Linear Stability Analysis of Rotating Horizontal Convection with a Moving Heated Surface

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Abstract

Rotating flows subjected to differential shear find practical engineering applications within rotating machinery, as well as providing physical insights into models of wind-driven ocean circulations. The key question is how does the surface shear stress, such as moving blade within machinery or wind stress on the ocean, the affect heat transfer characteristics and flow stability of the system? Previous studies (Barkan *et. al.,* 2015, Vreugdenhil *et. al.*, 2017) investigated rotating shear flow in a rectangular enclosure. However, to the best of the authors' knowledge, no research has been done to systematically investigate a coupled horizontal convection and surface shear stress on a rotating cylindrical setup. In this study, the nonlinear dynamics of a moving heated surface on the three-dimensional instability of a rotating horizontal convection flow in a cylindrical enclosure driven by a radially increasing temperature over the base is numerically investigated using a linear stability analysis. The instability modes are classified based on energetics of the perturbation flow fields.

The control parameters used in this investigation are rotation parameter, Q, which quantifies the importance of rotation, and the Rossby number, Ro, which represents the differential rotation rate between the moving bottom base and the main rotating tank. The results demonstrate two distinct unsteady regimes within the rotation parameter Q and the Rossby (Ro) parameter space separated by a region of time independent flow. Based on linear stability and energetics analysis, the steady region is further divided into four linearly unstable regions: (R) rotation affected zero Rossby number, (L-) low Q negative Rossby number, (H-) high Q negative Rossby number and (H+) high Q positive Rossby number as depicted in figure 1.

In the low Q negative Rossby number regime, instability is localized near the buoyant end of the cylinder, whereas the high Q negative Rossby number regime has disturbance features toward centre of the tank which extends deep into the enclosure. On the other hand, the high Q positive Rossby number instability is confined near the edge of the cylinder due to vertical shear induced by the moving heated surface.

References

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Vreugdenhil, C. A., Griffiths, R. W., & Gayen, B. (2017). "Geostrophic and chimney regimes in rotating horizontal convection with imposed heat flux", *Journal of Fluid Mechanics*, *823*, 57-99.

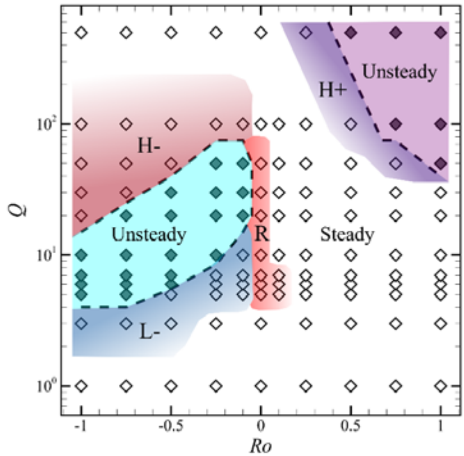

Figure 1. Flow regime map in the rotation parameter (Q) and Rossby number (Ro) space. The plot identifies time-dependent regimes shaded with light blue and light purple. The linearly unstable regions are shaded with colour gradient, each with a label as described in the text.

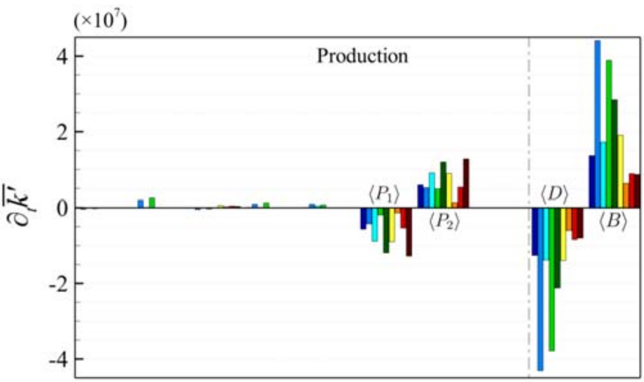

Figure 2. Contributions to rate of change of the perturbation kinetic energy from eight production terms due to velocity shear with two dominant terms labelled as $\langle P_1 \rangle$ and $\langle P_2 \rangle$, viscous dissipation, $\langle D \rangle$, and contribution from buoyancy flux $\langle B \rangle$. The parameters (Q, Ro, wavenumber) for each of the nine columns are as follow: (6, -0.1, 12), (6, -0.1, 26), (6, -0.25, 12), (6, -0.25, 21), (10, -0.1, 23), (20, -1, 9), (50, -0.5, 23), (50, -0.75, 21) and (50, -1, 15).

Brief Biography

TzeKih Tsai is a PhD researcher from the Department of Mechanical and Aerospace Engineering, Monash University, with research interests in understanding the fundamental dynamics of horizontal convection under the influence of buoyancy forcing and the effect of rotation through idealised numerical modelling.