LAGRANGIAN ANALYSIS OF TURBULENT ROTATING CONVECTION

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Abstract This study aims to explore how the flow transition from one state to the other in rotating convection will affect the Lagrangian statistics of (fluid) particles. 3D Particle Tracking Velocimetry (3D-PTV) is employed in a water-filled cylindrical tank of equal height and diameter 200 mm. The measurements are performed in the central volume of 50 × 50 × 50 mm^3 at a Rayleigh number Ra = 1.28 × 10^9 and Prandtl number Pr = 6.7. We are reporting the velocity and acceleration pdfs for different Rossby numbers. For different rotation rates, the transverse velocity pdfs show a Gaussian distribution. The vertical velocity pdf has slightly wider tails for stationary and high rotation rate cases, while it approaches the Gaussian distribution for intermediate rotation rates. The acceleration pdfs have significantly wider tails in comparison to those of a Gaussian distribution which is similar to the other turbulent flows. Increasing rotation results in less intermittency in vertical acceleration in the center of RB.

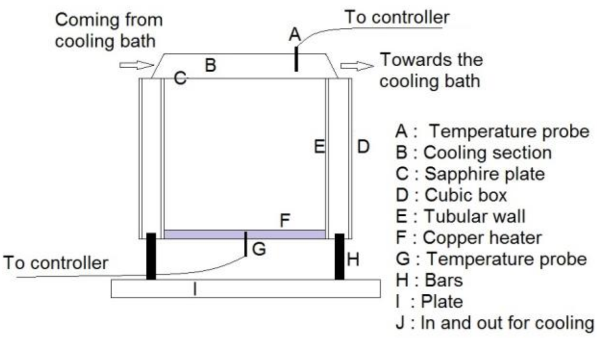
INTRODUCTION

In the present study, the classical Rayleigh-Bénard convection is subjected to background rotation. In rotating RB two regimes are observed; regime I where the flow is dominated by a large scale circulation (weak rotation), and regime II where the flow is dominated by vertical vortices (strong rotation). The transition between these two regimes is concomitant with an abrupt increase in heat transfer [1]. Up to now, the global parameters like the overall heat transfer or the wind Reynolds number are used to characterize the different turbulent states. However, it is obvious that the flow transition from weakly rotating Rayleigh-Bénard (RB) convection to strongly rotating RB also is reflected in the Lagrangian dynamics of immersed tracer particles. This study focuses on how the flow transition from one state to the other in rotating convection will affect the Lagrangian statistics of (fluid) particles.

EXPERIMENTAL SETUP

The experimental setup consists of a convection cell and tracking system. The convection cell is composed of a transparent cooling chamber at the top, a copper plate at the bottom and a transparent cylindrical cell. The cylindrical cell, with inner diameter and height of 200 mm, is confined in a rectangular box. The cell and rectangular box are both made of Plexiglass. Figure 1-left shows a schematic view of the convection cell.

Three-dimensional particle tracking velocimetry (3D-PTV) is employed to track tracer particles. The particle positions are recorded by four CCD cameras equipped with 50 mm lenses. The array of cameras is located above the convection cell, see figure 1-right.



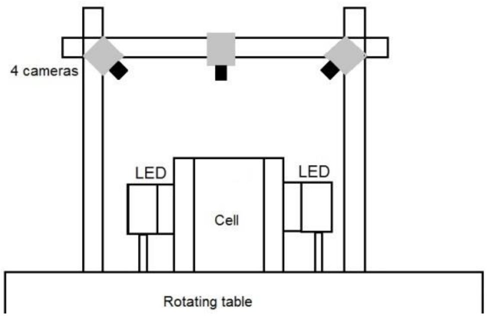


Figure 1. Convection cell (left) – cameras positioning (right).

The measurements are performed in the central volume of 50 × 50 × 50 mm^3 at a Rayleigh number Ra = 1.28 × 10^9 ($Ra = g\alpha\Delta T H^3/(\nu\kappa)$) and Prandtl number Pr = 6.7 ($Pr = \nu/\kappa$) for 8 different Rossby numbers ($Ro = U/(2\Omega H)$) with g the standard gravity, α thermal expansion coefficient, ΔT the temperature difference between two plates, H the cell height, ν kinematic viscosity, κ thermal diffusivity, U the free-fall velocity ($U = \sqrt{g\alpha\Delta T H}$) and Ω the rotation rate.

