"Flying Free "
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TEASE

ALAN ALDA My eyes are about to take to the air while the rest of me stays firmly on the ground. I'm very nervous.

PAUL MACCREADY That makes two of us.

ALAN ALDA (NARRATION) We're joining a legendary engineer inspired by nature.

PAUL MACCREADY That bird looks like it was having fun.

ALAN ALDA (NARRATION) A quarter century after he built the first human powered plane, Paul MacCready's creations are still revolutionary… and are themselves inspiring a new generation of flying machines… including a plane that may one day fly on Mars.

ALAN ALDA I'm Alan Alda. Join me as Scientific American Frontiers enjoys the pleasures of Flying Free.

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IS IT A BIRD?

ALAN ALDA (NARRATION) We're here to do some bird watching -- once we spot the bird.

BOB HOEY It's hanging underneath the fuselage. It's black. You'll see it when it gets airborne.

ALAN ALDA Oh, I see it, yeah.

ALAN ALDA (NARRATION) The bird is actually a glider, built by this man, Bob Hoey. Watching with me is Paul MacCready, who's been encouraging Bob in his quest to design a glider that can soar as well as a real bird. To MacCready's delight, Bob seems to have done it.

PAUL MACCREADY That's a real bird.

ALAN ALDA It really does look real, you're right.

ALAN ALDA (NARRATION) Paul MacCready has been watching birds for most of his 75 years. Much of the next hour will be kept in his company, as we explore some of the extraordinary accomplishments of a man whose childhood passion for all things that fly has never left him.

ALAN ALDA Paul, why do you do this? What do you learn from this?

PAUL MACCREADY Well, first of all, I think everybody is interested in birds. And when you're four years old and ten years old and twelve years old you like to watch birds, wish you could be up there, with them.

ALAN ALDA Look, look how close he is, look at it!

ALAN ALDA (NARRATION) In those boyhood days, the closest Paul could come to being up there with the birds was by building model airplanes. His father encouraged but never instructed him. Paul experimented with planes of all kinds -- setting records and winning prizes. Meanwhile his fascination with birds expanded to include other flying creatures.

PAUL MACCREADY Nature has shown us the great value of flight. For instance, if you're a mouse crawling around through woods at night, you can maybe cover quarter of an acre and you're crawling up and down through muck and swamp and risking you life with snakes and scorpions and so on. Whereas a mouse with wings, the same size, called a bat, can cover maybe 2000 square miles that same night, safely up above all the ground. And it makes flight seem pretty appealing… So it kinds of shows us that we humans who are docilely walking

around on two dimensional flat ground all the time might do a lot more going up in the air and get some of those benefits birds get.

ALAN ALDA (NARRATION) MacCready himself joined the birds as a young man, when he became an avid -- and highly competitive -- sailplane pilot. He was US national soaring champion three times, and in 1956 he became the first American to win the international soaring championship. Today he's invited us to watch Bob Hoey's bird glider with him because it so perfectly captures the philosophy that has guided MacCready for the last half century.

PAUL MACCREADY Humans are part of nature, and we can learn an awful lot about our technological flying devices by looking at nature, first as a role model and then as something to show how to solve some of the big problems.

ALAN ALDA (NARRATION) The problem Bob Hoey set out to solve was how to get his glider to turn.

BOB HOEY The thing that's different about these ailerons and normal ailerons is that they…

ALAN ALDA (NARRATION) Watching real soaring birds, he suspected they somehow employ the feathers on the tips of their wings.

BOB HOEY Now we've learned if we will get a little bit of forward thrust out of these feathers, actually.

ALAN ALDA What does that enable the bird to do?

BOB HOEY It enables him to turn. You see if we put one of them up and one of them down, then it's like an aileron.

PAUL MACCREADY When it gets lift on this wing he also gets a little thrust.

ALAN ALDA (NARRATION) The thrust pushes the wing forward so that the bird can turn as it banks -- with little or no help from the bird's tail.

PAUL MACCREADY This works. And it took nature 200 million years to do it. And it took Bob about two years?

BOB HOEY About one year.

PAUL MACCREADY One year, yeah.

ALAN ALDA (NARRATION) Inspiration from nature, insight from theory and lots and lots of experimentation -- to make something fly that's unlike anything that's ever flown before -- that's the MacCready credo. Oh, and one more thing…

PAUL MACCREADY That bird looked like it was having fun.

