OSCILLATIONS OF HEAT TRANSFER AND LARGE-SCALE CIRCULATION IN TURBULENT MIXED CONVECTION

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Mixed convection (MC) describes the transport of heat in fluids when forced convection (FC) and thermal convection (TC) coexists. It is a very often occurring flow condition e.g. in the oceans, the atmosphere, indoor climatisation or in many industrial processes and applications. MC can be characterised by the dimensionless parameters Rayleigh number $Ra \equiv \Delta T \beta g H^3/\kappa\nu$, Reynolds number $Re \equiv UH/\nu$, Prandtl number $Pr \equiv \nu/\kappa$ and Archimedes number $Ar = Ra/(Re^2 \times Pr)$ which is the ratio of buoyancy to inertia forces.

In this study we investigated the influence of torsional oscillations of the large-scale circulations (LSC) on the heat transfer at MC in a rectangular cavity. To cover a large range of $600 < Re < 3 \times 10^6$ and $1 \times 10^5 < Ra < 1 \times 10^{11}$ two convection cells with an aspect ratio of 1:1:5 (height:width:length) have been constructed using air as working fluid. As a characteristic length the height H of the cell is chosen and the spatially averaged inflow velocity as characteristic velocity U. The convection cells consist of a rectangular container with an air inlet at the top and an air outlet at the bottom. Inlet and outlet are located at the same side of the cell. They span the whole length of the cell and are constituted by rectangular channels. The bottom is equipped with a heated copper plate and the top with an aluminium heat exchanger with cooling fins. The small cell with the dimensions $H = 100$ mm, $W = 100$ mm and $L = 500$ mm was designed to be operated under high pressure conditions up to 100 bar. The large convection cell has been designed to work under ambient pressure with the same aspect ratio. However, its dimensions are scaled by a factor of 5.

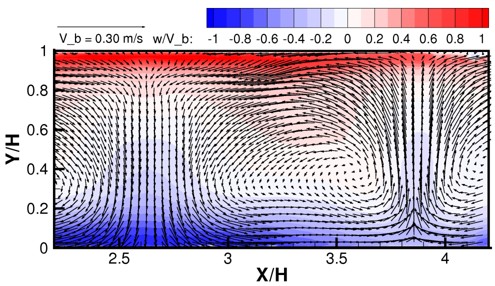

Figure 1: Time averaged velocity field of the 2D3C-PIV measurement for MC at $Ar = 3.3$ with $Ra = 2.4 \times 10^8$, $Re = 1.0 \times 10^4$ at $Z = W/2$ in the longitudinal cross section (for the sake of visibility only every fifth velocity vector is plotted).

One mechanism that drives the heat transport in MC is the buoyancy force. Rising hot plumes from the bottom thermal boundary layer and falling cold plumes emitted at the top boundary layer are generated. As the result of this plume-motion a LSC is formed [3]. In our enclosure the plume-motion induces four large-scale circulating role structures, which are arranged in longitudinal direction. Figure 1 illustrates one of these structures. It shows the interaction of the LSC due to the thermal plumes and the large-scale role structure due to FC. The flow field was measured by means of two Dimension three Component (2D3C) Particle Image Velocimetry (PIV) in the centre plane. Colour coded is the out of plane velocity component w and the vectors depict the in-plane velocity components.

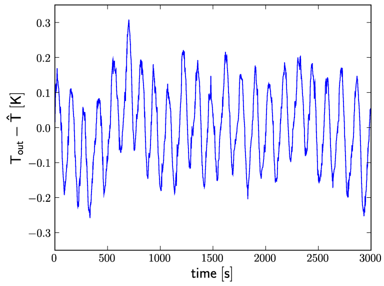

Figure 2: Outlet temperature fluctuations with a characteristic frequency of $f \approx 0.008$ Hz at $0.5 \times L$ for $Ar = 2.6$, $Ra = 7.2 \times 10^7$ and $Re = 6 \times 10^3$.

The superpostion of the nearly orthogonally oriented LSCs leads to a large number of flow structures [2]. The dynamics of these structures strongly affect the global heat transfer. Particularly, for $Ar > 1$ the torsional oscillations of the four LSCs induced by the buoyancy forces lead to a low frequency oscillation of the temperature at the outlet. Torsional oscillation of the LSC has already been investigated for Rayleigh-Bénard (RB) convection in a cylindrical sample by Funfschilling et al. [1]. Their measurement suggests that the existence of the oscillations is a consequence of a stochastic driving by the small-scale turbulent background fluctuations.

The frequency of the oscillation found in our experiment is much lower than the angular frequency of the large-scale role structures and depends strongly on Ar and the magnitude of Re and Ra. Figure 2 shows the time series of the outlet temperature fluctuations induced by the torsional oscillation of the LSC for $Ar = 2.6$, $Ra = 7.2 \times 10^7$ and $Re = 7.7 \times 10^3$ with a characteristic frequency of $f \approx 0.008$ Hz. The same characteristic frequency has also been found for the time coefficient of the modes with the largest energy eigenvalues calculated by a Proper Orthogonal Decomposition (POD).

In the full paper we want to report in detail on the dynamics of the large-scale structures torsional oscillation and their influence on the heat transfer for different magnitudes of Ra and Re. Also the results of a POD analysis of the measured velocity fields will be presented and discussed.

[1] Funfschilling, D., Brown, E., and Ahlers, G. Torsional oscillations of the large-scale circulation in turbulent Rayleigh-Bénard convection. *J. Fluid Mech. 607* (2008), 119–139.

[2] Westhoff, A., Bosbach, J., and Wagner, C. Scaling of mixed convection in aircraft cabins. *26th International Congress of the Aeronautical Sciences* (2008).

[3] Xia, K. Q., Sun, C., and Zhou, S.-Q. Particle image velocimetry measurements of the velocity field in turbulent thermal convection. *Physical Review E 68* (2003), 066303.