Tiny rotating particles create vorticity in viscous fluids, yielding fascinating new behaviors

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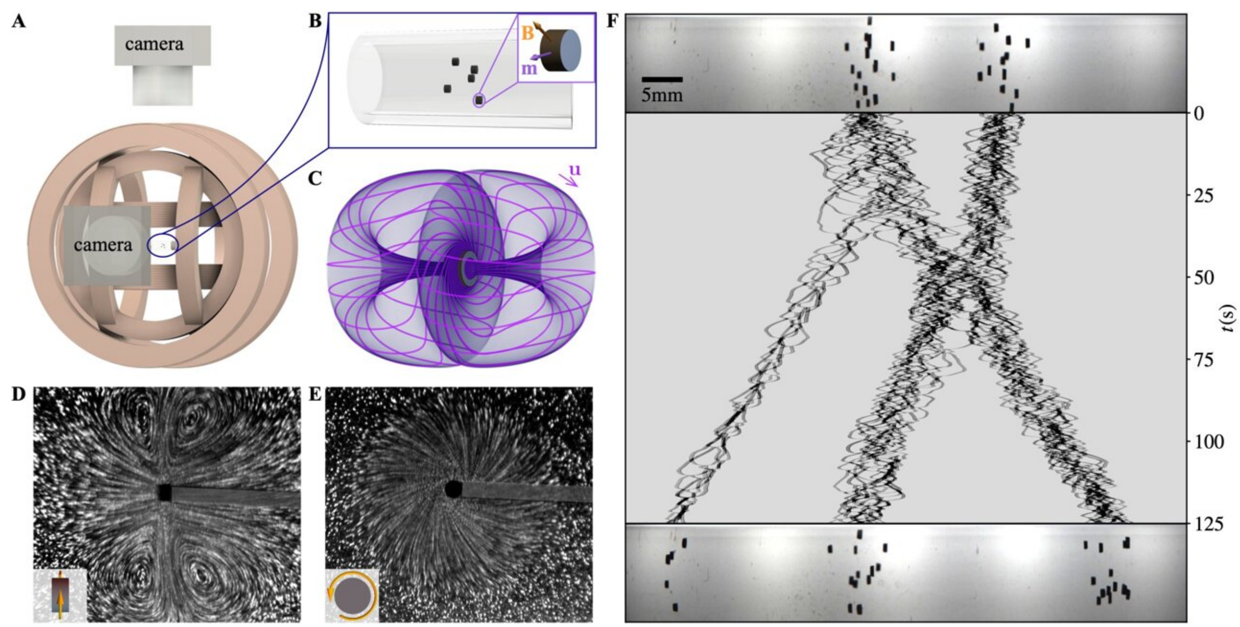