ALAN ALDA (NARRATION) For Paul MacCready the fun really began in the mid-1970s. A British businessman, Henry Kremer, was offering a large cash prize to the builder of the first successful human powered airplane -- and MacCready had just taken on a $100,000 debt for a friend.

PAUL MACCREADY I had no interest in human powered flight, but I had heard of the Kremer Prize and I knew it was 50,000 pounds, and when I noticed in the newspaper that at that moment the pound was exactly two dollars, suddenly this light glowed -- why that's the amount of my debt, how exciting human powered airplanes are… and seriously, if I hadn't had that debt there wouldn't have been a Gossamer Condor project. And when I give talks I tell people I strongly recommend they acquire a $100,000 debt to get motivated, and many of them say they have.

ALAN ALDA (NARRATION) The debt may have been the motive, but it was MacCready's love of watching birds that put the Kremer Prize within his grasp. He was on a vacation trip with his three young sons.

PAUL MACCREADY We began really studying different kinds of birds. Because it turns out if you time how long it takes to do a circle and you estimate the bank angle, you can immediately calculate with a simple formula how fast the bird is flying and the size of the turning radius, and how that compares with a hang glider, how does that compare with a sailplane, it provided some insight about scaling laws that suddenly made you realize that the human powered airplane that I was trying to think about became feasible. And if you just simply take a hang glider and make it three times the wing span but keep the weight the same, it cuts the power down to one third and that's down to what a human can put out. And suddenly that was the idea for the Gossamer Condor, which wouldn't have arisen if these birds hadn't been circling around and us making measurements.

ALAN ALDA Did you know when you started watching the birds and measuring their circles that that was going to lead to a human powered airplane?

PAUL MACCREADY No it was just a fun thing to do to keep the kids quiet on a vacation trip. They kept reciting Monty Python skits state after state till you were going out of your mind.

ALAN ALDA You started…let's measure birds now!

ALAN ALDA (NARRATION) Large and light was the lesson from the birds. Paul also realized he could even sacrifice strength for lightness, knowing that the plane's low speed and altitude meant that even a crash would be relatively harmless. Then, in September 1977, just two years after being inspired by the circling birds, Paul MacCready and his Gossamer Condor won the Kremer Prize. His debt was paid off. And a new kind of flying was born.

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THE ETERNAL WING

ALAN ALDA (NARRATION) Dawn in California's Mojave Desert. Almost 20 years after the Gossamer Condor flew into history, its direct descendent is being rolled out for another historic flight. The Pathfinder is a flying wing, powered by the sun. Built by Paul MacCready's company, Aerovironment, the Pathfinder has been prepared for this moment by project manager Bob Curtin.

ALAN ALDA It's very long. How long is this wing?

BOB CURTIN That's a hundred-foot wing span.

ALAN ALDA A hundred feet, and it's all wing, right?

BOB CURTIN That's right. It's all wing, there's no surfaces in back like a normal airplane.

ALAN ALDA Why did you make it all wing?

BOB CURTIN Well it's the optimum shape for something that you need to, to make very light, and collect a lot of solar energy. It happens to be a wing.

ALAN ALDA (NARRATION) Every inch of the wing is covered with wafer-thin solar cells. Even so, there's not exactly power to spare.

ALAN ALDA How much energy are these solar cells collecting?

BOB CURTIN They'll collect at noon about 6,000 watts, which is about four hair dryers' worth of energy.

ALAN ALDA C'mon. Now wait a minute, wait a minute. You fly this 100-foot long wing with the energy that it takes to run four hair dryers?

BOB CURTIN Exactly, four hair dryers.

ALAN ALDA (NARRATION) There's also a small reserve of battery power.

ALAN ALDA Is that how you keep it closed when it's in flight or do you --

BOB CURTIN Well, there will be more tape. There's, there will be tape strips.

ALAN ALDA More tape...

BOB CURTIN That's right, more tape. But you're right, I mean, there is a lot of tape on this airplane.

ALAN ALDA This is the battery?

BOB CURTIN This is the battery pack, it's, it weighs about 40 pounds, and it'll power the airplane for about three or four hours.

ALAN ALDA (NARRATION) Like the Gossamer Condor, the wing owes a debt to MacCready's model building youth.

