Bathtub physics

Despite their apparent simplicity, the so-called bathtub vortices that form in draining containers exhibit complex flow patterns and are an active area of research. The whirlpools that form above the drains exhibit much of the same physics found in turbine intakes and tornadoes. (For more on tornadoes, see the article by Paul Markowski and Yvette Richardson, PHYSICS TODAY, September 2014, page 26.) These photos are from experiments carried out by Katrine Haaning in the research group of Anders Andersen and Tomas Bohr at the Technical University of Denmark. The experiments employ a rotating cylindrical tub, 20 cm in diameter and filled with water to a depth of 25 cm, to study the shape, stability, flow, boundary layers, and other aspects of bathtub vortices. The vortices themselves are in a steady state: As water drains through the centered 2.4-mm hole on the bottom (not visible here), it gets recirculated through a rotationally symmetric opening in the wall near the tub's base.

The left photo, taken through the transparent wall, shows the symmetric, needle-shaped surface deformation (and its reflection) of the vortex that developed as the tub rotated at a steady 40 rpm; the water near the vortex core was spinning almost a thousand times that fast. A bubble is visible just below the core's tip. The depth of the core and its stability against bubble formation depend sensitively on the tub rotation rate.

Through carefully perturbing the flow, the researchers have studied the formation of waves on the vortex surface. The middle photo captures the transient waves produced when a mass impacts vertically on the laboratory table. Whereas those waves are rotationally symmetric, the photo on the right shows the corkscrew-like waves that develop when the researchers mount a rigid rod near the rim of the tub, here spinning at 100 rpm. The rod creates persistent traveling waves that spiral along the tub's axis of rotation. (A. Andersen et al., *J. Fluid Mech.* **556**, 121, 2006; R. Bergmann et al., *Phys. Rev. Lett.* **102**, 204501, 2009. Images submitted by Katrine Haaning and Anders Andersen.)

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