Dandelion seeds are optimized for wind-based travel

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A newly observed type of vortex stabilizes the flight of plumed seeds.

For a plant species to survive and proliferate, it must disperse its seeds. A seed is more likely to thrive away from its parent plant because there is less competition for resources. Spreading helps the population find new environments, be less vulnerable to predators and pathogens, and boost its genetic diversity.

Seeds, though, do not propel themselves; rather, they hitch rides on animals, flowing water, or gusting wind. For travel by wind, seeds use one of two mechanisms: wings or plumes. Winged seeds, like those from maple trees, generate lift by using a stable leading-edge vortex as they fall.[1] Plumed seeds, such as those of dandelions, amplify drag by using a bundle of filaments known as a plume or pappus. The additional drag prolongs the seed's descent and increases the chance that a breeze can arrive to carry it away.

Whereas some researchers assumed that pappus-mediated flight functioned in the same way as a parachute, Cathal Cummins, Ignazio Maria Viola, Naomi Nakayama, and their coworkers at the University of Edinburgh suspected that something else might be going on. They used a vertical wind tunnel to look at the flow around a falling dandelion seed and observed above the pappus a hovering ring of circulating air known as a separated vortex ring (SVR).[2] Such fluid flow had been considered theoretically, but until now was presumed too unstable to be physically realized.

During a seed's flight, the researchers found, aerodynamic interactions between filaments enhance the drag on the pappus so much that the pappus generates four times as much drag as a solid membrane of the same surface area. To investigate the source of the drag, they fabricated artificial dandelion seeds with different pappus geometries. Not every artificial pappus generated an SVR, but the researchers found that real dandelion seeds are optimized to do just that.

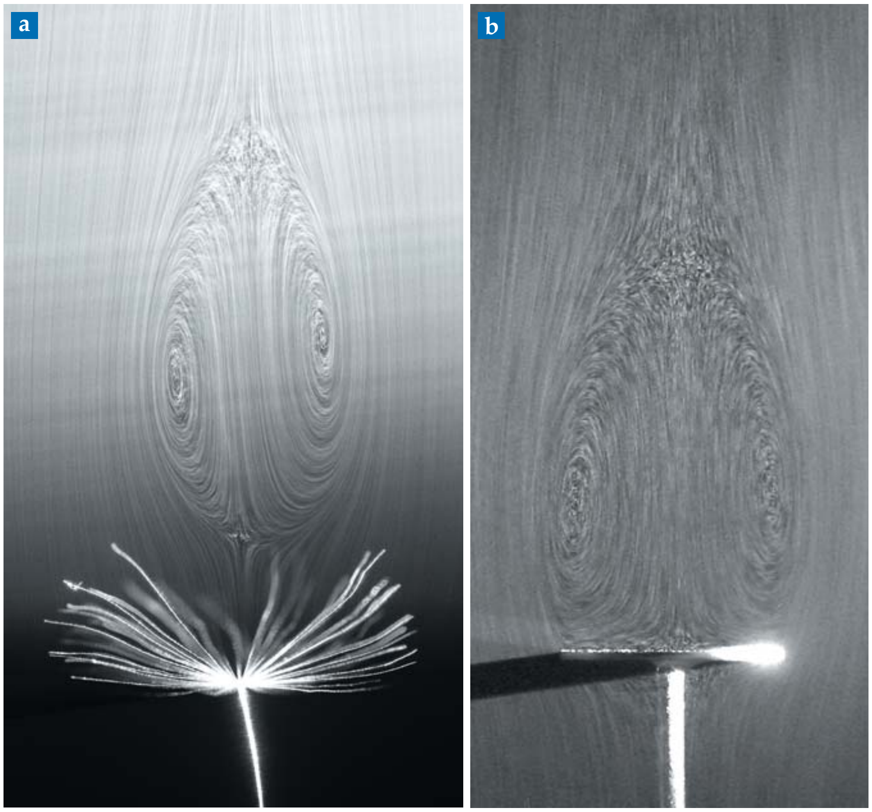

FIGURE 1. TWO TYPES OF VORTICES. (a) A dandelion seed in a vertical wind tunnel generates a separated vortex ring with the stagnation point sitting above the pappus. **(b)** By contrast, the vortex for a solid disk is attached and has a stagnation point on the disk's surface. (Images courtesy of Cathal Cummins, Madeleine Seale, Enrico Mastropaolo, Ignazio Maria Viola, and Naomi Nakayama.)

