Ask-a-Biologist Vol 052 (Guest: Ken Dial)

Evolution of Bird Flight

To fly like a bird. It's the dream of many people - being able to soar in the air without a plane or other device. But have birds always been masters of the sky? Dr. Biology talks with ornithologist Ken Dial about the evolution of bird flight and what he and other scientists have learned with the help from some modern baby dinosaurs (birds).

Transcript

Dr. Biology: This is Ask a Biologist, a program about the living world, and I am Dr. Biology. Have you ever dreamed you could fly like a bird? Maybe you watched a bird on this lazy summer day, flying from tree to tree without any effort and you thought: "That would be a great way to move around!" Oh, sure, you and I fly - that's with the aid of a plane or some other device. But humans just aren't built for flying without some extra equipment.

But have birds always been able to soar in the sky? If we could build a time machine and go back to the age of the dinosaurs what would we see?

[Prehistoric bird sounds]

Possibly some pretty strange flying animals.

Well, my guest scientist today is Ken Dial. He is a researcher at the University of Montana Flight Laboratory, and he has been studying bird flight and has been able to use some modern dinosaurs [dinosaurs roaring sound] -! I wonder what those could be - to learn how they might have evolved the ability to fly.

And in case you didn't know, for the past 100 years there have been several theories about the evolution of flight. And Professor Dial, along with other scientists, have added one more to the list. In fact, this new theory of evolution of flight is changing text books around the world. So you can see that parts of science can change as we learn more about the living world.

Professor Dial, I want to thank you for joining me on Ask A Biologist and filling us in on some bird flight biology.

Ken Dial: It's a pleasure to be here.

Dr. Biology: All right. You are working with one of the most amazing set of animals on the planet. And you actually mentioned to me -I didn't realize more animals fly to get around than any other method?

Ken: That is correct. But while I am vertebrate biased - the vertebrates are fish and amphibians; they are reptiles, they are birds, they are mammals - the animals with backbones, I study those for a living and gravitate to those. That within all of the birds and mammals, which are both vertebrates, there's about 4000 mammals and about 10,000 birds, a quarter of all mammals or bats, and so 11,000, effectively, of the 14,000 warm blooded animals, birds and mammals, they fly.

But anybody who studies fish would say yes. But fish are by far the most dominant or diverse vertebrate, and I would say they are absolutely correct. But they live in a fluid environment and they are moving in a fluid environment, arguably a form of flight, but not flight as we think of it with airplanes and birds and bats.

And then, what really trumps all of this, all you have to do is go to the invertebrate world, and insects by far outnumber all other organisms. They are well over a million already, that is a million species identified and we will find more, most of which fly. And so that's what really trumps this is that insects are the spectacular flying organisms on earth or the diverse group on earth.

Dr. Biology: Definitely great acrobats.

Ken: Yes, spectacular.

Dr. Biology: We talk about birds, when did they learn to how to fly? There is this talk about dinosaurs evolving into birds, and actually we often say that birds right now are living dinosaurs. And there have been some hypotheses that scientists have had about how that transition occurred - the evolution of flight. First, let's talk about what has always been talked about, and then I want to talk about what you have discovered or what your experiments are showing?

Ken: Well, for at least 100 to 150 years people have tried to understand where birds came from. And for many years, 100 to 200 years, all the evidence has shown that birds are a group of reptiles, they have come from some kind of reptiles, more specifically, the dinosaur theropod reptiles. And more specifically now, with lots and lots of beautiful fossils over the last 10 to 12 years from China and other parts of the world extraordinary intermediate forms, show us that these theropod dinosaurs velociraptor type animals that you know from Jurassic Park-

-that they, these bipedal two legged animals, running across the horizon seem to have been, in every way, the evidence shows that they were the precursors or the ones that gave rise to living birds.

And so, the hypothesis... hypothesis is what? It's someone's best guess. And so, a hypothesis is a guess. We use a fancy word to say it's a best guess. But it needs to be supported by some kind of evidence. And so, the anecdotal evidence, that is evidence of people just walking down the street, they might see something that reminds them of organisms that might have led to flight.

We see flying squirrels. They climb trees and jump out of the tree to glide to either another tree or the ground. They do not fly despite their name flying squirrels. They are gliding mammals. But these animals have lots of skin that their increases their surface areas so that reduce their ballistic trajectory towards the earth.

In other words, they hit the ground softer then they would have if they were just a big rock going straight down, and so, more like a kite coming down to earth than a boulder.

