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Instability of a potential swirling flow with a free surface

Jérôme Mougel ^{*†}, David Fabre^{*}, Laurent Lacaze^{*‡}

Rotating flows with free surface are commonly observed in everyday-life, the most popular example being the drain vortex observed in bathtubs and sinks. These flows are known to support spectacular patterns arising from breaking of the axial symmetry. A situation which has been particularly investigated through experiments is the case of a partially filled container with a rotating bottom. In this situation, an instability leads to the appearance of rotating polygons along the free surface ^{1 2}. The axisymmetric base flow preexisting the instability is rather complex, involving strong recirculations, but includes a region where the rotation is approximately potential, ³ suggesting that the potential vortex may be a relevant model to investigate the instability mechanism.

Consequently, we investigate here the linear inviscid stability of the potential swirling flow with a free surface; namely, the flow defined $V_\theta = \Gamma/(2\pi r)$, with a free surface given by $h_0(r) \sim \frac{1}{R_1^2} - \frac{1}{r^2}$, where R_1 corresponds to the radius of the dry area. For the study, we use both a global stability approach based on the finite element software Freefem++ and a shallow water approach. Our results show that unstable modes exist in narrow ranges of the Froude number (defined by $Fr = \Gamma/2\pi\sqrt{gR_0^3}$, R_0 being the radius of the cylinder), for all non-zero values of the azimuthal wavenumber m (see figure 1). The instability seems to be related to the "strato-rotational" instability mechanism existing in stratified rotating fluids⁴.

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²Jansson et al, *PRL* **96**, 174502 (2006).

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⁴Le Dizés and Riedinger, *J. Fluid Mech.* **660**, 147 (2010).

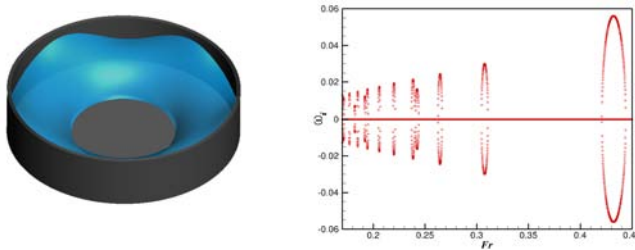


Figure 1: (a) 3D free surface reconstruction of the most amplified mode for an azimuthal wave number $m = 5$ (b) Amplification rate as a fonction of the Froude number for $m = 5$ (the liquid volume in the container is kept constant as the Froude number is varied).