A new type of flow

A vortex that is generated in the wake of a falling object has two stagnation points at which the fluid velocity goes to zero. For a solid body, like a disk or a parachute, one of those points is attached to the surface of the object. A vortex creates a region of low pressure behind the object that retards its fall through the air. If the vortex becomes unstable, it separates from the surface and moves upward as another vortex forms in its place. That sequence of events creates an oscillating flow in the wake of the object and causes it to tumble chaotically like a falling coin instead of descending smoothly like a parachute.[3]

Unlike a solid body, a dandelion pappus is filamentous, so air can flow through it in addition to going around it. To investigate how that difference might affect the flow around the whole seed, Cummins built a vertical wind tunnel. He added smoke as a tracer and used laser light to image a two-dimensional vertical cross section of the three-dimensional flow. From the light scattered in the imaging plane, the paths of the smoke particles could be reconstructed and used as a proxy for the airflow.

When Cummins placed the dandelion seeds in the wind tunnel and tuned the flow such that the seeds hovered at a fixed height, he observed the formation of an SVR. In the images, it looked like a vortex bubble was hovering above the pappus, as shown in figure 1a. Unlike in the case of a solid disk, shown in figure 1b, the stagnation point sits above the pappus; it can't be attached because air is flowing through the filamentous structure. However, the separated vortex does not move away from the seed. Instead, it stays at a

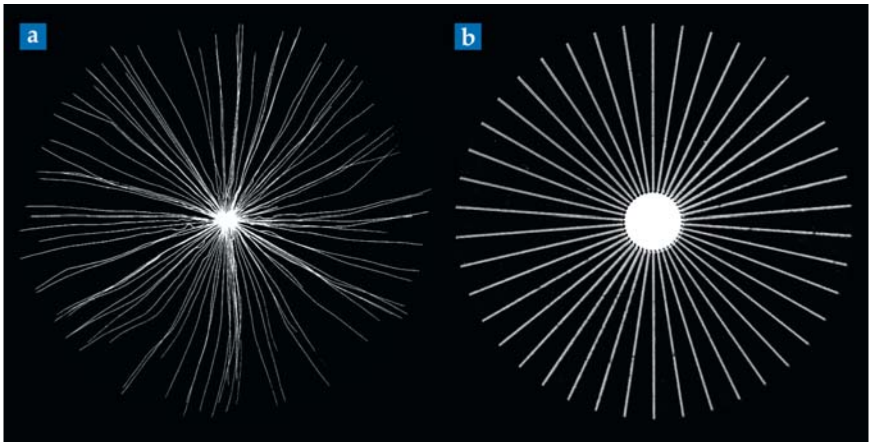

FIGURE 2. POROUS PAPPI. (a) Dandelion seed pappi have porosities close to 92%. **(b)** Replica structures made from silicon enabled the researchers to investigate the formation of a separated vortex ring. Pappus diameters are approximately 1 cm. (Images courtesy of Cathal Cummins, Madeleine Seale, Enrico Mastropaolo, Ignazio Maria Viola, and Naomi Nakayama.)

fixed height above the pappus and creates a low-pressure region that stabilizes the seed's flight.

When the researchers set out to study dandelion-seed flight, they didn't expect to find an SVR. "It was a surprise," says Nakayama. But they did have an inkling that they would see interesting flows. "We kind of knew that something cool was going on, so we were definitely keen to see the fluid behavior from the beginning." And their intuition proved right: The SVR, with its steady detached flow, had never been seen before. The mechanism they uncovered is "effectively a new way of flying," says Viola.

Artificial plumes

Nakayama, a biomechanics researcher, was always interested in studying plumed-seed flight for its implications in plant ecology and habitat establishment. However, it was not until she moved to the University of Edinburgh that she could tackle the problem. There, she teamed up with her "partner in crime" Viola, a fluid mechanist, and with Cummins, an applied mathematician studying biological flows.

