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# Instability of a potential swirling flow with a free surface

Jérôme Mougel <sup>\*†</sup>, David Fabre<sup>\*</sup>, Laurent Lacaze<sup>\*‡</sup>

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 <sup>1 2</sup>. The axisymmetric base flow preexisting the instability is rather complex, involving strong recirculations, but includes a region where the rotation is approximately potential, <sup>3</sup> 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 fluids<sup>4</sup>.

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<sup>1</sup>Vatistas et al, *PRL* **100**, 174503 (2008).

<sup>2</sup>Jansson et al, *PRL* **96**, 174502 (2006).

<sup>3</sup>Tophøj, *Phd Thesis*, Danmark Technical University (2012).

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

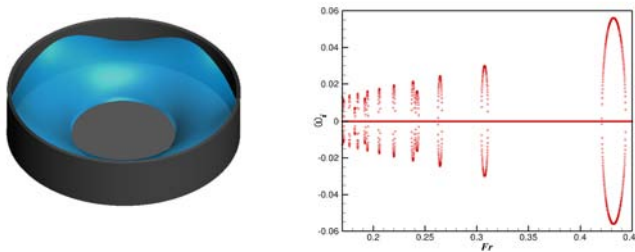


Figure 1: (a) 3D free surface reconstruction of the most amplified mode for an azimuthal wave number  $m = 5$  (b) Amplification rate as a fonction of the Froude number for  $m = 5$  (the liquid volume in the container is kept constant as the Froude number is varied).