QUICK STUDY

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How plant seeds fly

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Although plants often rely on wind and water to carry their seeds and spores, some have evolved extraordinary launch mechanisms to disperse them.

Without the ability to move from one location to another, plants must disperse their spores and seeds for their offspring to reap the benefits of locomotion, such as finding nutrients, escaping predators, and avoiding diseases. Through natural selection, various dispersal mechanisms have evolved to efficiently scatter seeds and spores—often called by their technical term diaspores by researchers.

The most effective and familiar dispersal strategy of plants is fluid-aided transport, in which the lift, drag, and buoyancy of seeds and spores are exploited so that they can move far away from the host plant. A buoyant coconut, for example, can ride the ocean's currents for thousands of kilometers before washing up on a beach and growing into a palm tree. The fluffy pappi of dandelion fruits utilize their high drag coefficients to stay aloft and sow their seeds in grassy fields (see the 2019 Physics Today article "Dandelion seeds are optimized for wind-based travel").

Other fruits, like the autorotating samara of a maple tree, provide lift, similar to that produced by a helicopter blade, to stay aloft. The various mechanisms that keep spores and seeds suspended have evolved convergently across multiple taxa.

In contrast to fluid-aided transport, a more dynamic way that plants have evolved to disperse seeds and spores is to launch them as projectiles. That approach means that some plants can scatter seeds even if they aren't tall enough to have the seeds carried by wind or close enough to water or animals that can carry the seeds.

Rapid release

Plants that swiftly propel their seeds or spores utilize a collection of rapid motions called latch-mediated spring actuation. The process begins with a slow buildup of energy followed by a sudden release of the energy to create a powerful launch. A familiar example happens with a bow and arrow: An archer slowly loads tension into the bow, and when the bowstring is released, the stored energy is rapidly converted into kinetic energy in the arrow. Similarly, plants can slowly load stress into tissue through growing, desiccating, and increasing the pressure inside cells. Then the stresses are released rapidly through the explosive rupture of tissue.

Some flowers launch their diaspores at extraordinary speeds, which lead to impressive dispersal distances. The stamens of bunchberry flowers, for example, are unable to grow straight because the petal tips fuse together and restrain them. Consequently, elastic energy increases as the growing stamens bend, much like what happens when a loaded catapult bends its launch arm. Eventually, the petals quickly break apart so that the straightening stamens can launch the pollen like a trebuchet. The pollen travels several centimeters, which is enough for them to reach air currents. The elastic energy in the stamens is released in about 0.5 ms, which makes the bunchberry the fastest-blooming flower on Earth.

Fruits use similar mechanisms to disperse seeds. The fruits of touch-me-nots, for example, have valves, which can be thought of as spring-loaded banana peels, that are fused along their seams. The valves grow straight despite the internal stresses that act to curl them inward. A slight disturbance—even a breeze—breaks the valves apart and, as they curl up, they launch seeds at speeds of up to 4 m/s.

Flight dynamics

Fluid-aided diaspores are shaped to match their motion to the surrounding fluid. But ballistic projectiles need to reduce their drag as much as possible to best utilize the kinetic energy they acquire during launch. The drag force on rapidly moving projectiles depends primarily on inertial drag, whose magnitude is given by the equation $F_D = ½\, C_D \rho A v^2$, where C_D is the drag coefficient, ρ is the density of air, A is the frontal area of the projectile, and v is its speed.

The drag force does not tell the whole story. A Ping-Pong ball and a golf ball, for example, have approximately the same area and drag coefficient, but with the same launch velocity,

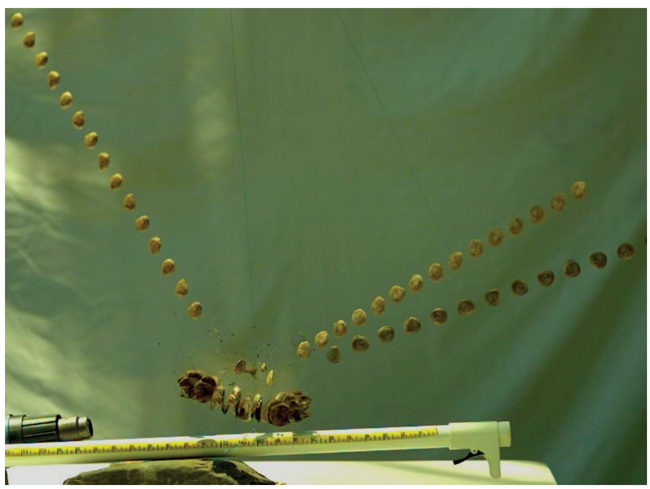

FIGURE 1. THE SANDBOX TREE launches its disk-shaped seeds with a backspin. This composite photo is made of several images; successive frames were taken 4.5 ms apart. (Image courtesy of Dwight Whitaker.)