ALAN ALDA When you look through this transparent material here, it's almost like looking at a model airplane.

BOB CURTIN That's right.

ALAN ALDA There's little struts like something like what I used to carve out of balsa wood when I was a kid.

BOB CURTIN It's very similar to a model airplane. The ribs that form the wing shape that are made out of Styrofoam. They're made out of balsa wood in model airplanes, but very similar.

ALAN ALDA (NARRATION) Hollow Kevlar propellers are driven by high-tech electric motors. Each streamlined cone weighs less than one ounce. The entire plane, with six motors, the battery pack and sixty pounds of solar cells weighs under five hundred pounds. The wing is so large and so light that even taking it out of its hanger is a tricky operation. The team has to keep a constant eye on the wind. The fear is that a sudden gust could snatch the wing into the air.

BOB CURTIN We have a bit of a tail wind right now, so I think we should rotate the airplane around about 180 degrees.

ALAN ALDA (NARRATION) Up until this day in 1995, the Pathfinder had so far flown only at a thousand feet or so. Now the team is preparing for the first high-altitude flight. The motors are now running on the sunlight falling on the wing. Yet it's so light, the engineers have to hold it back. It'll take off, either from the blowing wind or the movement of the plane, at just nineteen miles an hour. Using the sun to power a plane is the sort of outrageous idea that once only a mind like Paul MacCready's could take seriously. But his first such plane, a hybrid running on both human and solar power, successfully crossed the English Channel in the early 1980s. It was a typical MacCready stunt. But by September 1995, the potential of a solar-powered plane had become so great that NASA was paying the bills as the wing was being prepared for its first high altitude flight.

BOB CURTIN We're going to try to fly the airplane as high as it can, as high as it can fly, basically. And as long as weather holds - right now the weather isn't looking very good.

ALAN ALDA (NARRATION) On this day, the winds became dangerously high for the fragile plane. For several days the team rolled the wing out to the lakebed at dawn…

BOB CURTIN So the wind is blowing at about 7 miles an hour; we're at our limit. We don't want it to get much higher than this.

ALAN ALDA (NARRATION) And then they rolled it back to the hanger to wait for the next morning. Finally, with winds no more than five miles an hour, the first high-altitude flight was ready for launch. Of course the wing had no pilot, so it was to be flown remotely from the ground. Takeoff was handled from a nearby chase van.

PILOT Everybody ready?

CO-PILOT I'm ready.

BOB CURTIN I'm ready.

PILOT -- Looks good, go for a throttle up.

PILOT Four and five, on...

ALAN ALDA (NARRATION) At full power in the morning sun, the wing accelerated across the lakebed. The nineteen mile-an-hour lift-off speed was

reached within seconds. PILOTS Main's lifting off. Nose wheel's lifting off. Ten feet. Airspeed's 27. 60 feet. Airspeed hold on at 27. 30 feet per second.

BOB CURTIN Maybe around 600 feet, 5-600 feet right now. It was a good climb out.

ALAN ALDA (NARRATION) As the wing gently spiraled up from the desert floor, it was followed with cameras more used to observing the space shuttle. And that's appropriate, because MacCready's idea is that solar wings, circling at high altitude, can replace many space satellites.

PILOT I wonder if we'll ever see it again.

BOB CURTIN I hope so.

ALAN ALDA (NARRATION) On this flight, the crew's aim was to see how high they could push the Pathfinder.

BOB CURTIN We're at 33,000 feet, things are going well. No serious problems right now. In fact we don't have any problems right now.

ALAN ALDA (NARRATION) They worked from a control room in an old army truck.

BOB CURTIN Now select waypoint 98.

PILOT OK. Waypoint 98.

BOB CURTIN We are heading towards a high wind area at 40,000 feet.

ALAN ALDA (NARRATION) Now came a big hurdle. The wing had never before flown through the strong winds of the jet stream. But the on-board camera showed the flexible structure riding the turbulence beautifully.

PILOT We're going to increase the speed a little bit because we're not doing so well in the climb.

ALAN ALDA (NARRATION) By late afternoon it was clear that because of greater than expected winds they wouldn't make their sixty-five-thousand-feet goal. But it was still a flight that broke the altitude record for solar-powered planes by an enormous forty thousand feet.

