How Spiders Catch the Air for Their Flight

A hairy structure is usually found in microorganisms, such as bacteria, spermatozoa, and paramecium. They can swim with this hairy structure, which is known as cilium and flagellum, in a fluidic environment. But are there any organisms that use these structures for flight? Dandelion and thistle seeds, with their parachute hairs called pappus, are good examples. But this is not limited to plant seeds. Some animals also do aerial dispersal using such a hairy structure. One weird aviator is a spider. Spiders can travel aerially using their fine silks, from tens of meters to hundreds of kilometers, and this behavior is called ballooning. Some spiders were caught in the air at a few kilometers above the ground. But the physics of spiders' ballooning is not well known.

Most flying spiders are young or small adult spiders, less than 2 mm in length and 2 mg in weight. Just a few days after eclosion from their eggs, these young spiders balloon to avoid cannibalism at their birth sites. Some adult spiders balloon to find a place for a new colony, food, and mates. Although the ballooning of large spiders (10 to 150 mg) was also observed, the flight mechanics could not be explained because the ballooning silks observed were not sufficient for the large spiders to be airborne with light updrafts. The calculated required updrafts were 9.2±21.6 m/s. Even the multiple silks observed later were not quantified exactly. Quantitative information on ballooning fibers was a prerequisite for elucidation of large spiders' ballooning flight. Unfortunately, until now information about the ballooning silks was not available, and there was no footage that could help us picture the whole sequential process of ballooning.

To figure this out, we selected crab spiders, 10 to 25 mg, which are among the relatively large spiders that do ballooning. We first observed detailed ballooning behaviors in the field. After that, we placed other spiders in front of an open jet wind tunnel to acquire samples of ballooning silks. Measuring the physical dimensions of ballooning silks was not easy because microscopic thin silks flutter in wind fluctuation. The separated multiple ballooning fibers were sampled on a microscope slide on which two narrow strips of a double-sided bonding tape were attached. Later, the fibers were observed with a scanning electron microscope. By winding the spun ballooning silks around a reel, we could quantify the length of the ballooning lines.

The observation of ballooning behaviors revealed to us a couple of new facts. Spiders seemed to show an evaluating motion for wind conditions before taking off. In crab spiders, the ballooning silks were not identical to a dragline, which was thought to be used for their ballooning. Rather, the dragline is used as an anchored/tethered line for safety during the takeoff process. Furthermore, the acquired quantity of ballooning fibers was interesting. Spiders spin 50 to 60 thin fibers for their flight. The thickness of these fibers was about 200 nm. This thinness is shorter than the wavelength of visible light, 400 to 700 nm. This was why the observation of fibers had been difficult, even with an optical microscope. The length of ballooning fibers was, on average, 3 meters, with a maximum of 6 meters.

Although spiders spin nanoscale fibers, the acquired length and the number of ballooning fibers are enough for them to soar up with a light updraft, 0.05 to 0.2 m/s, according to our calculation. We may question the meaning of this extreme thin silk. If some objects are extremely small, normal aerodynamics, which winged insects and birds use, is no longer valid. While flying insects and birds normally utilize the inertial force of the air flow, generating vortices on their wings to produce lift force, the air’s viscous force is much more dominant than the air flow’s inertial force on spider silk because of the tiny scale. From the viewpoint of spider silk, the air is like a sticky medium. This flow regime is mostly found in the locomotion of microorganisms, which use their cilia or flagella to swim. Spiders utilize this form of micro fluid-dynamics to catch the air by spinning their nanoscale ballooning silks.

As we can see a hairy structure in dandelion and thistle seeds, we find hairy structures in spiders’ ballooning. In a microscopic world, this hairy structure is a materially efficient structure to produce fluid-dynamic force. The interesting thing is that a spider is the heaviest organism using this type of unique mechanics for its flight. This is possible because spiders can produce high tensile strength silks, which is one of their unique characteristics.