The first observation of a stable torus of fluid's resonance frequencies

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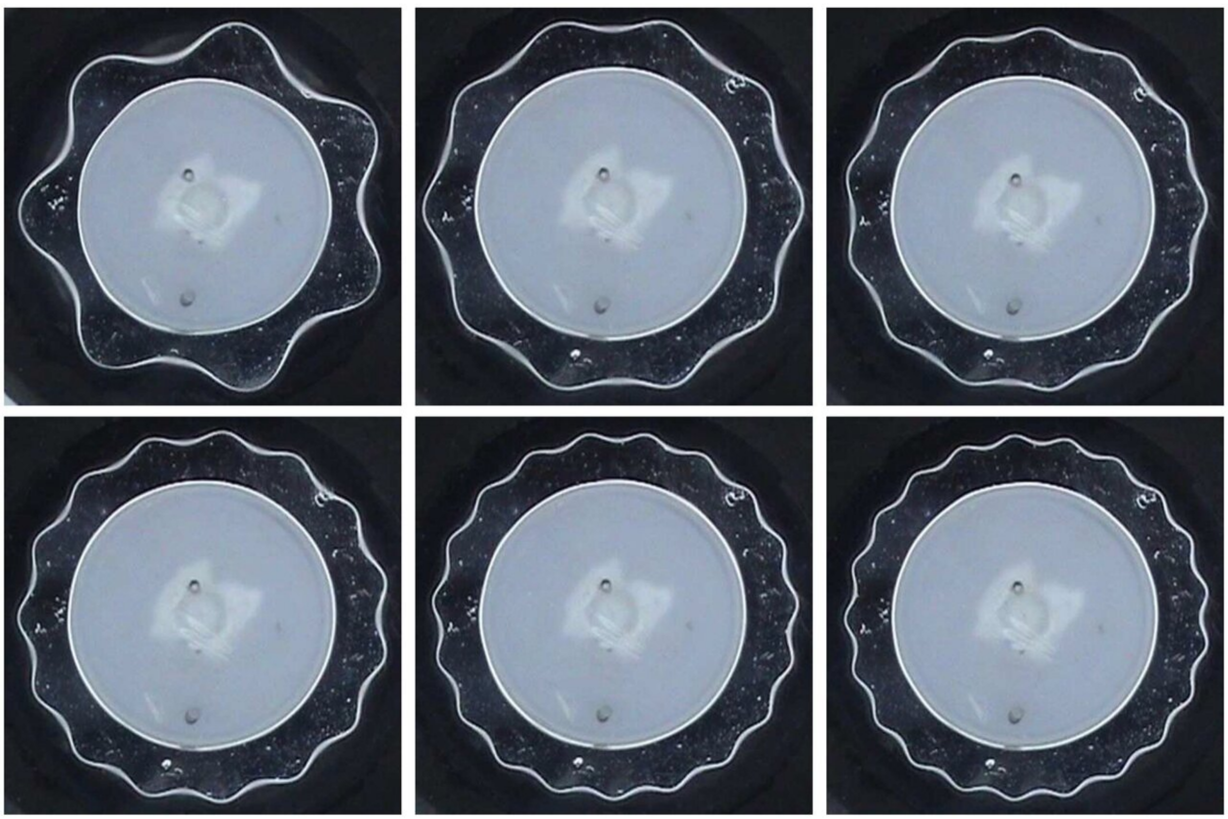


Top view of the pattern observed on the outer periphery of a mercury ring subjected to vibrations. The number of lobes increases with the frequency of the vibration (respectively from left to right, from top to bottom). The gray area corresponds to the central solid cylinder. Diameter of the torus ~ 4 cm. Credit: Laroche et al.

A team of researchers at Laroche Laboratory, Université Paris Diderot and Université de Lyon has recently collected the first measurements of the resonance frequencies of a stable torus of fluid. The method they used to collect these observations, outlined in a paper published in *Physical Review Letters*, could enable the modeling of a variety of large-scale structures that transiently arise in vortex rings.

Vortex rings are torus-shaped vortexes that can appear in both liquids and gases in a variety of settings. In nature, there are several examples of these vortex rings, including underwater bubble rings produced by divers or dolphins, smoke rings, and blood rings in the human heart.

"Although it has been shown that the dynamics of a vortex ring are dominated by large-scale structures at its periphery, the mechanisms governing their appearance are not well understood, reflecting to a large extent the experimental difficulties in generating a stable liquid torus under well-controlled conditions," Eric Falcon, one of the researchers who carried out the recent study, told Phys.org. "It is in this context that we wanted to make a fluid ring stable."

Vortex rings were first analyzed in depth by physicist Hermann von Helmholtz. Since then, several researchers have been extensively studying their formation, dynamics and collisions.

Past studies have found that it is possible to generate ephemeral vortex rings in a laboratory setting by pushing a fluid out of a hole, by impacting a solid disk into a fluid at rest, or when a liquid drop falls into another liquid. However, the liquid ring that arises during these experiments quickly becomes unstable and breaks down into individual droplets.