And so what happens is, you start to have these hypotheses that animals must have gone up in the trees and come down. This is called the tree-down hypothesis or theory. It is sometimes called the arboreal theory, like Arbor Day means Tree Day.

The arboreal theory is such that we think that the early dinosaurs or early reptiles or early birds that led to our birds today were in the trees first gliding down and then just decided to beat their wings.

The other theory or hypothesis or guess is that they ran across the ground like velociraptor on two legs and took to the heavens by beating their forelimbs.

Dr. Biology: OK. So those are two; they have been around for over 100 years, what is your hypothesis?

Ken: My hypothesis or my best guess is that by looking at living baby birds, we are able to, we think, look into a window of behaviors and morphologies or shapes of the animals with half a wing that seem more logical as to how you could have gone through these transitional stages from two legged animals that finally took to the skies, than it would be to do what we call the cursorial or ground-up theory or the arboreal tree-down theory. And so, we argue, some of us, that it was a false start - we would give a fancy name "a false dichotomy". But it really means that you don't choose just between this and that, but it could be a mixture of elements of the ground-up or the tree-down that makes a lot more sense, particularly, particularly if you show how living organisms demonstrate those behaviors and those transitional forms.

So that is what the bulk of my work is to show now how living animals, I don't have to wave my arms or draw this on a piece of paper at my desk and come up with a thesis, I can show people with real pictures.

I can show people how animals behave, how they deal with the real world when they're babies and we've come to find some beautiful, new observations. And that's animals use their wings and their legs together in ways we never imagined.

Dr. Biology: You mentioned you're working with baby birds. What is that the baby birds have been teaching you?

Ken: Well baby birds hatch out of the ground vulnerable, especially ground birds like chicken-like birds, Quails, Chuckers and Turkey type birds. Birds that are born are the ground are very vulnerable to getting eaten much like a Zebra or Wildebeest on the African plains, is very vulnerable when it's first born, because of all the predators and there they are out in the wild and in the open and not able to hide behind a bush. They need to get on their feet and move immediately.

And similarly, there are certain birds on earth who have a similar kind of behavior. That is when you see a little Quail hatch, moments later, or a Duckling hatch, they can walk. Then they start to walk in their world, which sometimes isn't flat anymore. Sometimes it has a branch or a boulder or a little ravine in their way.

We come to see that they deal with this environment, this non-flat environment, by using their baby wings that are of yet unable to take them into the sky, but to complement their feet in having, what we call, traction.

That is, to be able to hold onto the ground while they let their strong, powerful legs carry them up to safety. And we see this in many animals now that we're watching. And we film it, because sometimes it happens so quickly, that even somebody who's observed this didn't appreciate it until to take a picture of it and slow it down.

Dr. Biology: When you talk about getting traction, being able to climb a steep incline, people often see these little sports cars. They have the little foil on the back or even if you watch nice racecars. That actually pushes them down so that they stick to the ground better right?

Ken: That's correct. What they are is essentially baby wings. These are called spoilers and you see them on certain kinds of racecars: Formula One cars, Can-Am cars. You see them on some of the cars even those that we can buy now that we see on the streets. They have a little wing off the back of them. Some are just for show and really don't have a function. But those that do have a function are those that are built like an airplane wing, but it's really an upside airplane right because instead of lifting the car off the ground like an airplane wing wants to do, it pushes, essentially, the rear end of the car down.

The reason this is so important is that a car can only generate power, and force and control if it's in very good contact with the asphalt, with the ground itself. As soon as it starts to get air there, it actually becomes uncontrollable and that's when crashes occur.

So to keep control and to keep power to your rear wheels or to wheels at all, you want them to push against the ground and this fancy racecar is actually built overall like a wing.

It actually wants to fly so you want to push it back down by putting a spoiler on the back of the car to push the tires down, so that there's always good contact with the tires to the sub-straight or to the asphalt.

Dr. Biology: You talk a little bit about gliding and you talk about flapping. What's the difference?

Ken: Well frequently we compare birds to airplanes but we really can't compare a flapping bird to an airplane, because there's two parts to an airplane that make it fly. There's one that holds its up as a glider and that's the wing that tries to resist coming back down to earth, because gravity is pulling it down. It wants something to try and resist that is the lift generated by the wing. So that's what called an airfoil. It's built so it's more rounded on top and flat on the bottom.

It makes the air move faster on the top, which creates negative pressure like a vacuum cleaner sucking and pulling this entity and airplane up in the air.