BOB CURTIN The sun is going down now. We still have a climb rate so we're climbing. But at some point the sun's going to get low enough that our climb rate

goes to zero. And, and when the climb rate goes to zero, we'll be at our maximum altitude. PILOT There it is, five zero zero zero zero.

BOB CURTIN This is an extraordinary flight; now we've just got to get it home.

ALAN ALDA (NARRATION) They switch to the onboard batteries to bring the plane back in the darkness. Two hours after sunset, and the Pathfinder arrives home.

BOB CURTIN 300 feet. PILOT I guess we're higher than that. PILOT OK, you want to slow down a little...

ALAN ALDA (NARRATION) This 1995 flight showed that a plane powered by the sun could fly high above even the largest and most powerful commercial jetliners. PILOT Beautiful, that's the most beautiful thing I've seen in my life.

ALAN ALDA (NARRATION) But it was only the first step toward Paul MacCready's vision of what his solar wing could become. Five years later, in the fall of 2000, the wing had more than doubled in length to almost 250 ft, while the number of motors had gone from six to fourteen. Now called Helios, the giant flying wing was undergoing low altitude tests for what is intended to be a flight to 100,000 ft -- almost 19 miles high-- in the late spring of 2001.

ALAN ALDA This would fly way above other aircraft. I mean, nobody's going to bump into it because they're all below it. Do I have that right?

PAUL MACCREADY That's pretty much right. This one is slated to do just a demonstration stunt, to see if we can do it, the challenge to get to 100,000 feet, where there's only about one percent as much air density as there is on the ground. But mostly it's aimed at flying at around 65,000 feet because the wind is light enough there so it can stay in one place.

ALAN ALDA (NARRATION) And here we come to the reason why the solar powered wing is much more than a stunt. Circling, like MacCready's favorite birds, high above a city, a flying wing could be an alternative to space satellites for relaying voice or television or Internet signals. Aerovironment's plan is for Helios to circle silently on solar power for as long as six-months. Then one wing would descend as another flies up to take its place.

ALAN ALDA So you would bring it down every six months to make sure that it's in tiptop shape. Is that the main reason?

PAUL MACCREADY Yeah, I'm sure you'd have to replace something. But also every six months you'd probably have better communication gear to put in it. One

of the bad features of satellites is that you put 'em up with today's technology and to get them to be economically viable you have to keep it up for say ten years. In ten years, say the last five of these years, your technology is old fashioned. So here you get a chance to redo it every six months.

ALAN ALDA (NARRATION) Since last fall, Aerovironment engineers have been laboriously testing and applying to the giant wing sections the solar cells that will power the Helios. Since the solar panels will provide power only during daylight hours, the team is also working on a system of fuel cells -- a kind of lightweight and highly efficient battery -- to store daytime electricity and keep the wing flying during the night. In the low altitude flight tests last fall, the Helios was still powered by conventional batteries. But the plane performed flawlessly, experimenting with using its motors to turn and even to pitch up and down. If the method works, the control systems for the wing could be greatly simplified -- another spectacular example of the MacCready credo of more for less.

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EYES IN THE SKY

ALAN ALDA Now what have they got in those cases?

PAUL MACCREADY Well, that's a small surveillance airplane, kind of a nine pound, nine foot, collapsible that we've been making for over ten years now. They get pretty widely used for being a pair of roving eyeglasses wherever you want to see what's over the next hill.

ALAN ALDA (NARRATION) Paul MacCready's fascination with flying began with model airplanes -- and now he makes them for people who want the advantage of a bird's eye view. Called the Pointer, the plane is a typically MacCreadian combination of high and low tech.

ALAN ALDA So this wing is held on only with rubber bands, huh? Why do you do that?

PAUL MACCREADY So they'll pop off.

MARK LEVOE Yeah, it's a safety device. So that if it lands really hard the wing will pop off and not cause any damage.

ALAN ALDA (NARRATION) The idea behind the Pointer is that it can be taken anywhere and be launched and flown by people with only minimal training.

ALAN ALDA How high is it now?

PAUL MACCREADY I'd imagine it's about 250 feet and it's making a little more noise because it's climbing. If it's just cruising along it can go over your head at 50 feet and nobody even notices it because you're not looking up all the time.

ALAN ALDA What is that structure down there that the plane is flying near?