RESULTS

The velocity and acceleration pdfs in the center of the rotating RB cell are measured. The normalized longitudinal-velocity pdf shows a semi-Gaussian distribution. It is Gaussian for $Ro > 1$ and starts to deviate from the Gaussian shape for $Ro < 1$. On the other hand, the normalized vertical-velocity pdf shows different behavior. The vertical-velocity pdf has slightly wider tails for stationary and high rotation rate cases, while it approaches the Gaussian distribution for intermediate rotation rate ($Ro = 2.5$).

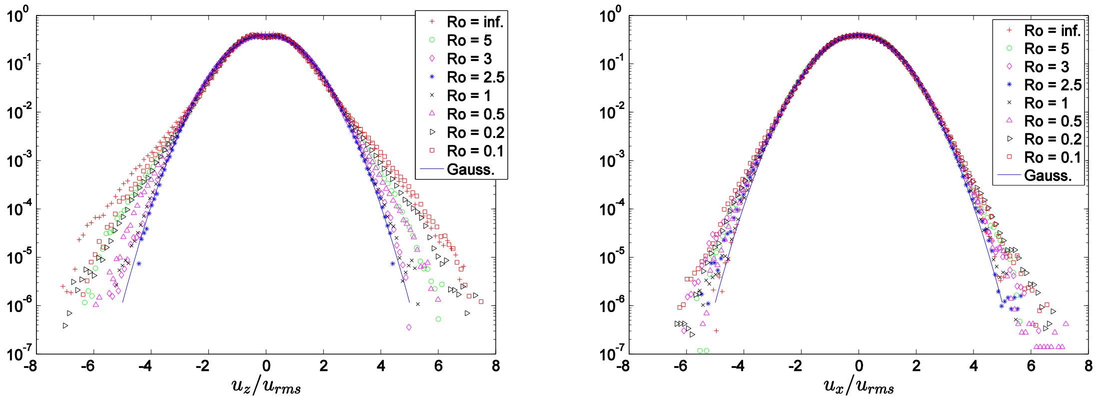


Figure 2. Normalized vertical-velocity pdf (left) and normalized longitudinal-velocity pdf (right).

The acceleration pdfs show the extremely wide tails which is customary in turbulent flows [2]. The longitudinal-acceleration is almost independent of the rotation rate. However, the vertical-acceleration pdfs shows that rotation damps intermittency. This is explained by the Taylor-Proudman theorem which states that at sufficiently high background rotation, the flow velocity is uniform along any line parallel to the rotation axis. Our rotation rate is far from this state, but it shows that the flow is in transition to this state.

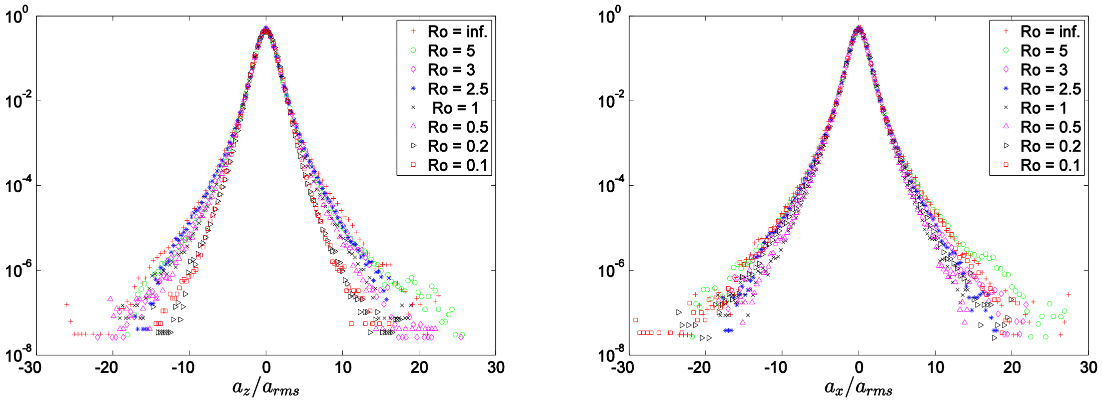


Figure 3. Normalized vertical-acceleration pdf (left) and normalized longitudinal-acceleration pdf (right).

ACKNOWLEGMENT

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References

[1] R. J. A. M. Stevens, H. J. H. Clercx, and D. Lohse. Heat transfer and flow structure in rotating Rayleigh-Bénard convection. *European Journal of Mechanics* **40**: 41–49, 2013.

[2] A. Voth , A. La Porta , A. M. Crawford , J. Alexander , E. Bodenschatz. Measurement of particle acceleration in fully developed turbulence, *Journal of Fluid Mechanics* **469** : 121-160, 2002