Instabilities and inertial waves generated in a librating cylinder

Juan M. Lopez* **and Francisco Marques**†

* School of Mathematical and Statistical Sciences, Arizona State University, Tempe AZ 85287, USA
e-mail: lopez@math.asu.edu, web page: http://math.asu.edu/∼lopez

†Departament de Física Aplicada, Univ. Politècnica de Catalunya, Barcelona 08034, Spain
e-mail: marques@fa.upc.edu, web page: http://www-fa.upc.es/websfa/fluids/marques/marques.html

ABSTRACT

Longitudinal librations refer to torsional oscillations about the axis of a rotating axisymmetric fluid-filled cavity. A librating cylinder consists of a rotating cylinder whose rate of rotation is modulated. There has been, and continues to be much interest in these flows motivated by issues in planetology (Aldridge & Lumb 1987, Noir *et al.* 2009). The scales involved in planetary hydrodynamics present grand challenges to theoretical and numerical modeling, and the need for compromises in laboratory-scale experiments designed to investigate such flows. The rapid background rotation leads to an interior flow that is very close to solid-body rotation that is capable of sustaining inertial waves (Aldridge & Toomre 1969). When the mean rotation rate is large compared to the viscous damping rate, the flow may support inertial waves, depending on the frequency of the modulation. The modulation also produces time-dependent boundary layers on the cylinder endwalls and sidewall, and the sidewall boundary layer flow in particular is susceptible to instabilities which can introduce additional forcing on the interior flow with time scales different from the modulation period. These instabilities may also drive and/or modify the inertial waves.

Recent experiments in a librating cylinder (Noir *et al.* 2010) report that the transition to wavy turbulence is abrupt. They also comment on the presence of inertial waves since the modulation frequencies they impose are typically less than twice the background rotation frequency, but they do not present direct measurements of these waves. At larger modulation amplitudes, they find that the sidewall layer is unstable to Taylor–Görtler-type vortices which abruptly become wavy turbulent with a very small further increase in modulation amplitude.

Here, we explore such flows numerically using a spectral-collocation code solving the Navier–Stokes equations in order to capture the dynamics involved in the interactions between the inertial waves and the viscous boundary layer flows.

REFERENCES

[1] Aldridge, K. D. & Toomre, A. *Axisymmetric inertial oscillations of a fluid in a rotating spherical container*, J. Fluid Mech. **37**, 307-323, (1969).

[2] Aldridge, K. D. & Lumb, L. I. *Inertial waves identified in the Earth's fluid outer core*, Nature **325**, 421-423, (1987).

[3] Noir, J., Hemmerlin, F., Wicht, J., Baca, S. M. & Aurnou, J. M. *An experimental and numerical study of librationally driven flow in planetary cores and subsurface oceans*, Phys. Earth Planetary Int. **173**, 141-152, (2009).

[4] Noir, J., Calkins, M. A., Cantwell, J. & Aurnou, J. M. *Experimental study of libration-driven zonal flows in a straight cylinder*, Phys. Earth Planetary Int. **182**, 98-106, (2010).