AirSpace Transcript Season 10, Episode 8: Bats!

AirSpace theme in then under

Matt: Welcome to AirSpace from the Smithsonian's National Air and Space Museum. I'm Matt.

Emily: And I'm Emily. We've talked about birds on this podcast, and we've talked about planes a lot on this podcast, and we've even talked about Superman that one time. But today we're talking about bats.

Matt: Bats are the only mammals that truly fly, and they do it in a way that's completely different from how birds fly. Engineers who often look to the animal kingdom for inspiration have looked at bat flight, but it's proven difficult to replicate.

Emily: We're talking about why that is today on AirSpace sponsored by Lockheed Martin.

AirSpace theme up and out

Matt: Bats are one of my favorite animals, but they're not the most obvious AirSpace topic. But they do make a good topic because they fly in a way that's totally unique to them. We don't see that in other parts of nature.

And you know, Emily, you and I, we like all things flight here at the Museum, and we thought we'd get a primer on bats[1] and share it with everybody, right?

Emily: Totally. And I think there's a lot of inspiration that engineers take from nature and in the case of things that fly in nature, engineers are gonna pay attention to that in terms of whether or not there's some inspiration for how they might apply that to aircraft and things that fly here on Earth that are not animals.

Matt: Yeah, and you can look as far back as the Renaissance to Leonardo da Vinci, a guy, who probably everybody has heard of, when he was thinking about his flying machine[2], he looked at the wings of bats because he thought that was a logical place to start when thinking about how to fly. And there's a long tradition of that that so far hasn't added up

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[1] https://www.batcon.org/about-bats/bats-101/
[2] https://sandiegoairandspace.org/collection/item/leonardo-da-vinci-ornithopter-mock-up

to anything because it turns out the bat wing is very difficult to duplicate in a flying machine. But that very idea, called biomimicry[3], still stimulates a lot of work in the field.

Emily: And so while there's been a lot of interest since Leonardo da Vinci, maybe even sooner in how bats fly, it's only been relatively recently that scientists have really been able to understand exactly how bats fly differently than birds.

Sharon: I love that question and I partly love that question because when I first started studying bats, I feel like what the general literature told me is bats fly like birds. Only not as well.

Emily: That's Dr. Sharon Swartz.

Sharon: Hi, I'm Sharon Swartz[4]. I'm a professor in the Department of Ecology, evolution and Organismal Biology at Brown University, and I also have an appointment to the School of Engineering.

But I feel like my, if I were to sum up what I've done in my professional life. It's to show that bats are not birds. They're their own thing, and their flight is completely different.

Matt: So it turns out that bats fly differently from birds, partially because they have just very different physiology, right? Bird physiology and mammal physiology just aren't quite the same, and the wings aren't built the same way.

Emily: Yeah. And I think beyond reminding yourself that bats are mammals and birds are not mammals because birds lay eggs and we don't have time to talk about platypus[5]. But what's really kind of fundamentally different is that a bird wing is you have these joints, just two or three of 'em that are really controlling that flapping motion and that lift and that flight is really facilitated by feathers[6].

Whereas when you look at a bat wing, it's kind of like looking at a human hand, and then that's all covered in skin. And that skin is what helps provide the lift. And what that also means is that that bat wing has all the articulation of a human hand because it's kind of a really big hand inside that wing[7].

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[3] https://en.wikipedia.org/wiki/Biomimetics
[4] https://vivo.brown.edu/display/sswartz
[5] Famously, platypus are mammals that lay eggs.
[6] https://www.sciencelearn.org.nz/resources/303-how-birds-fly
[7] https://askabiologist.asu.edu/human-bird-and-bat-bone-comparison

But if a bat didn't have any skin on its wing and it kind of held it out, it would kind of look like Edward Scissor hands with these like really long fingers.

But no scissors.

Matt: Yeah, Yeah, I think that's true, but it does have the webbing in between the fingers, which makes all the difference here.

Emily: Right. So to learn more, we also talked to Dr. Nancy Simmons.

Nancy: I'm Dr. Nancy Simmons[8], and I'm the curator in charge for the Department of Mammalogy at the American Museum of Natural History in New York, and I study bat evolution and ecology.

Bats wings are built differently than birds wings. Bird wings are bones of the forearm, which support, uh, a wing made of feathers. So the all of the lift and, um, forward motion of birds is generated by them flapping their arms with the feathers attached. And the feathers can move independently, but the airfoil is made of feathers.

Bats have a slightly different design. They still use the forelimb, so it's, it's evolved independently from ancestors that had legs. A bat wing is built from the upper arm, the lower arm bones, their forearm, and the hand and finger bones, which have become greatly elongated and support a membrane of skin that forms the wing of the bat.

