NUMERICAL INVESTIGATION OF FLOW REVERSALS IN A FLAT RAYLEIGH-BÉNARD CELL

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Abstract The present work deals with the reversal process of the large-scale circulation filling a flat square Rayleigh-Bénard cell of transverse aspect ratio 0.25 (depth by height). 3D spectral computations have been performed at $Ra = 10^7$ and $Pr = 5.5$. Results present agreement with the experimental and 2D numerical observations [5] of a diagonal main roll coupled to two smaller rolls located in both remaining opposite corners. However additional patterns are identified which reveal a more complex reversal process than in a perfectly 2D configuration.

MOTIVATION

The coexistence of different structures of large-scale circulation (LSC) and their impact on the Nusselt number are the topic of several experimental studies [6, 4] or 2D computations (see for example [5, 2]) or more rarely by 3D computations [1, 3]. Most of these studies have been done in cylinder for experiment and perfectly 2D cavity for numerical simulations. A previous study based on application of the proper orthogonal decomposition (POD) [3] in a 3D rectangular cell of moderate aspect ratio has shown the coexistence of two pairs of orthogonal horizontal rolls and the role of the secondary rolls in the reversal process. However this process seems to be very different from those observed in 2D simulations or in a flat cavity [5, 7]. The objective of the present work is to investigate the different flow states appearing in the reversal process in a flat cavity by performing 3D computations and POD.

NUMERICAL SET-UP

We consider a flat water-filled Rayleigh-Bénard cavity ($\overline{T} = 30°C$, $Pr = 5.5$) of square vertical section and one quarter horizontal aspect ratio (depth by height). This geometry is close to the experimental set-up of [7]. The Rayleigh number is set to 10^7. The fluid is heated from below and cooled from above by two isothermal walls. The four vertical walls are perfectly adiabatic. No slip boundary conditions are applied on the six walls. 3D simulations are carried out with a multi-domain spectral code [8] developped at LIMSI. A Chebyshev collocation method is used for spatial discretization of the Boussinesq equations. Incompressibility is enforced by the projection-correction method. The equations are integrated in time with a second-order mixed explicit-implicit scheme. The domain decomposition is carried out by the Schur complement and implemented with the MPI library.

RESULTS

As expected regarding [5], spontaneous and abrupt reversals are observed in the present configuration, as shown on figure 1. To get insight into the reversal process, several snapshots of streamlines in the vertical mid-plane colored by the temperature are presented in figure 2. Accordingly with [5], a main roll oscillates between both perpendicular diagonal orientations, inbetween wich a quadipolar flow structure appears (see (a)(b)(c) of figure 2). However it is not clear if, in 3D calculations, only a process based on the growth of the corner flows is responsible of the reversals. Indeed, additional patterns have been identified during the time marching (see the bottom line in the figure 2). For example: figure 2-d presents the splitting of the main diagonal roll in two vortices; in figures 2-e and 2-f, two main vortices fill a large bottom part of the cavity, whereas two top corner rolls are growing; in figure 2-g, four vortices replace the two top corner rolls. Proper orthogonal decomposition will be carried out on the DNS database to clarify the reversal process. The conclusions will be compared to the previous analyses [3].

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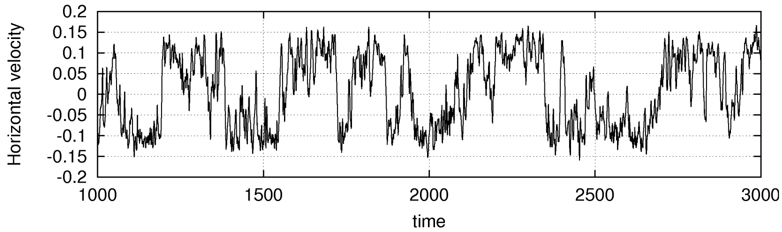

Figure 1. Time series of horizontal velocity in the bottom boundary layer. Time units are given in dimensionless form, calculated from the natural convection velocity as the reference velocity.

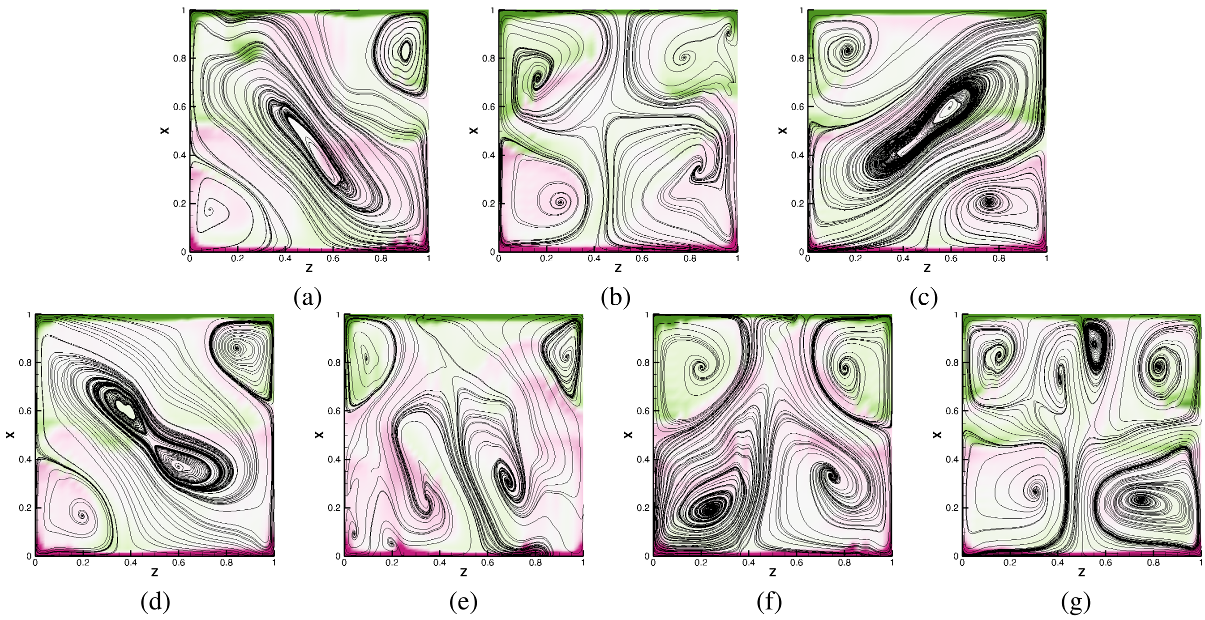

Figure 2. Snapshots of the streamlines on the vertical midplane colored by the temperature.