After observing the SVR above the dandelion pappus, Nakayama, Viola, and Cummins wanted to further investigate seed flight and vortex formation. Natural dandelion seeds are remarkably uniform in their geometry. To explore a range of seed geometries, the researchers needed to replicate the delicate structures. Enrico Mastropaolo, a microfabrication expert at Edinburgh, became the fourth crucial collaborator on their team. He used photolithography and microfabrication techniques to make artificial silicon seeds with pappi ranging from solid to highly filamentous. One of his replica seeds is shown in figure 2.

The researchers found that a pappus's ability to form a stable SVR depended on two factors: its porosity, which is defined as the empty fraction of a circle enclosing the pappus, and the ambient Reynolds number, which describes the relative importance of inertial forces to viscous forces in the flow around the seed; for a seed fixed in the wind tunnel, the Reynolds number is directly proportional to the wind speed. Figure 3 shows the measured dependence of stable vortex formation on porosity and Reynolds number. At each porosity, the SVR became unstable above a critical Reynolds number, and that value increased with porosity.

All of the freely flying natural seeds that the researchers tested generated stable SVRs. Their measured Reynolds numbers were just below the critical value when they were falling at their terminal velocity (about 39 cm/s). At 92%, the porosity of a real pappus could hardly be higher, but if it were any lower, the resulting vortex would be unstable. Dandelion seeds have very similar porosities and weights wherever they come from, notes Nakayama. "A lot of things in biology tend to be so variable," she says, but for dandelions, "when you look at their design, their structure, the variations are quite tight. And that tightness is necessary to hit the sweet spot in how this flight mechanism works."

Generating drag

With such high porosity, it's not obvious that a dandelion pappus would be able to significantly slow a seed's descent. Traditional models of pappus drag assumed that each filament could be treated as a cylinder and that the total drag would be the sum of each filament's contribution. But the Edinburgh researchers found that the drag coefficient predicted by a noninteracting pappus model fell far short of the value they derived from their observations. The experiment was better described by a model for flow through comb-like structures. Such a

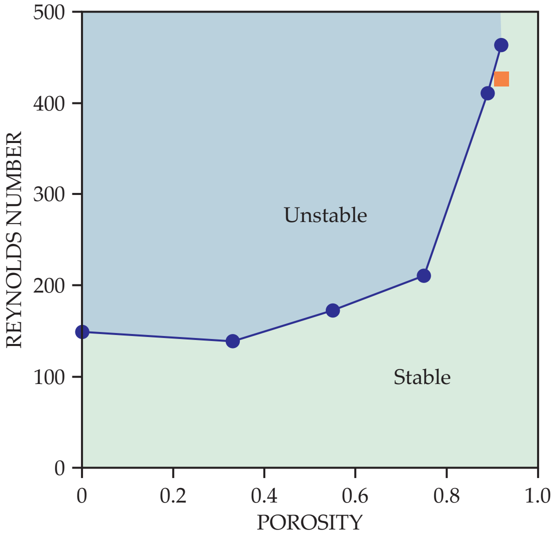

FIGURE 3. VORTEX STABILITY. The pappus porosity and Reynolds number, a dimensionless measure of a flow's turbulence, determine the vortex stability. For a given porosity, there is a critical Reynolds number below which a stable separated vortex ring (SVR) forms. Dandelion pappi, indicated by the orange square, have a porosity that is just high enough to ensure stability. That makes them optimized for generating drag with an SVR, which is how they fly. Above that value, the vortex ring is unstable and moves away from the pappus. (Adapted from ref. 2.)

model accounted for thick boundary layers around the filaments[4] and explained the increased drag that keeps a seed aloft.

To investigate how efficiently a real pappus generates drag, the researchers compared it with a solid disk that generates the same amount of drag. Because the dandelion seeds are naturally so uniform in weight and geometry, they had to be weighted and trimmed to vary their drag force. The researchers then determined the drag coefficients of the seeds by measuring their terminal velocities.

In each case, the solid disk that generated the same drag as a dandelion pappus had a smaller diameter but took up four times as much area. In terms of material used, that makes the pappus more efficient than a solid membrane. If an equivalent disk used as little material as a pappus, it would be about 1 μm thick, which is about the size of a small bacterium. The membranes of real seeds are typically hundreds of microns thick.[5]

Plants aren't the only ones using bristly structures to generate drag. Some small insects, such as *Thrips physapus*, have wings that resemble dandelion filaments. "They're just a bunch of hairs. And then they fly with it," says Nakayama. The wings of such insects have a similar size and porosity to dandelion pappi, which suggests that they may also generate SVRs when the insects fly. She also notes that underwater organisms use tentacled feeding structures to sift food out of water. "They're just around the right size for this kind of vortex to occur," says Nakayama, "so marine scientists wonder if they might navigate particles in water with this kind of interesting flow behavior."