The way that the bones move and the way that the skin, it's, when you see a picture of a bat wing, it usually looks flat, but when a bat is flying, the skin, the skin stretches in different directions and so there's curvature to these membranes and the fingers are moving and the arms are moving and so the overall movement of the airfoil is different in bats versus birds.

Matt: So if you went through a dinosaur phase as a kid and you followed any of the revelations about dinosaurs with feathers[9] that have come out more recently, you know, at least for me in my adulthood then you know, like there's this strong relationship, right, between the birds of today and the ancestors of the past. They share a common ancestor.

Bats, however, are more closely descended to our own common ancestor. They are mammals like us, and mammals and birds are not the same. Right? Bats probably evolved from some kind of small gliding mammal. That itself kind of evolved from a scurrying mammal. It's very cute.

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[8] https://www.amnh.org/research/staff-directory/nancy-b-simmons
[9] https://www.amnh.org/exhibitions/dinosaurs-among-us/feathers

Emily: Very cute. How do you know? All you've ever seen are the skeletons.

Matt: In my brain it's very cute

Emily: Oh, in your brain, they're really cute.

Nancy: The earliest bats that we find in the fossil record were clearly already flying mammals. They have a forearm and hand bones that look basically just like living bats. So they already had the long fingers that support the end of the wing, the long arm bones. And so I'm a little bit different proportioned in the, in the fossil bats, but this is 52 million years ago bats were already bats in essence

So we have to reconstruct how the bat wing evolved by comparing them to other fossil animals and also thinking of hypotheses about how this might have taken place, so our best guess at this point, based on the other animals that bats are related to is that Bats evolved from a small, scrambling mammal that probably was moving around up in the trees or up in bushes catching insects.

Matt: So Nancy and Sharon study bat evolution by tracing the animals back through the fossil record, what they can see in the fossil record of where those bats came from and what changes occurred along the way, and also how those changes varied in different places of the world at different times.

Emily: There are two very old fossil bats, and the fossils were found in what's now Wyoming and both of these fossil bats are more than 52 million years old.

Nancy: One of them is called Icaronycteris after Icarus from Greek mythology. Anyway, Icaronycteris Index[10], it already was an echolocator. So we know from looking at the form of its ear region that this bat was most likely capable of hunting flying insects on the wing.

A different fossil bat called Onychonycteris Finneyi[11] is interesting in many ways because it seems to be a more primitive bat. It had claws on all of its wing digits. So, living bats today, their finger bones end in little nubs, but then they have a thumb with a claw on it, so they only have one clawed digit. Icaronycteris was like that. It had a clawed thumb and just little nubs on the end of the fingers. But Onychonycteris still has little tiny claws that it hasn't yet lost in an evolutionary sense.

[10] https://en.wikipedia.org/wiki/Icaronycteris
[11] https://www.nps.gov/fobu/learn/nature/fossil-mammals.htm

But neither of them is thought to be like the ancestor of all living bats. These are some of the first side branches of bats for which we have fossils to study.

Matt: So what they do see in the fossil record is two very old bat species that have fully formed wings capable of complex flight. So researchers know that flight was evolved pretty early on in the evolution of of the bat.

Nancy: The elongation of the arm and the development of the membranes between the fingers and between the arm bones and the body was probably a genetic change which happened very rapidly. And that we can think today of animals that have membranes that help them move through the air, but don't have fully formed wings.

And so an example is flying squirrels. They can glide, so they have membranes between the foreleg and the hindleg. And they can glide between trees, but they can't generate lift to keep going. So they have to climb up a new tree and jump off again to be able to move through the air.

Whereas bats developed flapping flight which allows them to stay airborne for long periods of time. We're not sure exactly how all of this happened, but we do believe that that early in bat evolution, a gliding mammal like a flying squirrel evolved membranes between the fingers and elongated the finger bones in the hand, and at this point was able to generate enough lift to stay airborne.

Matt: So what scientists think is that all bats kind of descend from one common ancestor along that branch of the family tree. In the fossil record, this common ancestor would be represented by what is called an "Ur fossil," or the "Ur Bat" which would be the bat that all bats had descended from that itself descended from that jumping, gliding creature into real flight.

Nancy: We believe that flight evolved only once in bats in the bat lineage. So yes, at some point there was an ancestral species, just one, and from that species evolved the huge diversity we see today. So there's nearly 1,500 living species of bats today and several hundred extinct species of bats as well.

What we have in the fossil record is not that ancestor though. We, we know that it lived, but we, we don't have fossils of the Ur Bat.

