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MEAN FLOW GENERATION AND INERTIAL WAVE ATTRACTORS IN A LIBRATING ANNULUS: DNS and Theory

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Rotation Ω_0 is one of the most important system parameters in geophysical fluid dynamics (GFD) due to stratification of angular momentum. Oscillatory motion (libration) of the fluid over solid surfaces is generated in many systems by harmonic forces, usually resulting from rotation of the fluid in a homogeneous gravitational and/or electromagnetic field.
Small amplitudes of libration can excite inertial waves, which are shear waves, band-limited to frequencies $0 < \omega < 2\Omega_0$ and dispersive with respect to direction. Large amplitudes of libration can excite turbulent motion (Görtler vortices), which is transpored into the bulk by the Coriolis force. Waves and vortices may take part in the redistribution of kinetic energy and angular momentum. Complex system responses are possible so that it is of fundamental interest to understand inertial waves and related turbulent phenomena in order to quantify their relevance for applications.

Direct numerical simulations (DNS) of an axially rotating annulus have been carried out for straight and inclined cylinder walls, with and without lids. The system was perturbed by libration of inner and/or outer cylinder walls and/or of the lids with small libration amplitude $\epsilon \leq 0.1$ and frequency $\omega < 2\Omega_0$ to study the intertial wave regime and with $\epsilon > 0.3$ and frequencies $\omega < 4\Omega_0$ to study the turbulent regime.
We present the analysis of the wave excitation mechanism, the resulting wave attractors found and the spectra of the kinetic energy in the bulk. The localisation of wave excitation at the edges of the annulus was clarified by applying boundary layer theory. Resonance peaks in the simulated spectra of the energy in the bulk were found to have up to one order of magnitude higher energy. The spatial structure and wave frequency of the peaks agree with those of low-order wave attractors obtained by geometric ray tracing.

We present results found in the weakly supercritical regime of libration, in which the Stokes boundary layer was centrifugally unstable in a portion of a libration cycle only generating Görtler vortices. We show for the first time that these vortices propagate into the fluids bulk due to the Coriolis force and generate an azimuthal mean flow which is retrograde (prograde) in the outer (inner) cylinder side wall is librated. Reynolds-averaged equations and kinetic energy budget of mean and fluctuating flow are used as diagnostic equations to discuss the generation mechanism and scaling behavior of the azimuthal mean flow in the fluid bulk.
Other mean flow generation mechanisms, already known, have been investigated for this configuration as well. We present a comparison of the mean flows generated by different mechanisms.

The DNS results and theory are found in agreement with laboratory experiments carried out at BTU Cottbus-Senftenberg.

CONFIGURATION AND NUMERICAL MODEL: We consider a Taylor-Cuettte system. At top and bottom rigid lids or periodic boundary conditions are used. The vessel of height h has height dependent radii $r_1(z) < r_2$. It is rotating with a mean angular velocity Ω_0 around its axis of symmetry. It is filled with an incompressible Newtonian fluid. The Ekman numbers down to $E = 10^{-6}$ can be assessed by DNS. In order to study inertial wave focusing (wave attractors) and the effect of a particular inclination angle, the inner straight cylinder has been replaced with a frustum of apex half-angle $\alpha \simeq 5.7^{\circ}$.
Perturbations are excited by longitudinal librations of different parts of the walls. That is, the mean rotation rate is modulated by harmonic oscillations: $\Omega(t) = \Omega_0(1 + \epsilon \sin[\omega t])$, where ω denotes the frequency and $0 < \epsilon < 1$ the amplitude of libration. We are focusing on the weakly non-linear regimes with Rossby numbers $R\epsilon = O(10^{-1}) to investigate wave attractors and weakly unstable regime with \epsilon = 0.6$ to investigate Görtler vortices.