Research helps to show how turbulence can occur without inertia

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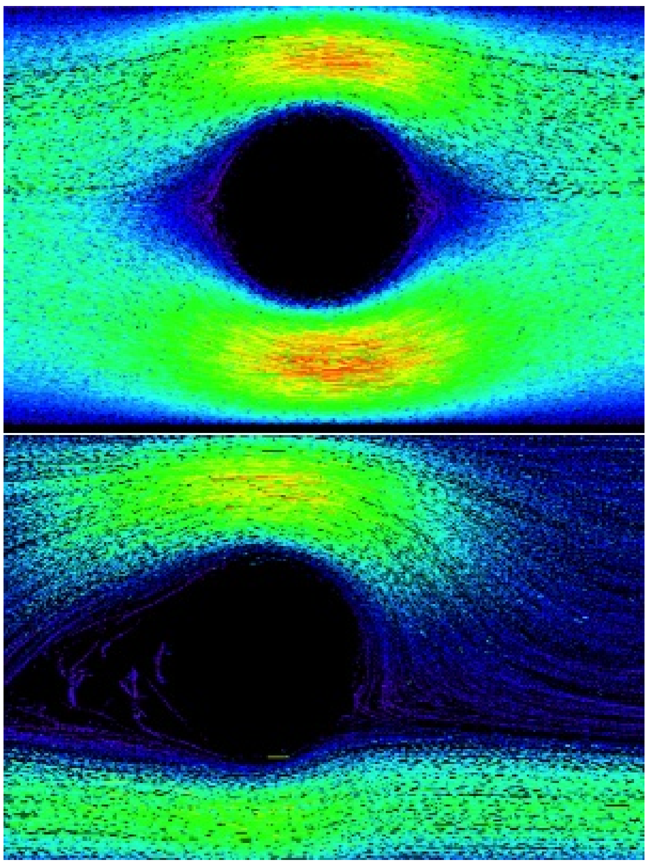

Data from the experiment, showing laminar (top) and turbulent (flow) flow around the posts at the beginning of the pipe.

(Phys.org) —Anyone who has flown in an airplane knows about turbulence, or when the flow of a fluid—in this case, the flow of air over the wings—becomes chaotic and unstable. For more than a century, the field of fluid mechanics has posited that turbulence scales with inertia, and so massive things, like planes, have an easier time causing it.

Now, research led by engineers at the University of Pennsylvania has shown that this transition to turbulence can occur without inertia at all.

The study was conducted by associate professor Paulo E. Arratia and graduate student Lichao Pan, both of the Department of Mechanical Engineering and Applied Mechanics of Penn's School of Engineering and Applied Science. They collaborated with professor Christian Wagner of Germany's Saarland University and with professor Alexander Morozov of Scotland's University of Edinburgh.

It was published in the journal *Physical Review Letters*.

One of the most fundamental concepts in fluid dynamics is the Reynolds number. Named for Osborne Reynolds, the late 19th century physicist who demonstrated how fluid flowing through a pipe transitioned into a turbulent state. Reynolds numbers describe the ratio between viscous forces and inertial forces for given fluids and the conditions they are flowing in. Low Reynolds numbers are associated with "laminar" flow, which is smooth and orderly, while high Reynolds numbers are associated with turbulent flow, which is nonlinear and chaotic.

In laminar, or linear, flow, there is a direct relationship between the force applied to the fluid and how fast it moves. When the applied force is removed, viscous forces stop the fluid's motion. With turbulent, or nonlinear, flows, this relationship is no longer straight forward. This is because inertial forces keep the fluid moving even after the applied force is removed. Briefly stirring a cup of coffee with a spoon will keep the coffee swirling for minutes, but the same effect can't be achieved with a cup of honey.

"What Reynolds elegantly suggested was that the force that makes things go nonlinear or irregular is inertia, since inertia is a nonlinear force itself," Arratia said. "As water flows faster, it has more inertia and thus becomes more turbulent, which is something you can see as you turn the tap on the faucet in your sink."

The transition from smooth to turbulent has obvious implications for massive things, such as airplanes, but surprisingly, it also has an impact on small scales where mass should theoretically not play a factor. It is relevant to the flow of blood in capillaries, or in extracting oil or natural gas from porous rock, as is the case with fracking.

"In fracking, all of these liquids go through tiny pores. Originally, people thought that, since the pores were so small, there would be no inertia and therefore no turbulence, but it's there," Arratia said. "They get all of these fluctuations and unusual pressure drops, and a lot of things would fail because of it."

To explain how turbulence could arise even in the absence of inertia, Arratia's team set out to conduct an experiment similar to Reynolds' famous one, but instead of changing the inertia of the fluid, they changed the fluid itself. In their study, they pumped a polymer-infused fluid through a pipe at a constant rate. Polymers are a common feature of non-Newtonian fluids—such as blood, ketchup or yogurt—which have flow properties that change under certain conditions. One of the main features of non-Newtonian fluids is that their material properties, such as viscosity, are nonlinear—there is not a direct relationship between the amount of force exerted on them and the speed at which they flow.

Another factor in the transition to turbulence is how the linear, smooth flow is initially disturbed so that a chaotic, non-linear flow begins. In Reynolds' experiment, the roughness of the walls of the pipe was sufficient to "kick" the flow into a turbulent state once a sufficient amount of inertia was present. In Arratia's experiment, this roughness was a precisely controlled via a series of cylindrical posts at the beginning of the pipe.

"After 'kicking' the pipe with these posts, we watch the fluid flow a certain distance. If that disturbance decays, the flow is laminar, but if the disturbance is maintained or grows, it's turbulent," Arratia said. "And we saw it grow."

Beyond medical or industrial applications, understanding the interplay between non-Newtonian fluids and turbulence is an important contribution to the fundamentals of fluid mechanics.

"We always thought that inertia had to be there for this transition to take place, but there are other non-linear forces out there," Arratia said. "In this case, even though we're at a low Reynolds number as there's no inertia coming from the mass, because the fluid is non-linear itself you get a very similar transition to the one Osborne Reynolds saw in 1883."

More information: prl.aps.org/abstract/PRL/v110/i17/e174502

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