Emily: The way these early bats flew. Is more or less the same way modern bats fly today. The wings are made out of this super cool stretchy skin and muscle, and that's draped over a very thin, long kind of hand-like structure. And then the wings have all these little tiny adaptive sensors along them to help bats be really precise flyers and all these different tools and different evolutionary adaptations really help bats fly in a way that's super unique to them.

Matt: So let's dive into how bat wings work, and let's start with that skin, back to Sharon Swartz from Brown

Sharon: Skin makes bat wings what they are. So of course, bat wings don't have feathers. They don't need feathers. They're made of this stretchy, um, magical material. The skin of the bat wing is really thin, even though it's really tough and strong, it's really thin.

So a fraction of a, of a millimeter, 40 microns is pretty typical, so it's less than a 10th of a millimeter. Might be a little bit more in a really big bat.

And the skin is so fancy that not only is it super stretchy and it has different stretch and different directions. Embedded within the skin are tiny little muscles. So they're, they're the kind of muscle that we as, um, biologists call skeletal muscles. So our bodies have two kinds of muscles, skeletal muscles, which are the ones that we control voluntarily as humans, like the muscles that attach to our skeleton, but also some other muscles that don't actually attach to the skeleton, like the muscles in our tongue.

So in bat wings these skeletal muscles don't attach to the skeleton. They only attach to the skin and this lets bats use these little muscles in the skin of the wing to change how stiff the skin is.

Matt: And with all those little muscles that are actually controlling the skin, you can imagine why that would be difficult to replicate in an engineered aircraft, right? We just don't have muscles in the wings of airplanes that can do that sort of thing. It's, you know, not, not that muscles can't be replicated in some kind of mechanical way, but it would be very complicated.

But there are always advances in materials, and new aircraft often take advantage of stuff that just wasn't available in the past decades. And there are engineers in England[12] who've created a bat-like wing out of a polymer that stiffens and relaxes in response to an electric current. So kind of like a muscle.

12 https://www.imperial.ac.uk/news/170909/bat-wings-inspire-unique-design-miniature/#:~:text=Scientists%20have%20developed%20prototype%20bat.surveying%20remote%20and%20dangerous%20areas.

And those polymers can sort of replicate the, the motions of the muscle in the bat wing. And the electric currents are kind of, you know, acting like the bat brain. And eventually they hope that that wing can be used to propel micro vessels, sort of like tiny drones,[13]

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Matt: So even though scientists believed that flight evolved once for all of bats and then was carried forward into all the variety of bats we have today, there's still a lot of differences between bat wings in different species because they evolved slightly differently, different wing shapes and sizes that made them suited to whatever habitat it was that they were evolving in.

Nancy: So long, narrow wings are called high aspect ratio wings[14]. And those shaped wings enable bats to fly very fast, but they make them less maneuverable. So a bat that has a high aspect ratio wing may be able to travel very long distances quickly and may be able to go very fast to catch fast flying insects, for example.

But it can't make turns quickly. It's going to have a harder time maneuvering like in a dense forest environment. So we tend to see high aspect ratio wings in bats that live in open spaces. And one of the downsides of having wings that shape is that it's hard to take off. So you have to pick up speed before you can flap your wings fast enough to generate enough lift to get going.

So bats with high aspect ratio wings tend to roost during the day in places that are relatively high up so they can drop. They just let go and drop, pick up speed, then they spread their wings and then they fly. So they would live up in a tree hollow high in a tree, or inside a cave where there was enough space to drop and pick up speed before starting to fly.

The other end of the spectrum are low aspect ratio wings, which are shorter and wider. And those wings are not as good for fast flight or long distance flight, but they make the animal much more maneuverable. So bats, which live in dense forest environments, for instance, tend to have these low aspect ratio wings so that they can turn very quickly and they can maneuver around obstacles very rapidly.

Matt: So some of these differences that we see in bats, you might also see in airplanes that are designed for different purposes 'cause engineers have also recognized that, you know, you can use different size wings and different shapes of wings to achieve different

[13] https://www.southampton.ac.uk/news/2016/02/bat-mav.page

[14] https://pmc.ncbi.nlm.nih.gov/articles/PMC5206602/#:~:text=Aspect%20ratio%20(AR)%20is%20one,or%20to%20sustain%20longer%20flights.

types of flights. So, you know, look at the long distance flying airplanes with the longer wings, and then compare that to the aerobatic airplanes that have shorter wings for these tighter maneuvers. And you can see that airplane design uses these basic aspect ratios as well.

