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Mean flow generation in a rotating straight and sloping wall annulus with librating walls

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The work presented is about the investigation of the mean flow generation mechanism in a rotating straight and sloping wall annulus with librating walls. Three mean flow generation mechanism may be identified: the mean flow driven by inertial wave-wave interaction, mean flow driven by the action of Reynolds stress and mean flow driven by friction. Direct numerical simulation together with a laboratory experiment is used to investigate it. An incompressible Navier-Stokes solver with the equations formulated for volume fluxes in generalized curvilinear coordinates has been used. In terms of geometry, the current investigation is divided into two parts: mean flow generation mechanism in (i) a sloping wall annulus and (ii) a straight wall annulus.

For the sloping wall annulus we investigated mean flow induced by inertial wave-wave interaction and friction. Under consecutive reflections in a sloping wall annulus inertial waves may form wave attractors. It will be shown that when boundary layer over the sloping wall is centrifugally stable, a retrograde mean flow may be generated due to the focusing of inertial wave beam from the sloping wall via the inertial wave-wave interaction. In addition, we observed a prograde mean flow which is induced by the effect of friction and is scaled as a Stewartson layer. We studied the appearance of this mean flow by librating top/bottom lids and sloping wall either independently or together. A comparison with laboratory experiment (PIV) will be shown.

In the second part, mean flow in a straight wall annulus induced by the effect of Reynolds stress and friction is investigated. To study mean flow generation mechanism, we allow top/bottom lids and inner and outer cylinder side walls librate either together or independently. It has been shown experimentally (Noir et al. 2010) that a retrograde mean flow in the bulk of the fluid is due to the nonlinearity of the Ekman boundary layer and instability of the Stokes boundary layer and inertial waves does not have any contribution to that. In contrast, by libration of top/bottom lids and cylinder side walls independently or together we showed that the contribution of the unstable Stokes boundary layer and inertial waves is not negligible. By making an analogy to the acoustic standing waves, it will be explained that inertial waves may modify the bulk mean flow by the formation of standing wave via the action of Reynolds Stress. According to Ekman number, libration amplitude and libration frequency, Stokes boundary layer may be centrifugally stable or unstable. Unstable stokes boundary layer generates Geortler vortices. These vortices diffuse away into the bulk and via the effect of Reynolds stress generates a mean flow (called steady streaming). This mean flow is retrograde and prograde close to the outer and inner cylinder side wall, respectively. It is observed that the libration of tops/bottom lids together with cylinder side walls reduces the amplitude of the Steady streaming when Stokes boundary layer is centrifugally unstable and increases the amplitude of the Stewartson layer when Stokes boundary layer is centrifugally stable. By considering Reynolds average equations as diagnostic equations, the generation mechanism and the sign selection of the steady streaming will be discussed. It will be shown that steady streaming is a result of inverse cascade of energy from turbulent fluctuations to the mean flow. A comparison with laboratory experiment (PIV) will be shown.

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Reference

J. Noir, M. A. Calkins, J. Cantwell and J. M. Aurnou, Experimental study of libration-driven zonal flows in a straight cylinder. Phys. Earth Planet. Inter. 182 (2010), 98-106.