaller region. Hence, flow structure is strongly dependent of an accurate prediction of the transition point at the vertical boundary layers. Due to this complex behaviour, and despite the great effort devoted, an accurate turbulence modelling of this configuration remains as a great challenge [2].

In summary, turbulent natural convection is a very complex phenomenon that is not well understood yet and 3D instability mechanics are still a challenging field of research. Hence, these new DNS results shall

give new insights into the physics of turbulence and provide indispensable data for future progresses on turbulence modelling [2, 3].

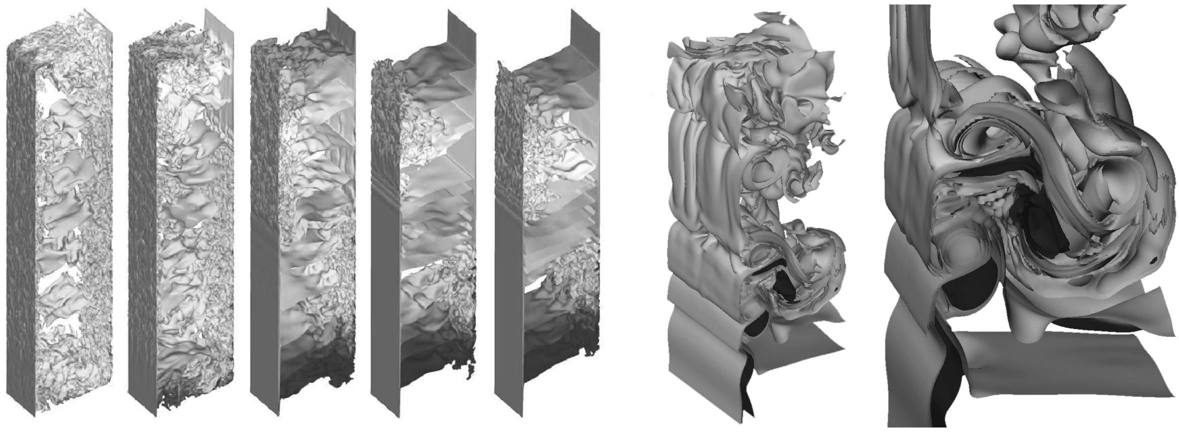

Figure 1: *Left: several instantaneous temperature fields at* $Ra = 10^{11}$ *and* $Pr = 0.71$ *(air). Right: zoom around the point where the vertical boundary layer becomes totally disrupted and large eddies are ejected.*

Several illustrative DNS results of instantaneous temperature maps obtained for the highest Ra-number are displayed in figure 1. The mesh size chosen for this simulation is $128 \times 682 \times 1278$. It has been carried out on the MareNostrum supercomputer using up to 512 processors. To the best of authors' knowledge, this is the largest DNS simulation with two wall-normal directions ever performed.

An overview of the numerical algorithms, the methodology to verify the code and the simulations and the new KSFD parallel Poisson solver [4] used to carry out these simulations will be given during the presentation and in the final paper. Numerical experiments showing the scalability and the flexibility on both the MareNostrum supercomputer and a PC cluster with a convectional 100 Mbits/s network will be presented and discussed. Speed-up results up to 1024 CPUs will be shown. Regarding DNS results, the main features of the flow, including time-averaged flow structure, turbulent statistics, the global kinetic energy balances and the internal waves of motion phenomenon will be discussed.

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