ON THE MOTION OF LARGE-SCALE CIRCULATIONS IN MIXED CONVECTION

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Abstract We present investigations on the motion of the large-scale circulations (LSCs) in turbulent mixed convection in a cuboidal cavity. The experimental studies are performed by combined temperature and velocity measurements.
Analysis of temperature measurements in previous studies revealed three different dynamical scenarios: stable LSCs, LSCs with spontaneous reversals as well as periodically oscillating temperature signals, which correspond to a continuous motion of the LSCs [8].
In the work presented here, we extend the temperature measurements by velocity measurements. These combined investigations help to answer open questions concerning the dynamics of the LSCs within the sample. In specific, we address the question which of the various dynamical processes observed in Rayleigh-Bénard convection in cylindrical samples, e.g. torsional oscillations or reversals of the LSC, [1] also occur in our cuboidal cavity in mixed convection.

INTRODUCTION

Mixed convection (MC) denotes a flow in which forced convection (FC), caused by inertia forces, and thermal convection (TC), initiated by buoyancy forces, are of the same order of magnitude. In MC, the Archimedes number $Ar = Ra \times Re^{-2} \times Pr^{-1}$ serves as a measure for the ratio between buoyancy and inertia forces. Here, Ra denotes the Rayleigh number with the height of the sample H and the temperature difference ΔT between the floor and the ceiling as characteristic length and temperature difference, respectively. For the Reynolds number Re, the mean inflow velocity U and the height of the sample H serve as characteristic values, while the Prandtl number Pr merely depends on the fluid properties.
The literature on the dynamics of the LSC in Rayleigh-Bénard convection (RBC) is vast [1, 2, 3, 4, 5, 6, 7, 10, 11, 12, 13] and provides a reasonable picture on the dynamical processes in RBC as well as presents models which describe the observed dynamics. However, little is known about the dynamics of the LSCs in MC. The aim of our work is to fill this gap for this field of important technical applications, e.g. heat exchangers or indoor climatisation. In the work in hand, we want to analyse which dynamical processes, e.g. torsional oscillations of the LSCs, occur in our sample.

EXPERIMENTAL SETUP

MC is studied in a cuboidal convection cell of length $L = 2500\,\mathrm{mm}$ with the aspect ratios $\Gamma_{xz} = \frac{L}{H} = 5$ and $\Gamma_{yz} = \frac{W}{H} = 1$, where H denotes the height and W the width of the container. Air at the atmospheric pressure ($Pr \approx 0.7$) is used as working fluid. A sketch of the cell is shown in Fig. 1. A vertical temperature gradient between bottom and ceiling is realised to induce TC. Furthermore, the cell is equipped with an air inlet at the top and an air outlet at the bottom. The height of the inlet and the outlet channels amounts to $25\,\mathrm{mm}$ and $15\,\mathrm{mm}$, respectively. Both are located on the same side wall and extend over the full length of the container. This configuration allows to generate a flow between the in- and outlet, driven by a pressure gradient. A more detailed description of the convection cell can be found in [9].

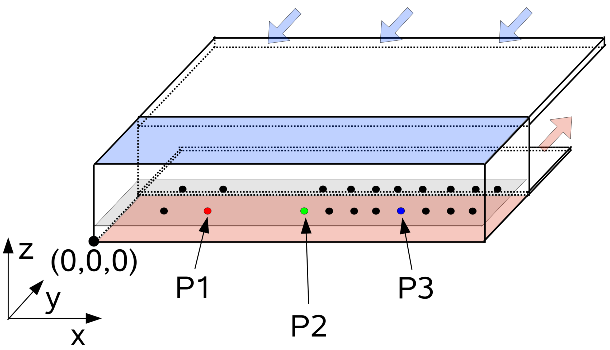

Figure 1. Sketch of the convection cell. The bottom plate of the cell is heated (red) while the ceiling is kept at the ambient temperature (blue). The in- and outflow channels are located at the same side wall and span the whole length of the cell. Dots mark the positions of the PT-100 sensors in the layer $Z/H = 0.2$ within the cell. More PT-100 sensors are placed in the layer $Z/H = 0.8$, but are not shown for the sake of clarity.