What keeps it in the air is thrust. It keeps going forward and keeping air over the wing. An airplane actually has an airfoil as a propeller, spinning to pull it forward, that's called thrust, and wings held outward off it's fuselage that's to counteract gravity, called lift.

Those are two different forces that have to be used simultaneously by an airplane for it to stay in the air.

What's different to a bird? Well a bird using its' wing both as the propeller and as the wing to hold it off the ground. In other words, it's doing both, the propeller and the wing work that an airplane has as separate structures. This is what makes flight extraordinarily complex to study but also beautiful, because they can do things that airplanes can't do.

Dr. Biology: You actually have these videos. One of them is with the Zebra Finch. And it's showing intermittent flight. I've seen birds do this: they flap, flap, flap, flap. Then all of a sudden they pull their wings all the way together; they almost look like a little torpedo. Of course when you do that, I see the drop a little bit, and then they flap, flap, flap again. What's up with that?

Ken: Well, that's called bounding flight. And many little birds do that. We actually don't know the reason. There are hypotheses or educated guesses. They might be too boring, but I'll just tell you this. When the animals beating its wings, it's lifting up toward the heavens and going forward. When it pulls its wings in, it's essentially a little ballistic missile coming slightly back down to earth, and then it goes through what looks like a wave of up and down, up and down, if you look at the profile of their flight.

We think this has to do because they are so small and again, fancy names like, Reynolds' number. The world they live in, it requires them to race through parts of it.

It may be rest, or be efficient by pulling their wings in for a second and using their body to help them glide and they just alternate between using their wings as a power output and then the body as airfoil to keep them from falling too far down. And it's way to use less energy to move across the environment.

Then you have animals instead of being called bounding flyers you have undulating flyers, animals that leave their wings out when they beat. Like a Raven does or a Red Tailed Hawk does. They do a little gliding with their wings. And then you have steady flapping animals like many shore birds do, that you might see Sanderling or some kind of Willet.

So birds have various forms of powered flight. There's at least three that we've identified: bounding, undulating, and then steady flapping.

Dr. Biology: So bounding, it seems that even though it gives them a little chance to rest, it also keeps speed up, while as for the others for example, the Condors or something like that, when they're gliding they're not really going as fast as those little birds that can jus keep that real aerodynamic bullet shape as they go through the air.

Ken: That's right. And again if I try to give a simple answer, I would be beaten up by my colleagues, and they would be right to verbally and intellectually beat me up, because it's a complex and fascinating story that has to do with energetic and with muscle physiology and with, of course, just the medium of air and air foils. And it's a mixture of things - body size being probably most important.

Dr. Biology: Now we are still learning about it, so this could be the future for our young scientists.

Ken: Oh, my goodness. The opportunities for young people to study engineering, to study animal form and function and marry the two, is endless. We are in a magical age right now where young people should be invited to just stay in the sciences. It's not for a bunch of nerds.

It's for a bunch of crazy kids who just haven't grown up. They might be 40, 50 or 60 year old kids who are extraordinarily interested in how the world works.

But this does require that you get an education in math, in physics, in engineering and in biology. And Mother Nature has just given us such an extraordinarily array of animals to study as models that we are in a wonderful, indeed, a wealthy world of examples.

Dr. Biology: You have another video up on the website and it's of a humming bird. There are two things about his humming bird. One is it's really interesting to watch it. Because people have seen this when they come up and they [have the] feeders - they can actually hover, which is really cool. But in slow motion, it's really amazing to watch their wings. What is going on there, because that doesn't look like the normal wing movement to me?

Ken: Well, humming birds actually get their names not because they hum a song, but because their wings move so fast that they develop a sound like a guitar string being plucked. And so, [makes a humming sound] those sounds come from the vibration of their wings moving at very high speeds, anywhere from 20 to 80 times a second, which is very fast. But what they are doing that is unusual and unique to humming birds is that they turn their wings completely upside down during the upstroke, and most birds simply cannot or do not do this.

And birds that hover, like humming birds, usually have a behavior or a biology that requires them to be very still so that they can reach their tongues into a flower and extract their dinner, which is nectar. And other animals that try to hover like the little sparrow hawk or Kestrel you see outside actually is not turning its wing upside down.

It's actually falling out of the air slightly during the upstroke and going slightly up during the down stroke, but its head stays perfectly still. So they do hover, but they don't hover by turning their wings upside down, they do so by recovering quickly the down stroke before they fall.

Dr. Biology: There is this perception that science is on one end of the spectrum and art is in the other. And quite, frankly, the two are so kindred, it's amazing. You have some interesting tools you are using in your laboratory. And I would like you talk a little bit about the ones you use.

