The structural unit of oscillatory large-scale circulation

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In Rayleigh–Bénard convection (RBC)[1], the size of the domain and its aspect ratio Γ (a ratio between the spatial length and height of the domain) affect the mean heat and momentum transport in the system[2], as well as the shape and properties of the large-scale circulation (LSC). For some aspect ratios, the flow dynamics include a three-dimensional oscillatory mode known as a jump-rope vortex[34] (JRV), however, the effects of varying Γ on this mode are not well investigated.

In this talk, we present a numerical and experimental study[5], of the Γ-effects in RBC in liquid metals (Prandtl number $Pr = 0.03$). Direct numerical simulations (DNS) and measurements are carried out for a Rayleigh number range $2.9 \times 10^4 \leq Ra \leq 1.6 \times 10^6$ and square cuboid domains with $\Gamma = 2$, 2.5, 3 and 5. The results show that the JRV-like structures form not only in cylindrical domains, but also in cuboid domains with $\Gamma = 2$ (Fig. 1d). For domains with $\Gamma = 2.5$ and $\Gamma = 3$, the JRV-like vortices form an orthogonal cross that periodically rotates, alternately clockwise and counterclockwise (Fig. 1 a-b). In a $\Gamma = 5$ cell, a lattice of four JRVs interlace each other[4] and oscillate in a synchronised manner (Fig. 1c). The structures in the lower aspect ratio cases ($\Gamma = 2$, 2.5 and 3) are building units of the structure formed within the largest aspect ratio case ($\Gamma = 5$).

The key finding of this study is that the JRV structures are extremely robust; they adapt and reorganise dependently on the aspect ratio of the domain, with ability to form intricate lattice of repetitive flow structures in large aspect-ratio containers.

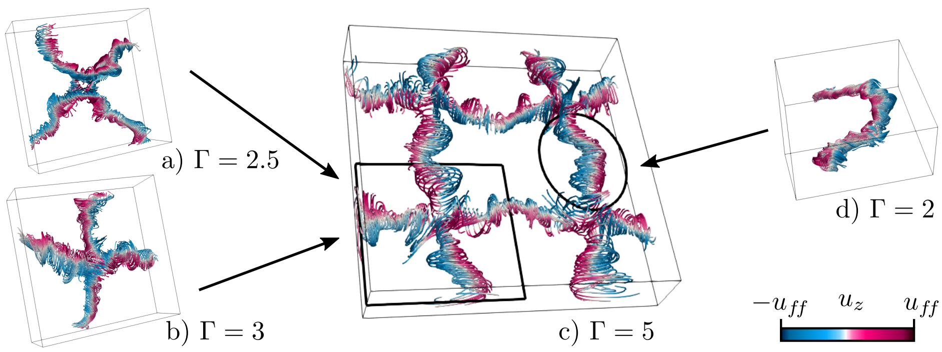

Figure 1: Phase-averaged streamlines for $Ra = 10^6$, as obtained in the DNS for different aspect ratios (a) $\Gamma = 2.5$, (b) $\Gamma = 3$, (c) $\Gamma = 5$ and (d) $\Gamma = 2$. The streamlines envelope the oscillating vortex, and the colour scale is according to the vertical velocity component u_z.

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