The temperature measurements are conducted using local temperature probes at fixed positions, and the velocity measurements are performed at different characteristic positions. The investigated parameter spans MC at $0.7 \times 10^4 \leq Re \leq 2.3 \times 10^4$, $0.8 \times 10^8 \leq Ra \leq 3.6 \times 10^8$ and $0.5 \leq Ar \leq 6.9$.

RESULTS

An example of a parameter combination (here $Ra = 2.0 \times 10^8$, $Re = 1.3 \times 10^4$ and $Ar = 1.8$) leading to periodic oscillations is shown in Fig. 2. Oscillations are found for the full measurement time of approximately 18 h (Fig. 2, left) and show very high periodicity, see the detailed view in Fig. 2 (right).

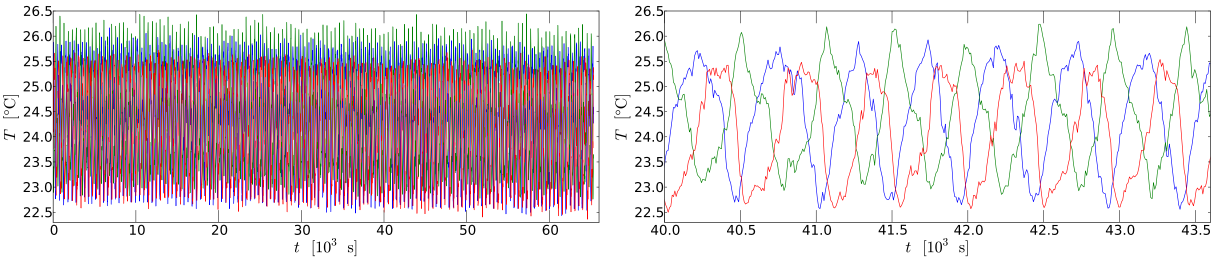

Figure 2. Temperature time series recorded at three selected sensor positions: P1 —, P2 — and P3 — at a parameter combination with periodically oscillating LSCs. Left: total recorded measurement time, right: detailed view of one hour.

A dependency of the dynamics on Re, Ra and thus Ar is found. However, the dynamic processes leading to these oscillations, i.e. the formation and breakdown of the convection rolls as well as the details of the coupling process between the side walls, is still under investigation.

So far, we know from smoke visualisations and temperature measurements [8], that the LSCs arrange as depicted in Fig. 3 and, furthermore, show a successive transition between the four shown modes. Results of upcoming velocity measurements at various characteristic locations, will help to further interpret and understand the observed dynamics of the LSCs.

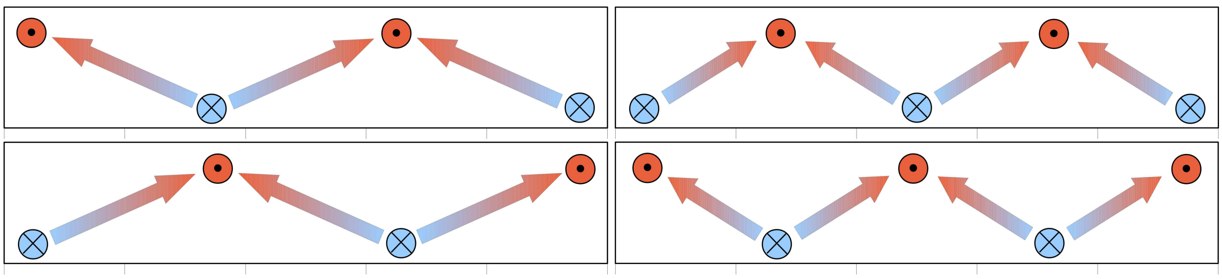

Figure 3. View from above on a layer close above the bottom plate, e.g. the layer with the temperature probes sketched in Fig. 1. Arrows indicate the direction of the in plane movement, ⊙ up- and ⊗ downstreaming fluid and the colour scales with the temperature. Top left: three LSCs, top right: four LSCs, bottom left: three LSCs counter rotating and bottom right: four LSCs counter rotating.

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