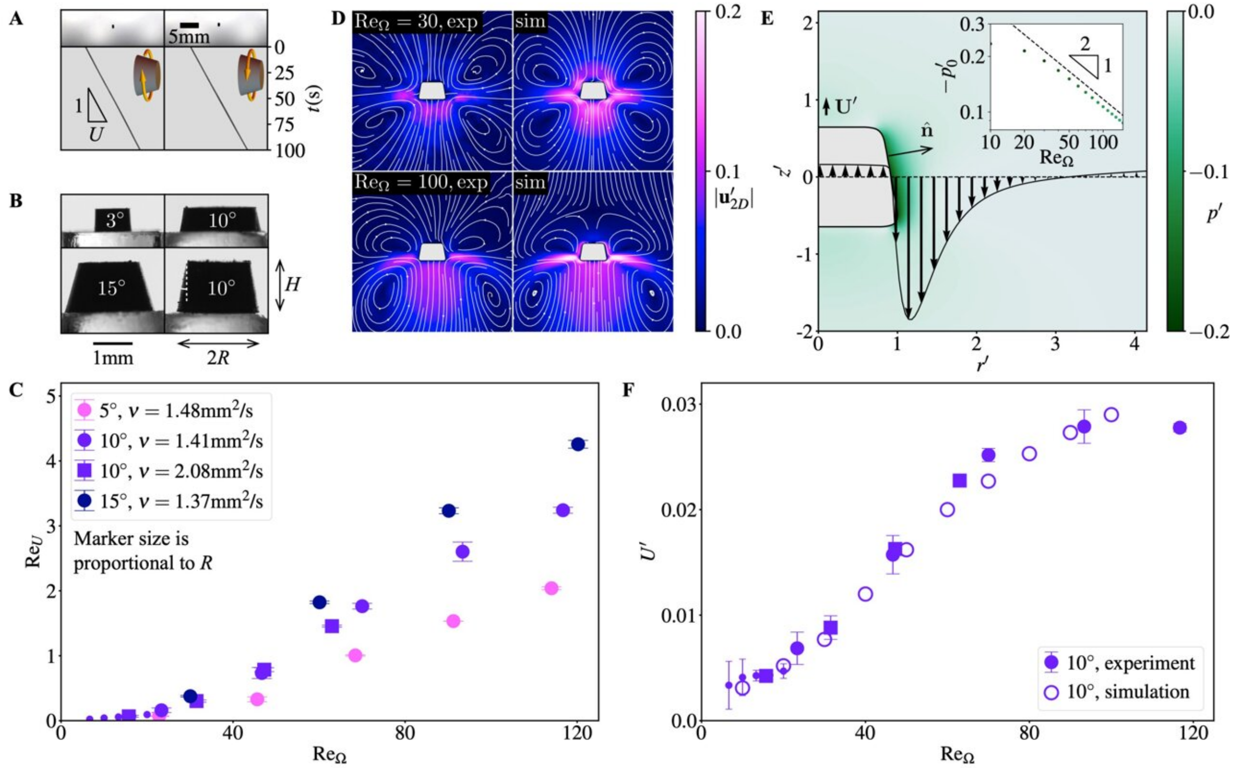
Suspensions of spinning particles and their vortlets self-organize into flocks. Credit: Chen et al.

Vorticity, a measure of the local rotation or swirling motion in a fluid, has long been studied by physicists and mathematicians. The dynamics of vorticity is governed by the famed Navier-Stokes equations, which tell us that vorticity is produced by the passage of fluid past walls. Moreover, due to their internal resistance to being sheared, viscous fluids will diffuse the vorticity within them and so any persistent swirling motions will require a constant resupply of vorticity.

Physicists at the University of Chicago and applied mathematicians at the Flatiron Institute recently carried out a study exploring the behavior of viscous fluids in which tiny rotating particles were suspended, acting as local, mobile sources of vorticity. Their paper, published in *Nature Physics*, outlines fluid behaviors that were never observed before, characterized by self-propulsion, flocking and the emergence of chiral active phases.

"This experiment was a confluence of three curiosities," William T.M. Irvine, a corresponding author of the paper, told Phys.org. "We had been studying and engineering parity-breaking meta-fluids with fundamentally new properties in 2D and were interested to see how a three-dimensional analog would behave.

"At the same time, we were interested in building active matter at intermediate Reynolds numbers to see what new behaviors inertia would give rise to, and finally, we had been playing with building turbulence by combining vortex loops and were interested if it could be done by combining 'point' vortices."



