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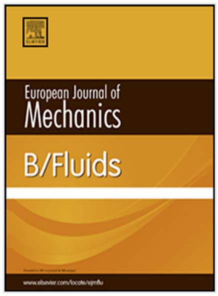

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Steady flows excited by circular oscillations of a free inner core in a rotating spherical cavity

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Abstract. This research involves experimental studies of the fluid flow excited by a light free spherical core in a spherical cavity rapidly rotating around the horizontal axis. The gravity force, directed perpendicular to the axis, causes a small radial displacement of the light core from the rotation axis; the displacement is steady in the laboratory reference frame. This corresponds to circular oscillations of the core in the rotating reference frame with the frequency equal to the rotation rate of the cavity. As a result, steady flows are generated in the fluid, which are accompanied by a lagging differential rotation of the core. Inertial waves created by the oscillating core also contribute to the generation of steady flows. The velocity field of fluid flow is studied using the PIV method. It is demonstrated that the mean azimuthal flow of the fluid has a two-dimensional structure, which means the azimuthal velocity magnitude is virtually constant with respect to the axial coordinate. The azimuthal flow consists of several coaxial cylindrical surfaces, nested into each other, rotating at different angular frequencies. The radial distribution of the azimuthal velocity is characterized by a series of inflexion points and is qualitatively different from the known case of a flow caused by a differential rotation of the core, mounted on the axis of the rotating cavity. The inflexion points, in their turn, form the basis for the development of various unstable modes. It is discovered that, before the instability threshold, the axisymmetric azimuthal flow of fluid is fully determined by the lagging differential rotation rate of the core. It is shown that the azimuthal fluid flow is accompanied by relatively weak flows of axial circulation in the form of toroidal vortices.

Keywords: rotation; inner core; inertial oscillations; steady flows; differential rotation.

I. INTRODUCTION

The investigation of the flow pattern in rotating spherical fluid layers is an actual problem for modern fluid mechanics. The interest in it is explained by the necessity of describing the interior structure of planets and satellites, many among which have a solid inner core and a melted (liquid) outer core [1]. Meanwhile, the fluid motion in the electrically conductive liquid core is responsible for the generation of magnetic fields of planetary bodies [2, 3]. Thermal convection is considered as the principal mechanism of flow generation on the core [4]. At the same time, the planet’s interaction with its gravitational partners leads to an oscillating fluid motion in the core as a result of periodic perturbations of: the planet’s shape, the direction of rotation axis or the rotation rate [5]. Fluid oscillations in liquid cores can generate steady flows, contributing to the motion along with thermal convection.

The Ekman viscous boundary layers transfer the perturbations of rotating systems into the fluid volume [6]. Under precession, there are critical latitudes where the Ekman layers break down [7]. These critical points are the sources of the so-called inertial waves [6, 8, 9], which propagate in the fluid volume along the conical surfaces, on which free shear layers are formed [10]. This is supported by direct numerical simulations [11, 12, 13] and experiments [14, 15, 16, 17]. The nonlinear effects in viscous boundary layers at the critical latitudes lead to the generation of a steady differential rotation of the fluid [18]. Thus, the experiments conducted in [14, 15, 19] and simulations [12, 20] demonstrate that the steady flows appear, having the form of nested cylindrical shear layers, which are approximately coaxial with the rotation axis of the fluid. The literature review dedicated to the flows excited by precession, and to their stability may be found in [21].

Besides the precession, a periodic variation of rotation speed, the so-called longitudinal librations, is proper for planetary bodies. The number of studied in this domain is large. Thus, analytical [22], experimental and numerical [23] investigations of the fluid motion in a librating sphere showed that in the limit of low libration frequencies, resulting from nonlinear effects in the Ekman boundary layers, a steady zonal flow is generated. The intensity of zonal flow does not depend on the frequency and is proportional to the squared libration amplitude. In the spherical layer, formed by two concentric spheres, the librations of the outer [24, 25] or the inner sphere [26] also lead to the generation of a steady streaming, the nature of which is also determined by non-