PAUL TRIST That was a movie set for Eddie Murphy's Coming to America and it's the remains of it.

ALAN ALDA So this is a perfect use for the plane. If we were paparazzi now…

PAUL TRIST Correct, correct….

ALAN ALDA And we wanted to spy on Eddie Murphy's house…

PAUL TRIST Yeah, we could look in someone's backyard and they probably wouldn't even know we were there.

ALAN ALDA You now it's great to know that scientific progress is being made like this.

ALAN ALDA (NARRATION) How's this for surreal: gazing down from the California sky at the remains of Eddie Murphy's fictional African movie mansion.

ALAN ALDA Is that it? That's it, isn't it?

PAUL TRIST There it is there.

PAUL MACCREADY Yeah. Alan, maybe we didn't mention it but you are going to do the flying on the next flight, all of it.

ALAN ALDA You're not afraid of that?

PAUL MACCREADY No, though we are making it the last flight of the day, just in case.

ALAN ALDA You know, I have to warn you that I flew a jet in a simulator once, and I crashed it.

ALAN ALDA (NARRATION) I actually crashed the simulated jet when I was trying to land it. At least I shouldn't have that problem with the Pointer, which goes into an automatic landing mode at the touch of a switch.

ALAN ALDA Oh, wait a minute, whoa. I though you were going to hit me with that plane. It looked like it was coming right at us.

PAUL TRIST Yeah it was, but that's about…. We could even get closer if we wanted to. It's just that I didn't want to hit the cameraman.

ALAN ALDA Believe me, that's the least of your worries.

PAUL TRIST OK, we're going to go through a pre-flight check.

ALAN ALDA Clear prop.

PAUL TRIST OK

ALAN ALDA I'm very nervous.

PAUL MACCREADY That makes two of us.

PAUL TRIST So the only thing you have to worry about is that we have a slight crosswind, and you'll probably have to give a little bit of left rudder. So we'll give it full throttle…

ALAN ALDA Full throttle. All the way forward?

PAUL TRIST All the way forward OK.

ALAN ALDA (NARRATION) Here we go. Now, it would be nice to claim that my belly flop was a calculated test of the plane's durability…

ALAN ALDA Oy, it's going down again.

ALAN ALDA (NARRATION) But the truth of course is that I need a little help.

ALAN ALDA It doesn't seem to want to go left.

PAUL TRIST You may have jarred something. It looks OK now.

ALAN ALDA (NARRATION) Looking down from above, it's easy to get lost.

ALAN ALDA I can't tell where I am on the ground.

PAUL TRIST Yeah, well you're coming across right to left now.

ALAN ALDA OK, should I go left a bit more?

PAUL TRIST Yeah, why don't you do that. It's like steering a bus. You've got to kind of anticipate and then let go.

ALAN ALDA OK, there's the structure. I'm going to go right a little bit.

PAUL TRIST Right. So basically you're just steering it. And you'll notice I'm giving you very little input, you're just kind of flying it around.

ALAN ALDA Yeah

ALAN ALDA (NARRATION) Now all I've got to do is land it.

PAUL TRIST Right about now. Let's do it now.

ALAN ALDA Oh.

PAUL TRIST That's fine. There you go.

ALAN ALDA Well. See, I'm good at getting it on the ground. In fact I did that almost immediately!

ALAN ALDA (NARRATION) One of Pointer's biggest users is the US military. It was employed in what are still classified missions during the Gulf War, and here it's beaming back aerial shots during an exercise at Lackland Airforce Base in Texas. Flown with an infrared camera, the plane can easily spot enemy troops at night. Recently the Defense Advanced Research Projects Agency began funding the development of planes even smaller and stealthier than the Pointer. To Paul MacCready, the challenge was irresistible.

PAUL MACCREADY Only weighs a couple of ounces…

ALAN ALDA (NARRATION) Called the Black Widow, this tiny plane is no heavier than the birds it's trying to emulate.

PAUL MACCREADY Nature still with birds and insects does it better than humans, but we're learning a lot from them and we're getting closer all the time.

ALAN ALDA Is this some kind of tracking thing, or is this just for fun? What is that?

PAUL MACCREADY That's the Black Widow.

ALAN ALDA Oh I see.

PAUL MACCREADY That's the insignia that they use -- the logo that nature puts on Black Widow spiders.