The reason I bring this up is you talked about the fact that you use Maya, which is a particular piece of software that is used, for example, in a lot of the animation studios in particular Pixar, which a lot of people will know from Toy Story. You use this in your laboratory?

Ken: Yes. And I personally am not really adept at this but my colleagues are, and my grad students are, my collaborators are. And so I do collaborate with some of the world expert animators, quite frankly. One at Brown University - well around the country, but one particularly at Brown, Steve Gatesy. I think it's a beautiful interface to know that computer of sciences and animation, which of course the animation is really trying emulate how things move, humans or animals, and put a cartoon figure to them are really after the same thing: understanding movements. So I study the movement of animals, both their hind limbs and their forelimbs. And I love to be able to understand the basis of their movement.

"What's underneath the hood there of that car that allows the legs to move?" So we study animals from the inside out. We study animals as they move with high speed x-rays, so that we can look at how the skeleton moves.

We want to know how the nervous system controls the muscles that are actually moving the limbs. And so we study essentially that. We are able to study how the nervous system controls muscles. We try to study how much force a muscle develops, so we can also use equipment that allows us to that; or how muscles shorten.

And probably the most important tool we have is high speed video and we use multiple cameras, because if you are doing three dimensional reconstruction that's what is required. And so this is where it interfaces with the animation that we started talking about.

So we use lots of different equipment, most of which, is effectively borrowed from a computer sciences or the medical world that are trying to better understand even how humans work.

We piggy back on the application of those products and try to do so in a way that allows us to understand animals in a dynamic setting, in other words, while they are moving. Not in a dissecting pan, dead and splayed open without any action.

And so the beauty of today's biomechanics and studying biology of movement is that we have so many tools now where you can look inside the animal and outside the animal, even using lasers, and looking how flow develops around the wind from the outside of the bird all the way to the inside. And that's extremely exciting.

And just 20 to 40 years ago, most of what we used didn't exist. And so we are able to peer inside of animals in a very magical way.

Dr. Biology: And, of course, using your wind tunnels. You have got some pretty elaborate wind tunnels too.

Ken: We do. We have wind tunnels which is nothing more than a tread mill for a flying animal or a water mill for a fish. It allow you to have an animal move in front of you, sometimes six inches in front of you, moving at 50 miles an hour, and instrumented, if we need to listen to the animals their internal workings actually function. But we have all of our equipment wrapped around the animal. So the animal may be moving at 50 miles an hour, but the equipment isn't moving at all. So we able to do things you couldn't do out in the wild.

Dr. Biology: There are what, about 10,000 different species of birds? Is that about right?

Ken: Living birds about 10,000, yeah.

Dr. Biology: What characteristics of flight do they all tend to share... or do they?

Ken: Characteristic or flight? Well, I would say that in most cases the simple beating of their wings as flapping is very important. We see birds soar and whatever. This flapping of a complex airfoil the structure that develops lift is really what defines flight. That is to be able to sustain yourself off the ground in the air and move across the horizon is not a simple thing, it's energetically expensive.

And flapping, essentially generating forces that allow them to continue to move in this fluid environment is the only thing I can say that flying birds share. Of course, there are some that are unable to do that because they are flightless.

There's only a few of them - emus and rheas and ostriches and cassowaries, you know.

But moving in the air is not simple. You can't cheat. You can't lean against the rock or a log and rest. You have to support your body 100% of the time in a very thin fluid. That sounds easy, but it is hard. And the birds, bats and insects are developing extraordinary forces to sustain them in this very thin fluid environment we call air in order to eke out a living.

Dr. Biology: Speaking about a rather interesting bird, one that is flightless, I guess my question is are they really flightless - penguins? Are they actually flying underwater or are they swimming?

Ken: They are flying; they are flyers. They are a flying bird. They just fly in a medium that is 900 times denser than air, but it's still fluid. And the way they move their wings and the forces that are generated by their forelimbs are very similar, if not identical, to the forces of birds that fly in the air. They are flying with their forelimbs. There are birds that do move under the water that don't use their forelimbs and they paddle. And so that's not really flying in the sense of forelimb developing lift. But they are absolutely, as are the alcids or puffin like birds, they are also doing that.

Dr. Biology: On Ask-a-Biologist every guest gets three questions, the same three questions. The first one is: When did you first know you wanted to be a scientist or a biologist? Was there ever an "aha!" moment?