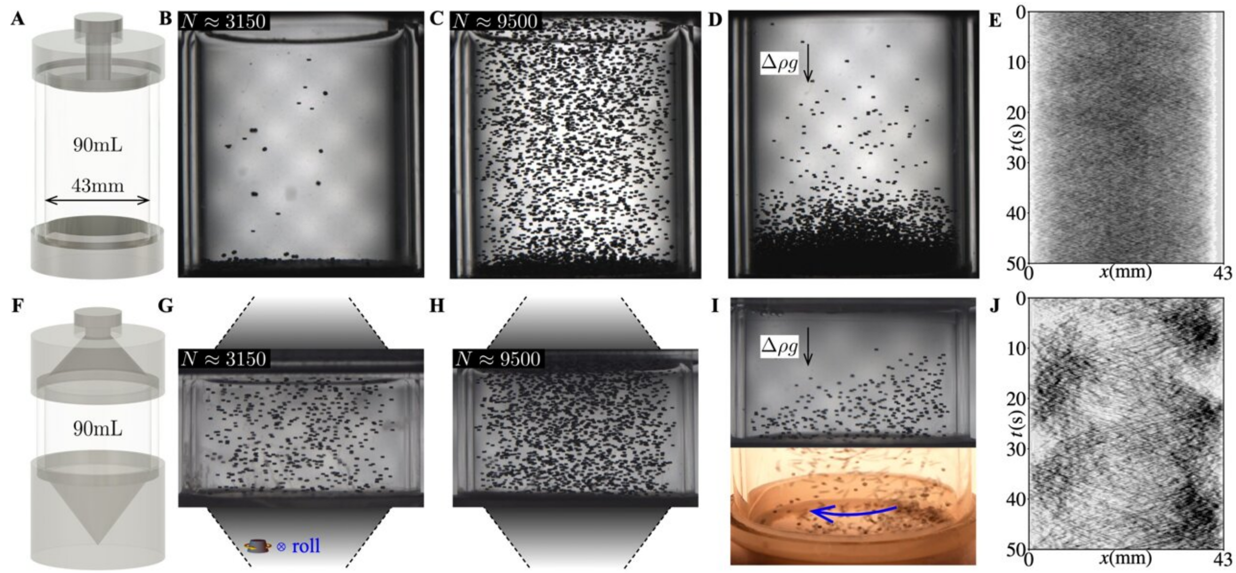
A spinner's shape harvests the active pressure to drive self-propulsion. Credit: Chen et al.

To carry out their experiments, Irvine and his colleagues first created a large number of cylindrical millimeter-sized particles. They then used magnetic fields to drive these particles to spin while suspended in a viscous fluid.

They observed that individual particles generated a localized three-dimensional region of vorticity around it. This swirling region, which they dubbed a "vortlet," produced various fascinating fluid behaviors.

"Driving the particles to spin creates point-like patches of vorticity in a 3D fluid," explained Irvine. "The fluid then needs to spin in turn, to close the vorticity field. How it would do so was an open question, and what the dynamics of such 'vortlets' were was unknown.

"By confining our spinners in a density-matched fluid and driving them to rotate using an [external magnetic field](), we were able to take video data from which we could observe several new behaviors."



Three-dimensional chiral active fluid in different geometries and under external force. Credit: Chen et al

Interestingly, the researchers observed that slight asymmetries in the shape of a particle could deform the vortlet it produced. This caused the particle to self-propel within the fluid.

"Numerical simulations of such rotating particles moving in a viscous fluid showed excellent agreement with the experiments, both in terms of the structure of the vortlet and the speed of self-propulsion," explained researcher Michael Shelley, from the Flatiron Institute in New York.

"And when combined with a mathematical analysis of the Navier-Stokes equations, the simulations showed that the self-propulsion arose from the tilting of a pressure boundary-layer, itself a consequence of rotation, along the particle side-wall."

The researchers also found that the spinning particles interacted through their vortlets, producing new and dynamic group behaviors.

"We found that our spinners spontaneously self-propel, form bound flocks and, in sufficient numbers, give rise to a 3D chiral active phase with a chaotic background flow," said Irvine. "Each of these was a surprise to us and demonstrates new behaviors uniquely tied to the inertial regime achieved in our experiments."

This recent study by Irvine, Shelley and their research teams opens interesting possibilities for research, as it introduces a new platform that could be used to study 3D flocking behaviors and 3D active chiral fluids in an experimental setting. The researchers now plan to build on their recent observations in the hope of better understanding the intriguing behaviors they reported.

"We will now be exploring each discovery in greater depth, starting with probing the bulk properties of our new 3D chiral active phase, especially its interplay with turbulence," added Irvine.

More information: Panyu Chen et al, Self-propulsion, flocking and chiral active phases from particles spinning at intermediate Reynolds numbers, *Nature Physics* (2024). DOI: 10.1038/s41567-024-02651-5