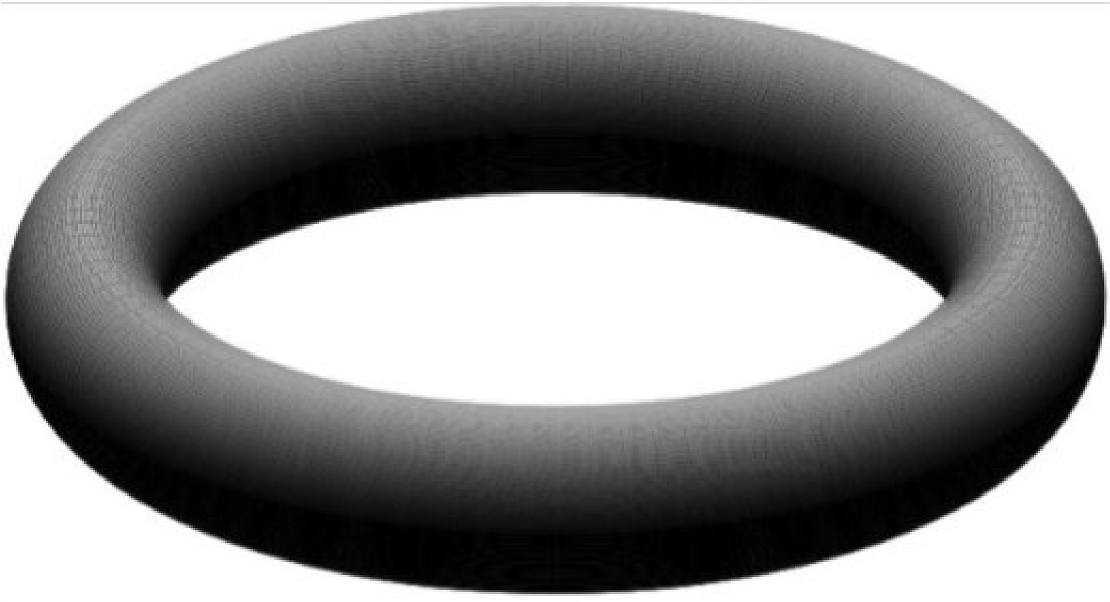
"Vortex rings, like smoke rings, are ubiquitous in nature, but their dynamics are not yet well understood, in part because of their transient nature," Falcon said. "In our study, we were able to stably generate a ring (or torus) of fluid using a liquid metal, which allowed us to study the frequencies at which the torus of fluid reacts."

To form a stable fluid torus that would not disappear quickly over time, Falcon and his colleagues used mercury, a liquid metal that does not wet surfaces it comes in contact with. The researchers injected mercury at the periphery of a solid cylinder and this formed a stable ring of liquid. The solid cylinder prevented undulations of the torus' inner periphery that would otherwise have no confinement to minimize its surface.

"This new technique enabled us to carry out the first measurements of the resonance frequencies of a torus of fluid subjected to vibrations: The liquid ring sees oscillations appear on its outer periphery, these lobe-shaped patterns being amplified at certain so-called resonance frequencies," Falcon explained.

The outer diameter of the liquid torus they observed was around 4 cm and its aspect ratio was roughly twice that of a typical confectionery donut. The fluid ring they created rested on a plate that vibrates vertically, with a frequency and amplitude of under 65 Hz and 0.5 mm, respectively. The acceleration corresponding to this vibration is lower than half of the acceleration of the Earth's gravity.

Falcon and his colleagues used a laser-based optical measurement method to accurately measure the horizontal oscillations at the outer periphery of the torus. They were also able to achieve a direct visualization of the vortex using a camera placed directly above the liquid ring.



Aspect ratio of the fluid torus at rest studied in the experiment, roughly twice the one of typical doughnut confectionery. Credit: Laroche et al.

"Using this accurate optical method, we were able to observe up to 25 lobes occurring at the periphery of the ring as the vibration frequency increases and we were able to characterize the corresponding zones of instability," Falcon said.

Once they gathered their observations, the researchers tried to interpret them based on existing physics theories. Comparing their experimental results, they successfully adapted the usual drop model proposed by Lord Rayleigh in 1879 to a torus of fluid. Their measurements also allowed them to indirectly infer the geometric properties of the torus.

The unique measurements collected by Falcon and his colleagues could have several interesting implications, both for fluid mechanics and other areas of physics research. For instance, their approach could be used to model large-scale structures transiently appearing in vortex rings studied in various fields, including plasma physics, biophysics or geophysics.

"In the near future, our experiment is easily modifiable to remove the solid internal confinement (replaced by a toroidal potential) and to impose to the fluid a rotational flow between the poles of the liquid ring ("poloidal vorticity"), simply by applying an electromagnetic force to the liquid metal," Falcon said. "This configuration should then be able to reveal more precisely the origin of these large-scale transient structures in vortex rings observed in nature."

More information: Claude Laroche et al. Observation of the Resonance Frequencies of a Stable Torus of Fluid, *Physical Review Letters* (2019). DOI: 10.1103/PhysRevLett.123.094502