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Structures in a rotating flow with free surface: simulations and experiments.

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We are interested in the free surface rotating flow driven by the rotation of the bottom in an open cylinder with radius R . Given an initial filling depth H , increasing the rotation disk frequency f_d breaks the flow axisymmetry. Two kinds of instability patterns can be observed: a modal structure with almost no free surface deformation (Fig. 1a) similar to those observed in [3] at intermediate Reynolds number values; a pattern of rotating polygons at high Reynolds numbers (Fig. 1b) with large free surface deformations [4]. In the present work, we carry out a detailed study of the flow structure for the intermediate Reynolds number regime by characterizing the influence of Froude number, aspect ratio and Reynolds number. The ultimate goal is to understand if the structures prevailing in the two regimes are related.

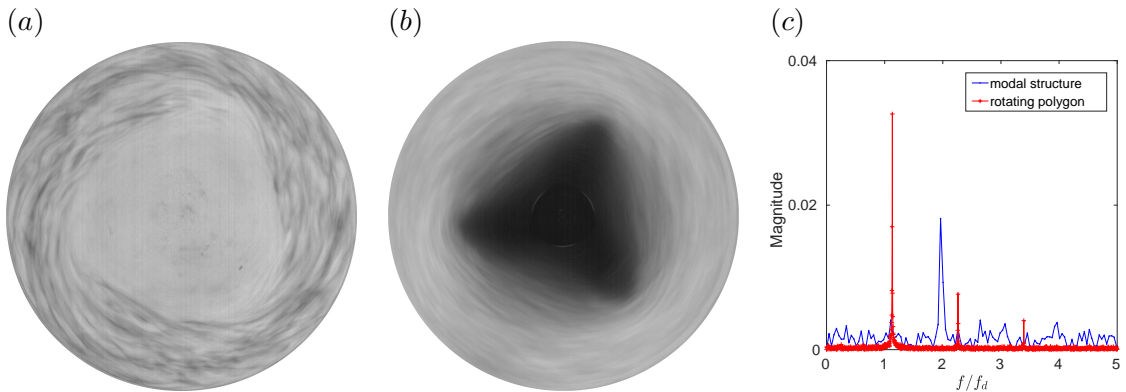


Figure 1: (a)-(b) Top view of the experiment using kalliroscope to visualise the flow structure ($H = 26$ mm, $R = 140$ mm). (a): azimuthal mode $m = 3$ for $f_d = 14.6$ rpm (no surface deformation is observed). (b): rotating triangle with a dry core at $f_d = 139$ rpm. (c): typical spectrum of the azimuthal velocity component [probe location $(r, z) = (112, 13)$ mm].

The intermediate Reynolds number regime has been investigated using several numerical techniques – computations of steady solutions, mean unsteady two-dimensional and three-dimensional direct simulations – as well as Laser-Doppler Velocimetry measurements. Simulations reveal the structure of a toroidal flow located at the periphery of a central solid body rotation region. This flow cell is found bordered by four layers in the meridional plane, a bottom layer on the disk, a side layer along the wall, a core layer separating the solid body rotation (discussed also in [1]) and a layer at the free surface. The Froude number that

quantifies surface deformation and the Reynolds number are shown to have little effect on the flow structure when the Reynolds number is sufficiently large. By increasing the aspect ratio, we find that the toroidal flow is composed of an upper sub-region with sinuous core layer and a mostly z -independent lower region. The mean flow and the rms of fluctuations in 3D simulations obtained through space and time averaging are compared with LDV measurements. A fair agreement is obtained for azimuthal and axial velocity distributions, except some local discrepancies.

Preliminary experiments show that the modal structure at intermediate Reynolds number is robust over a large range of f_d as long as the free surface does not touch the bottom disk. The spectrum shown in figure 1(c) indicates that this instability is observed always at a frequency close to $2f_d$ before moving abruptly to $1.13f_d$ when the rotating triangle occurs. Yet, the transition between the two regimes seems complex and depends on the protocol used to increase the disk speed [2].

References

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