

Libration-driven flow in planetary cores and subsurface oceans.

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Abstract

In the present study, we investigate the flow driven by longitudinal libration in the liquid layer of planetary bodies via a coupled experimental-numerical approach. Extending the work of [7], we consider the case of a non-axisymmetric container to account for the topographic coupling between the fluid and the solid shell that arises naturally in planets in low order spin-orbit resonance such as Mercury, Io, Titan, Europa, the Earth's moon or Ganymede. We show that depending on the libration frequency, laminar or turbulent flows can develop in the system as the result of growth and collapse of an elliptical instability. An analytical expression of the growth rate of the instability is obtained using a WKB analysis further validated by series of numerical simulations. Extrapolation of our findings to planetary conditions suggest that some librating planets may be subject to elliptical instabilities, therefore to turbulence in the liquid layer leading to significant energy dissipation [5].

1. Introduction

The experimental device used in the present study is represented in Figure 1. It consist in a turntable controlled by a PC that reproduces the mean rotation of the planet and an oscillating motor on which the container is attached to mimic the librational forcing. The container is made from two blocks of cast acrylic precisely machined into spherical or ellipsoidal cavities. To diagnose the flow we perform direct visualization using reflecting particles, Kalliroscope, and a digital camera recording still images and videos. In addition, a novel laser Doppler apparatus is used to acquire quantitative velocity measurements. The numerical simulations were performed using MagIc for the 3D spherical shell [7] and ComSol for the 3D-triaxial ellipsoidal cavity. We developed a 2D-Axisymmetric code to access the low Ekman number range of parameters [3].

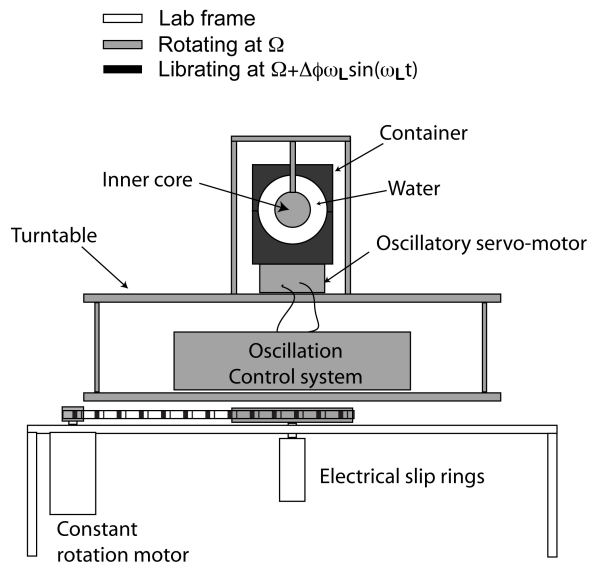


Figure 1: Experimental setup

2 Results

Let's first consider the case of a spherical cavity, for which viscosity is the sole mechanism that transfers energy from the librating container to the fluid. For low amplitude of libration, the resulting flow is well characterized by inertial modes and waves on diurnal time scale and a large scale mean zonal flow produced by non-linearities in the viscous boundary layers [2, 3, 6, 8]. As the forcing is increased, we observe a transition from the laminar regime to boundary layer centrifugal instabilities in the form of Taylor-Görtler vortices and localized turbulence [1, 9, 7, 3]. Meanwhile, the flow in the interior remains laminar. In contrast, for non axi-symmetric containers, we observe intermittency of laminar flow and space filling turbulence in a band of resonant libration frequencies as shown on the zonal velocity time series in Figure 2. We report a systematic correlation between large amplitude zonal flows and space filling turbulence.

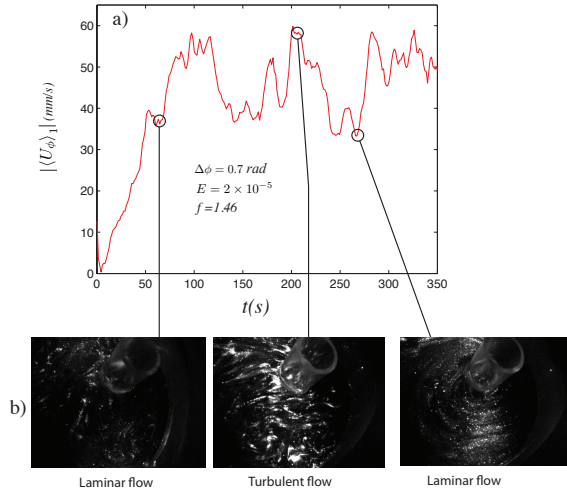


Figure 2: Intermittency of laminar and turbulent flow associated with low amplitude and large amplitude zonal flow, respectively.

Coupled numerical simulations allow us to conclude that the intermittency can be interpreted as the growth and collapse of an elliptical instability [4], hereafter referred as the Libration Driven Elliptical Instability (LDEI). We show that the growth rate of the LDEI derived from a WKB analysis is in quantitative agreement with our observations.

3. Summary and Conclusions

The present study continues the work of [7] by taking into account the topography naturally resulting from a spin-orbit resonance. We show that in a non-axisymmetric librating container LDEI can grow and collapse resulting in an intermittency of laminar flow and space filling turbulence. An analytical expression of the growth rate of the LDEI has been derived using a WKB approach, which has been further validated by comparison with the experimental and numerical results. Extrapolation of our results to planetary bodies suggest that Mercury, Io and Europa may be subject to an elliptical instability, therefore intermittent turbulence in the interior of their liquid layers leading to significant energy dissipation.

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