Is Turbulence Forever?

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If you have ever been on a bumpy plane ride, you may have asked yourself if the turbulence ever stops. This is a question that has long plagued physicists: is there a point where turbulence lasts forever? One long-standing theory is that at high enough speeds, fluid motion becomes chaotic (random and unpredictable) and remains that way indefinitely [1–4]. Recent studies contradict this. What if motion is only temporarily caught in chaos?

To understand this problem, it is necessary to understand two fundamental types of flow. At low speeds fluids move smoothly in orderly layers; this is known as laminar flow. As speed increases, the motion can become irregular and chaotic; this is turbulence. The transition between these states is often characterized by Reynolds numbers, a quantity that compares inertial forces (which keep fluid moving) to viscous forces (which resist motion). At low Reynolds numbers, viscosity dominates, and flow is smooth and laminar. At high Reynolds numbers, momentum dominates and turbulence becomes more probable. To better understand this, consider honey and water. Honey is much more viscous than water, so achieving the same Reynolds number would require the honey to move much faster to overcome its resistance to motion.

When it comes to duration of turbulence, two conflicting theories exist. Many numerical simulations support the idea that beyond a certain critical Reynolds number, turbulence would last indefinitely [4]. In this model, turbulence behaves as a chaotic attractor; it becomes stable and self-sustaining. Alternatively, several experimental simulations propose a chaotic repeller model, finding that turbulence is never truly permanent [5–7]. Instead, it can last for a long time, but always retains some probability of reverting back into laminar flow. In this view turbulence is fundamentally unstable–it is transient.

Daniel Borrero-Echeverry and collaborators set out to test these competing ideas using Taylor-Couette flow. In Taylor-Couette flow (seen in 1), fluid is confined between two concentric rotating cylinders. Past studies have used open flows–such as pipes–where fluid moves from one end to another which limits observation time.The circular nature of Taylor-Couette flow allows for extended observation without disturbances from boundaries.

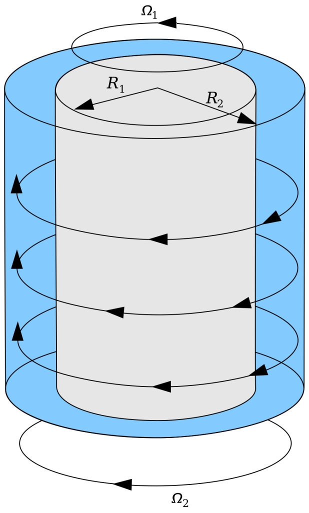

FIG. 1. Model of Taylor-Couette system adapted from [8].

In this experiment, the outer cylinder is first spun for three minutes at an angular velocity corresponding to the trials' Reynolds number to reach smooth laminar flow (Couette flow). While many experiments use localized perturbations to incite turbulence, this experiment creates a global perturbation by rapidly accelerating the inner cylinder in the direction opposite that of the outer cylinder, stopping it immediately. The outer cylinder continues to rotate until the flow relaminarizes and turbulence has disappeared. This is done through pictures; after the perturbation, images are subtracted from earlier images. The resulting difference in pixels is compared to a set number which represents the minimum difference for flow to be considered turbulent (N_t). Once the difference is less than that for turbulence for 30 seconds, the trial is stopped and the time it took for the flow to become smooth again is recorded.

This process was repeated 200-1200 times for each Reynolds number. This allowed them to construct a probability distribution describing how long turbulence survived. The resulting curve represented the probability that turbulence was still present after a given time.

The results revealed a pattern; the probability of turbulence surviving decreased exponentially over time. This means turbulence had no "memory." No matter how long it had already lasted, it was always equally likely to disappear in the next moment. This type of behavior is known as a Poisson process, and it is precisely what the chaotic repeller model predicts.

As the Reynolds number increased, the characteristic lifetime of turbulence grew very rapidly. At the highest Reynolds numbers tested, some turbulent states lasted nearly 29 hours before finally relaminarizing. To any practical observer, such a long lifetime might appear permanent. Yet every single turbulent episode eventually decayed. The researchers found no evidence of a finite Reynolds number at which turbulence became truly sustained.

The distinction between "very long-lived" and "infinite" is subtle but important. If turbulence were a chaotic attractor, lifetimes would diverge at a critical Reynolds number, making a sharp boundary between order and chaos. Instead, the data support a smoother picture: turbulence becomes increasingly persistent as the Reynolds number rises, but it remains fundamentally transient. The turbulent state behaves like a chaotic repeller rather than an attractor.

Turbulence continues to challenge our intuition nearly 150 years after Osborne Reynolds first distinguished between laminar and turbulent flows [9]. This study suggests that the transition to turbulence may not involve a sharp dividing line after all. Instead, chaos may simply become more and more patient, lingering longer as conditions intensify, but never fully settling in.

Turbulence, it seems, may not be forever. It might last just long enough to convince us that it is.

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