Emily: And this isn't unique to bats. Because birds also experience a lot of variety in their wing shapes as well, depending on the different environments and the different behaviors that those birds take part in.

But what bats have that's so additionally special is that bat wings also have these little tiny hairs all over them.

Sharon: The wing is covered with hair sensors. You could think of it as being like a cross between the whiskers on a cat or a mouse, and the cells of your inner ear.

So in a, like, typical North American bat that weighs 10 to 20 grams. Those hairs will be a couple of millimeters long. So they're long, they're, they're, they're thin. They're long enough that if you had a really good hand lens and plenty of light, you could see it. You don't need a microscope to see those hairs, and they're all over the wing. And they're, and they're sparse in some places and they're really dense in some places.

And one of the places where they're really dense is right in those muscles that control how stiff the wing is. So the hairs stick up there into the flow and down into the flow, and they're feeling in the skin. They're like a, they're doing proprioception for the bat[15]. They're sensing what's happening in the environment and in the muscle and in the skin, and they send the bat's central nervous system information.

They say to the central nervous system, the skin needs to be tighter, and that makes the muscle that they're attached to contract more. There's probably a reflex there. We don't know that for sure. We need some, we need a good neuroscientist to help us with that.

Matt: So we don't actually know that much about what kinds of information the hair sensors are giving to the bat. That is pretty new research. Uh, we don't know how it's impacting the flight or you know, how they're processing that information. But researchers in the United States[16] have done neurologic testing on bats that suggest the hairs act like speedometers or wind socks that may tell the bat how fast they're going and how the wind direction and speed impacts their flight.

[15] https://phys.org/news/2011-06-neuroscientist-air-tiny-hair-sensors.html
[16] https://hub.jhu.edu/2015/04/30/bat-agility-flight-sensors/

Emily: And when it comes to biomimicry in engineering, something built to work like the hair sensors on a bat's wing could be really useful in creating a technology that acts like a sensor on an airplane[17] or could allow uncrewed vehicles to do a better job of maneuvering and flying through turbulent air.

The end goal for engineers that are studying bat wings, their bones, their joints, the skin, the muscles, these little hair sensors is to recreate these biological mechanisms artificially. And I think what's maybe even more interesting is that it's not necessarily going to be the recreation of a bat wing, but mechanically. It's also being inspired by all of these adaptations that bats have evolved over a very long period of time, and using that inspiration to create technology.

Matt: So, you know, I wouldn't necessarily expect to be flying in a plane anytime in the near future that flies like a bat, although I would love it. But I might expect to see some kind of, maneuverable, uncrewed, small air vehicle, some kind of drone, for example, that might use that technology in some way.

Sharon: There are already quite a few small air vehicles that have non-rigid wings of one kind or another.

They're generally not as compliant, as stretchy as bat wings. So they're more like kite fabric than, than being rubbery. But if you had something that was more rubbery, the idea that you could build into it somehow a way of controlling stiffness rather than leaving the stiffness as a constant. I feel like that's such a, such a elegant and beautiful aspect of how bats control their flight.

So bats are changing the stiffness literally with every wing beat cycle. So that's part of how they fly, is they, you know, it's muscle. So the muscles of limbs of animals are programmed naturally to turn on and off with every locomotor cycle. They're meant to be activated and deactivated, cyclically in a rhythmic way.

I don't think you would necessarily need to do that in an aircraft, but you could have the tension in an aircraft wing, control the stiffness of the, of a wing material and change that with conditions.

Emily: And it's all still a work in progress. Research is always a work in progress, but some researchers, like the ones in England we mentioned earlier, have really early prototypes that are able to mimic some of the biological mechanisms that make bat flight really unique.

[17] https://techlinkcenter.org/news/air-force-researchers-mimic-bat-hair-for-fly-by-feel-sensor

Matt: Right. So the work is ongoing. There are labs and researchers working on, you know, batwing inspired technologies in Canada[18], in England, in Singapore, and here in the United States. So maybe someday we will have a little bat aircraft doing all kinds of cool things, right? And we might actually see those out in the wild, so to speak.

Emily: Or maybe we can have those little tiny black fly drones from Get Smart?

Matt: Yeah *laughs*

AirSpace Theme up then under

Matt: AirSpace is from the Smithsonian's National Air and Space Museum.

AirSpace is produced by Jennifer Weingart and mixed by Tarek Fouda, hosted by Dr. Emily Martin and me, Dr. Matt Shindell. Our managing producer is Erika Novak. Our production coordinator is Sofia Soto Sugar, and our social media manager is Amy Stamm.

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[18] https://mech.ubc.ca/2019/02/28/creating-the-next-generation-of-bat-inspired-aircraft/