Ken: Well, moment, I am not sure, but a period of my life that seemed ridiculously young. And that was I loved biology even when I was in junior high, and I wasn't a very good student because I was a little juvenile delinquent. And this is probably not politically correct to say, but you asked me so I am going to answer it. If I was raised in a very religious family environment and science and biology seemed to be a much more objective way to understand how the world works and is put together, and it was very pleasing to me to think that you could approach understanding how the world works without having somebody tell you how it works. And so, I found it far more refreshing than church.

Dr. Biology: OK. [laughs]

Ken: May I burn in hell for saying such a thing.

Dr. Biology: Well, some might say but quite frankly that's one of the things here, we are trying to decouple the idea of religion in science and trying to not put them at odd, because you can have a place for both and they can do great.

Ken: Absolutely.

Dr. Biology: OK. Well, let's move along. You know you are so passionate about your research, your science and the animals you work with. But I am going to take it all away from you. You cannot be a scientist. You can't be anything remotely resembling a scientist. You have to pick some other career, some other thing you like to do. It could even be a hobby.

Ken: That's easy. I play the guitar for two hours a day and I live for being the jazz or the blues professional guitarist and vocalist, so I love my music. But I also fly airplanes, and I wouldn't, you know, have a heart beat problem flying airplanes for a living. But I think if I had to choose one, I would absolutely want to be a musician.

Dr. Biology: How many guitars do you have?

Ken: More than I should tell you - probably about eight. I have electric guitars and acoustic guitars and jazz guitars and rock and roll guitars. And I just play them all the time. I have been playing since I was a little kid.

Dr. Biology: And jazz is your favorite?

Ken: It is now. But that's just because I am an old fart.

Dr. Biology: [laughs]

Ken: I played rock and roll and had long hair when I was a kid. And, of course, no one can see me but I am as bald as an egghead here. I have no hair on my head. I then went through college and did Coral music, loved Coral music, and actually got a scholarship in music as an undergraduate. And then, I got into blues in my 40's and I got into jazz in my 50's. And so, I guess, it's just some progression of getting old. But I have never felt younger.

Dr. Biology: Well, I just have to tell you, my son, long hair, but he is a big jazz guy. So it's not a matter of age, I think. It's a matter of attitude.

Ken: No, he sounds like he is much more mature. I wish I had been into jazz 20 years ago as I am now. It's just such a wonderfully rich dimension of music.

Dr. Biology: What advise do you have for young scientists?

Ken: I am stopping to think about this because there are a number of things. My talk today was to young scientists. My talk today was liberating young people from feeling as though they have to study something or anything. That they should have the opportunity to be engaged in biology and the study of life anytime, anywhere, in any discipline, in any dimension that they want. That there are so many wonderful questions yet to answer that we now know a lot about biology. But, just again, it's nothing but a coating on a building of what we know. There is so much more deep information to know about how life is put together.

This is a boring answer to you. But I am a little kid who is excited to have other children get engaged in science, because it not for people with lab coats necessarily. It's not for people who are super smart, book smart.

It's for people who are passionate about understanding how the world works, and over time you will become as smart as you need to be to be able to answer questions that have never ever been addressed before but need to be, and that's the most important thing I can tell a kid.

Dr. Biology: Yes, in particular, that there are a lot of questions still out there and a lot of things to learn.

Ken: We are just scratching the surface of what is out there to learn.

Dr. Biology: Well, Professor Dial, I want to thank you for visiting with us.

Ken: It is my pleasure to joy to be back in Arizona where I lived for six years, where my son was born. I lived up in Flagstaff. I have traveled to ASU and to Phoenix all the time. I learned to fly in Arizona and used to fly down here all the time. I miss it. It's a beautiful, beautiful state. I have had Arizona Highways for 30 years at my house. So there is a real connection between Arizona and me.

Dr. Biology: You been listening to Ask a Biologist, and my guest has been ornithologist Ken Dial. He is visiting the School of Life Sciences as part of our lecture series. If you want to check out the videos mentioned earlier, we will have a link to them from this shows content log or you can use this web address: dbs.umt.edu/flightlab. The Ask A Biologist podcast is produced on the campus of Arizona State University and is recorded in the GrassRoots Studio housed in the school of life sciences, which is a academic unit of the College of Liberal Arts and Sciences.

And, remember, even though our program is not broadcasted live, you can still send us your questions about biology using our companion website. The address is: askabiologist.asu.edu or you can just google the words "ask a biologist".

I am Dr. Biology.

[audio ends with prehistoric bird sounds]