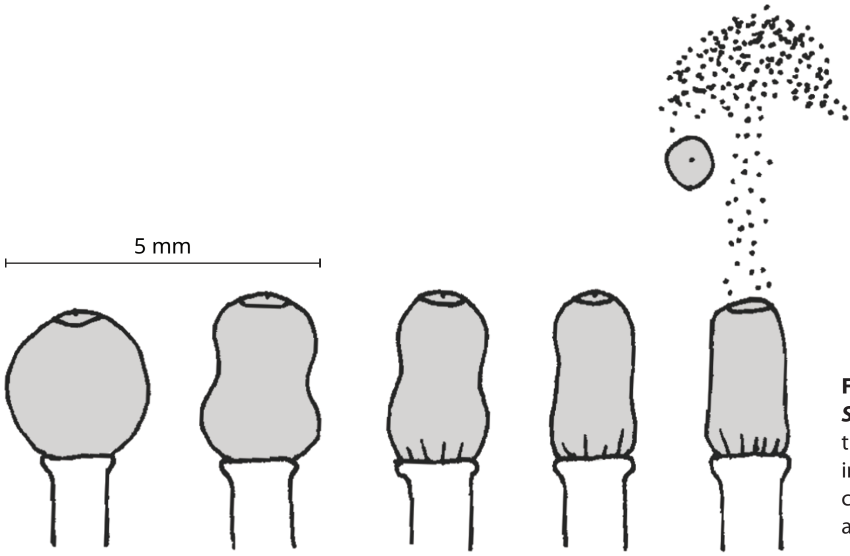

FIGURE 2. THE EXPLOSION OF A *SPHAGNUM PALUSTRE* SPORE CAPSULE. As the capsule loses water and shrinks, pressure increases and internal stress builds until the cap is blown off the capsule, and the spores are ejected. (Image courtesy of Emily Chang.)

the golf ball will fly significantly farther. That's because the same drag force induces a larger deceleration on the lighter Ping-Pong ball than it does on the heavier golf ball. A projectile's deceleration because of drag can be quantified by dividing the drag force by the projectile mass m, such that $a_D = F_D/m = \frac{1}{2} b\rho v^2$, where $b = C_D A/m$ is the ballistic parameter, which should be minimized to maximize launch distance.

Given that the mass of an object increases with an increase in its volume faster than with an increase in its area, one might conclude that larger seeds make better projectiles. A heavier seed, however, requires a commensurately more powerful launch than a lighter seed does to achieve the same velocity. The trade-off between launch speed and ballistic parameter means that for a diaspore of a given size, the plant will usually maximize range by reducing the projectile's frontal area, its drag coefficient, or both.

The seeds of a hairyflower wild petunia are small disks that are approximately 2.5 mm in diameter with a thickness of 0.5 mm, and the plant's fruits can launch them 7 m. The shape of the confetti-like seeds means that the seeds' orientation has an enormous effect on their drag force as they fly through the air. Figure 1 shows another example of drag minimization, in the sandbox tree.

Compared with a disk traveling edge on, one that's traveling with its axis of symmetry aligned with its velocity has an area five times as large and a significantly higher drag coefficient. Because of the torques that are applied on a disk as it moves through a fluid, the most stable orientation is the one with maximum drag. To maintain the drag-minimizing and edge-on orientation and thus achieve greater distances, the plant launches its seeds at about 10 m/s with a backspin of more than 1200 Hz. That frequency makes hairyflower wild petunia seeds the fastest-rotating natural thing on Earth.

The angular momentum from such tremendous spin gyroscopically stabilizes the seeds in their backspin orientation and minimizes their drag. Hairyflower wild petunia seeds that are launched with a backspin travel 60% farther than a sphere of equivalent volume and roughly twice as far as nonspinning seeds.

Vortex-induced dispersal

Peat moss, also known as sphagnum, uses aerodynamics to great effect to discharge its spores. Mosses lack a vascular system, so they can't grow tall enough to where the wind can easily carry their spores. Furthermore, the dust-sized spores can't be launched any significant distance because of their low mass and subsequently high ballistic parameter. Instead, a sphagnum spore capsule creates its own fluid flow to launch its spores efficiently into the turbulent boundary layer, where wind can carry them indefinitely.

On a warm summer day, the peppercorn-sized spore capsules, which are perched a couple centimeters above the bog's mat, desiccate and collapse. The pressure inside the capsules increases. Eventually, the strain from the collapsing capsule is strong enough to suddenly eject the capsule's lid, which releases pressurized gas—as shown in the illustration in figure 2. A vortex ring that emerges upward from the capsule can carry the spores to a height of about 10 cm, where they can be transported by air currents.

The vortex ring of peat moss is the only one known to be produced in the plant kingdom. The process combines both the projectile and fluid-aided dispersal strategies: The vortex ring provides a low-drag means of transporting the high-drag spores until they reach a height where wind dispersal then carries them over enormous distances. Once brought into the jet stream, the spores can be carried around the world.

The aforementioned adaptations are a small sample of the multitude of ways that plants efficiently transport their diaspores in the fluid that surrounds them. By studying the aerodynamics of seed and spore dispersal, physicists and engineers can learn from adaptations that evolved over millions of years and develop bioinspired engineering designs.

Additional resources

- M. Ilton et al., "The principles of cascading power limits in small, fast biological and engineered systems," *Science* **360**, 397 (2018).
- E. S. Cooper et al., "Gyroscopic stabilization minimizes drag on *Ruellia ciliatiflora* seeds," *J. R. Soc. Interface* **15**, 20170901 (2018).
- D. L. Whitaker, J. Edwards, "*Sphagnum* moss disperses spores with vortex rings," *Science* **329**, 406 (2010).
- A. Sakes et al., "Shooting mechanisms in nature: A systematic review," *PLOS One* **11**, e0158277 (2016). PT