CATCHING GREAT AIR

A research scientist documents the remarkable aerodynamic adaptations of northern flying squirrels

ARTICLE AND PHOTOGRAPHS BY
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LAUNCHING SKYWARD To quickly gain elevation, flying squirrels push from the ground using their powerful hind legs before opening their flying membrane and gliding to a nearby tree. Here a flying squirrel bursts from its cache of fir cones buried deep in snow, leaving a potential intruder startled while gliding away to safety. "Walking through the forest at night, it's like champagne bottle corks popping around you," says the author. Such escapes are far less successful with raptors. Flying squirrels rustling noisily under snow become too confident in their explosive escape strategy and become a staple winter food of great horned owls.

I spend the day in my research cabin north of Ovando in the Blackfoot River Valley poring through photographic equipment manuals to determine the lowest temperature of operation. Meanwhile, the radio is broadcasting severe winter weather warnings, with dangerously low overnight temperatures. Finally, I decide on a plan and head into the forest.

A few hours later, after snowshoeing six or seven miles into the backcountry, I stop and begin working in the diminishing February twilight. As quickly as possible in the freezing cold, I string a rope of strobe lights along the branches of several trees. The lights are connected to a high-speed camera set on the ground and aimed at a gap in the tree canopy. The trees frame a tiny half-acre forest pond on the southern boundary of the Bob Marshall Wilderness. From previous field research by my graduate students and me, I knew that local female northern flying squirrels regularly travel along the lakeshore. In winter, the squirrels emerge from roosting cavities shortly after midnight and range throughout the forest, traveling to their under-snow food caches by remarkably consistent routes.My goal was to photograph squirrels in flight in a natural context, something rarely documented.

Based on my previous observations , I expected the female squirrel I'd targeted to fly over the lake between 2:20 a.m. and 2:50 a.m. Unfortunately, the overnight temperature was predicted to plummet to -40 degrees F., greatly increasing the chance of camera failure. But the risks were worth it. In Montana, February is the middle of the northern flying squirrel's mating season. Even in severe cold, each female is typically escorted through the forest by a squabbling squadron of ardent males. I was hoping to also photograph those males and their dizzying aerial mating chases.

PREPARE FOR LANDING A flying squirrel's flattened tail adds an additional 25 percent of gliding surface. Just before landing, the squirrel drops its hips, opening up the patagia—the membranes on each side of its body—into a speed-slowing parachute and bringing the hind feet forward for landing.

MORE THAN JUST SOAR Scientist once thought flying squirrels could not actually fly, but only passively glide. Now researchers are thinking otherwise. Though the squirrels don't flap their patagia, they slightly adjust parts of their anatomy to increase lift and decrease air turbulence.

HIGH FLYER

The northern flying squirrel is one of two flying squirrel species in North America. The other is the smaller but almost identical southern flying squirrel. The species in Montana ranges across Canada and Alaska, through the northern Rockies and Great Lakes states, and down to Appalachia's cooler mountain zones as far south as North Carolina. The southern flying squirrel ranges across much of the eastern third of the United States, from Florida north to the Great Lakes.

Flying squirrels feed on plant material, including seeds, nuts, and flowers, and also eat insects, bird eggs, and even meat scavenged from dead animals. Their passion for eating lichen, truffles, and other mushrooms helps spread the fungi's mycorrhizal spores, essential for conifer root growth, through forest ecosystems. What's more, when excavating fungi on the ground in the middle of the night, flying squirrels get so preoccupied with finding food they become highly vulnerable to great horned owls and great gray owls, their primary predators. The squirrel's role as a central link in the forest food chain makes it a "keystone species," one essential for maintaining the habitat's ecological integrity.

The flying squirrel is well known for its amazing ability to glide among tree trunks on its outstretched patagia (the expandable furred flaps of skin on either side of its body that stretches from the animal's neck to its ankles.) For years, scientists assumed that flying squirrels were passive aerialists that used their gliding ability simply to prolong jumps across canopy gaps and lessen the impact of landing.

Alex Badyaev, a professor of evolutionary biology at the University of Arizona , conducts long-term field research projects throughout Montana, where he lives part time. Also a professional photographer, Badyaev was a winner of the 2011 BBC Wildlife Photographer of the Year and the 2011 National Wildlife Photography awards. His recent photos are featured in a new book, Mammals of Montana.

These assumptions became suspect, however, when recent laboratory studies uncovered several exceptional features of squirrel aerodynamics that strongly hinted the species might be capable of more than passive gliding. Time-lapse lab photos indicated that flying squirrels conducted airborne feats that aerodynamic theory suggested should be impossible for a species simply gliding through air.

In particular, studies found that airborne squirrels have an unusually high "angle of attack"—the angle between the gliding membrane and the direction of oncoming airflow. While greater angles generate greater lift, valuable for gaining midair height and distance, the angles observed in flying squirrels far exceed those sustained even by advanced military jets. In theory, the high angle should cause the soaring squirrel to stall midair and crash.

Scientists also found that somehow the squirrels are able to eliminate the destabilizing forces of unequal air pressure above and below the patagia. These "mini-tornadoes" on either side of the jet wings are the cause of turbulence, and the force increased as the plane angles upward. With their high angle of attack, increased turbulence should greatly reduce the squirrels' gliding distance and speed. But that doesn't seem the case. How do they do it?

Scientists have also wondered why flying squirrels don't crash. Simple calculations show that a squirrel landing from a routine 40-foot glide would hit a tree with an impact of more than 30 times its body weight unless it actively stalls well in advance of the landing. Yet such a stall would further decrease flight stability and duration. Based on what's known about aerodynamics, flying squirrels should be confined to slow, short, and steady glides or risk constant crashes, stalls, and falls. Yet they soar great distances. How is that possible?