Now that they know what to look for, scientists may find that SVRs underlie functions in a wide range of biological systems.

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An ancient merger helped form our galaxy

Measurements from the *Gaia* spacecraft suggest a large star system merged with the Milky Way 10 billion years ago.

The *Gaia* space observatory, built, launched, and managed by the European Space Agency, aims to create the most ambitious star catalog to date: a map of about 1% of the estimated 100 billion–400 billion stars in the Milky Way. The first data release in September 2016, DR1, provided astrometric information for about 1.1 billion stars. The second data set, DR2, released in April 2018, includes celestial positions for almost 1.7 billion additional stars.[1]

When a star is formed, it usually keeps the orbital energy and angular momentum from its parent galaxy (see the article by Joseph Silk, Physics Today, April 1987, page 28). By tracking the position and velocity of many stars, astronomers can learn whether any of them were part of a galaxy when it formed or whether a star group was accreted later in a merger. Today, it's relatively uncommon for two big galaxies to merge. But 12 billion to 13 billion years ago, when the Milky Way first formed, the probability of an event was likely higher because the universe was smaller and galaxies would have interacted more easily. Efforts to uncover that galactic history were limited before *Gaia*'s most recent star catalog release.

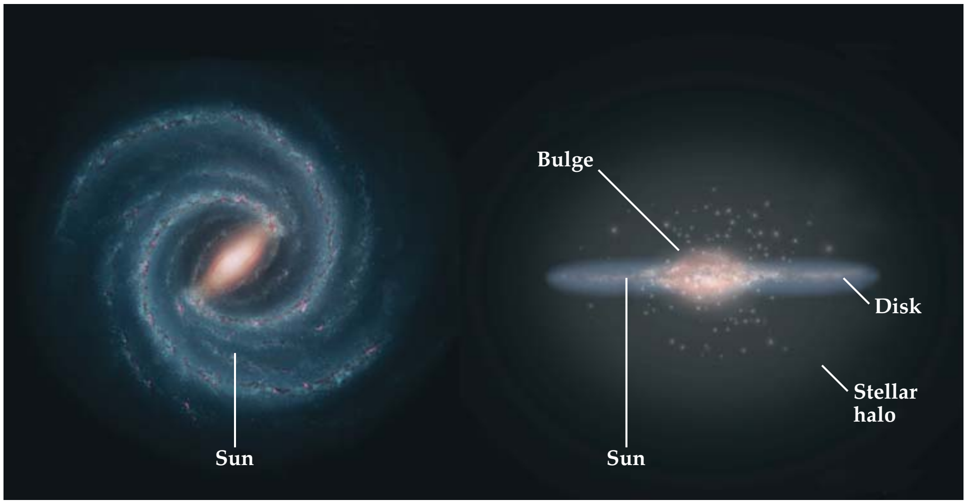

FIGURE 1. THE STRUCTURE OF THE MILKY WAY GALAXY. The Sun is about 8 kiloparsecs (about 26 000 light-years) from the galactic center. The disk is composed of a thin component surrounded by a thick component. The halo, a diffuse sphere of stars, envelops the galactic disk. (Left image by NASA/JPL-Caltech; right, ESA; layout, ESA/ATG medialab.)

From the new data, astronomers Giuliano Iorio and Vasily Belokurov from the University of Cambridge have found new evidence that the Milky Way merged with a smaller galaxy long before the birth of our solar system.[2] A second, independent team, led by the University of Groningen's Amina Helmi, came to the same conclusion and determined that the merging galaxy collided with ours about 10 billion years ago.[3] The work from both teams suggests that most of the galaxy's halo, a diffuse sphere of stars that envelops the galactic disk, was formed from that singular event.

Stars, stars everywhere

Our location deep inside the Milky Way, 8 kiloparsecs (about 26 000 light-years) from the center, makes it impossible to see the galaxy from a bird's-eye view, but we can infer its structure. The barred spiral galaxy, as shown in figure 1, comprises a dense, central bulge; a disk with