Those were just some of the questions I hoped answer as I knelt in the snow that frigid February night.

EYEWITNESS

Shortly after 2:30 a.m., under a nearly full moon, I was treated to a remarkable air show. It began with a cloud of snow kicked up by two males chasing each other on the upper branches of a spruce tree high over my head. One lost his grip then dove into a long glide over the pond, followed immediately by the second male in a rapidly accelerating glide.

Both landed in the upper canopy across the pond—seemingly without much loss of elevation, despite a glide of at least 60 feet—and resumed their squabble. Then I spotted a female sitting quietly on a snow-covered branch against a tree trunk, inspecting a large fir cone probably left by a red squirrel during the day. A few seconds later, another male parachuted down from a nearby tree, somehow steering the end of his nearly vertical descent to land on the trunk right below the female.

The female crouched, and in an exceptionally powerful jump with a fully extended body and outstretched hind- and forelimbs, launched herself at a 40-degree angle high into the air. She kept her patagia completely folded until reaching a height of about 10 feet. She then spread the membranes wide open, and lighted by a series of high-speed strobe flashes triggered by my camera, seemed to freeze in midair for a moment before gracefully gliding out of view across the snow-covered pond. After engaging in a few barely audible squabbles from across the frozen expanse, occasionally kicking up more snow dust, the squirrel group disappeared into the dark and the night's silence was restored.

I was amazed. What I had witnessed and documented with my camera that and subsequent nights were a series of astonishing aerial accomplishments: 150-foot-long flights across open fields; mid-air

UNEXPECTED VISITORS The author's introduction to flying squirrels' aerial abilities came one winter while waiting for weasels at a wolf-killed deer in a vast field in a northern Montana forest. "To my surprise, what landed on the deer instead were flying squirrels, gliding in from trees 100 meters away," he says.

GROUND-BREAKING DOCUMENTATION The author's contribution to science was to show how flying squirrels use their anatomy in a natural setting. "I documented how they used the various anatomical adaptations that scientists had noticed in the lab but didn't know what they were used for," he says.

180-degree turns to evade attacking owls; vertical leaps so high the squirrels could then soar from midair into a tree. It was obvious this species is capable of much more than just simple static gliding.

I spent the rest of that night walking around to keep warm, watching an occasional owl for entertainment. At first light, I dismantled the by-then solidly frozen equipment with its long-dead batteries and started my way back to the cabin. I would spend many days afterward replaying and analyzing, frame-by-frame, the footage of these stunning performances to understand how the species elegantly solves major aerodynamic problems.

Foremost among these solutions is the squirrel's "wing tip"—a short rod of cartilage outside the wrist that the animal moves at various angles to enable exceptional flight control and precision landings. This anatomical novelty, sort of like a sixth digit though not attached to the others, is controlled by a powerful muscle. By adjusting the angle of the wing tip, the squirrel can generate a substantial lift, modifying the speed, distance, and trajectory of its glides mid-flight. This anatomical gliding innovation precedes the static endplates ("winglets") that NASA began installing on the wings of modern jets in the mid-1970s by at least 20 million years.

A flying squirrel's second novel physiological adaptation is the extensive musculature that crisscrosses the thin gliding membrane. These muscles, combined with limb movements during flight, allow a squirrel to actively modify the billowing of its "wings" and the orientation of fur on their surface. In a typical aerial chase, this produces wing shapes such as completely folded patagia during powerful take-offs; thin, fully extended membranes in the middle of long-distance glides; and fully inflated furry parachutes for slowing nearly vertical descents.

Finally, unlike many other gliding mammals (which include some primates and marsupials), flying squirrels have an additional fur-covered membrane between their neck and wrists they can curve down during flight. These "mini-patagia" guide air flow away from the larger patagia to lessen turbulence, while generating significant forward acceleration and lift.

In short, flying squirrels flawlessly combine, in a small furry package, features of heavy transport planes, agile military jets, and flexible-wing parachute gliders. Their anatomy makes the flying squirrel one of the world's most sophisticated mammalian gliders.

BIOMIMICRY The flying squirrel possess an amazing evolutionary innovation—a "wing tip," This cartilage at the each wrist is held at variable angles to the rest of the wing to provide exceptional flight control and landing. It precedes the NASA-designed static winglets of modern jets by roughly 20 million years.

Scientists have long known that flying squirrels were loaded with excess anatomical abilities. But what purpose did they serve? Flying squirrels seemed overbuilt for simply gliding from one tree to another. My contribution from the nights spent in western Montanan's frigid woods was to document in the wild just how the squirrels use those remarkable features in flight. It turns out that flying squirrels are not just passive gliders. For instance, I saw them leap into the air from a tree trunk and then, as if forgetting something, turn 180 degrees in midair and return to the same trunk. And I witnessed that they can not only accelerate when gliding but also just as quickly decelerate just before landing so they don't smash into the destination tree.

Over millions of year, flying squirrels have come up with elegant solutions to the same aerodynamic problems that face modern aircraft engineers. Maybe flight engineers and others can learn from these small, furry mammals. If nothing else, we now know why a flying squirrel is equipped with these sophisticated features—to perform astonishing aerial maneuvers previously thought possible only in birds, bats, and other winged animals.

I have to wonder: What other marvels in these and Montana's many other mammal species are still out there waiting to be discovered?

Want to see a flying squirrel in the wild? Badyaev recommends watching your bird feeder after midnight if you live in forested areas of western Montana where the squirrels frequent. "The main way people know they have flying squirrels around is they see the tails left behind by great horned owls that feed on them," he says.