MATT KEENNON Throttle check…

ALAN ALDA (NARRATION) Matt Keennon has nursed the Black Widow through most of its development.

MATT KEENNON 3, 2, 1, launch.

ALAN ALDA (NARRATION) But this morning its onboard camera records one of its less impressive flights.

ALAN ALDA What went wrong there?

MATT KEENNON Um, there was a sequencing problem and um -- I'm not quite sure…

ALAN ALDA (NARRATION) Two hours later, Matt figures he's fixed the problem.

ALAN ALDA Is it ready to fly now?

MATT KEENNON It's all ready. Just had a connector come undone, and it's charged, ready to go.

ALAN ALDA (NARRATION) Incredibly, this six-inch wingspan airplane, weighing no more than a slice of bread -- and looking like no airplane I've ever seen -- carries an onboard video camera, three computers, an electric motor and batteries to run it all.

MATT KEENNON Excellent. Install it on the launcher.

ALAN ALDA (NARRATION) It's launched from a compressed air catapult.

MATT KEENNON Cross your fingers. 3,2,1 launch.

PAUL MACCREADY I'm not scared.

ALAN ALDA Oh, that's great.

ALAN ALDA (NARRATION) The batteries on board today limit the flight time to just a few minutes. But with the batteries it will use in the field the plane can fly for over twenty minutes.

ALAN ALDA There we are, there we are.

ALAN ALDA (NARRATION) It's so fast and quiet that an enemy probably wouldn't even notice it, let alone be able to shoot it down.

MATT KEENNON Now can anybody hear it?

ALAN ALDA Just barely. Sounds like a fly.

MATT KEENNON And it's right overhead. So when it's a few hundred yards away you literally cannot hear it.

ALAN ALDA (NARRATION) In combat, the tiny spy plane is disposable. Its mission done, it simply crashes.

MATT KEENNON All right. What you call a belly landing.

ALAN ALDA (NARRATION) But this developmental model will get to fly again.

ALAN ALDA And here is a little fin that came off. Just one.

MATT KEENNON Right.

ALAN ALDA Is the propeller intact?

MATT KEENNON Well, it's a little bit damaged but those are disposable. Again we just pull it off, put on another one.

ALAN ALDA Did you ever think that you'd see this flying like this?

PAUL MACCREADY We never even dreamt such things could exist when we started on this round about three years ago. We didn't dream that it could end up so successful, and if we had imagined it, then we could have leapt to the solution, we would have saved ourselves three years.

MATT KEENNON You have to give Paul a lot of credit. I've been working on this for the last three years but we use his inspiration, his design ideas of evolving a design and trying things and just go out and try it and don't try to analyze the hell out of it. And that helped a lot because this is a very unconventional design we ended up with.

PAUL MACCREADY The pioneering is the exciting part, and somehow at Aerovironment we've accumulated just the most wonderful staff of inventive

people. The problem is to keep everyone from being too inventive or we wouldn't get any work done, we have to keep beating people down saying, no, focus on the project. The people who work here are dynamite.

ALAN ALDA (NARRATION) Aerovionment's inventiveness is now paying off in a plane whose mission is literally out of this world.

ALAN ALDA This could fly on Mars?

CARLOS MIRALES This could fly on Mars, right.

ALAN ALDA How do you know this could fly on Mars?

CARLOS MIRALES Well the atmosphere on Mars is a lot like it is here on Earth at 100,000 feet.

ALAN ALDA So your planes are perfect…

CARLOS MIRALES Our experience is very good for designing airplanes that fly on Mars. This airplane actually folds up, a lot like this little model right here. The wings fold, fuselage folds down like that, and the tail folds down over that to fit inside a small probe which is carried by a spacecraft all the way to Mars. When that probe enters the atmosphere, it will open under a parachute, the airplane will unfold, release the parachute and begin flying along the canyon walls on Mars.

ALAN ALDA (NARRATION) Looking uncannily like a flight on Mars itself, this was actually a test of the plane flying in Red Rock Canyon, in California's Mojave Desert. But within the next decade, the plane could be flying along the walls of the largest known canyon in the solar system, the 2500 mile long, 6 mile deep Valles Marineris on Mars -- giving us a bird's eye view of a place where, as far as we know, birds have never been.

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TAKING TO THE AIR

ALAN ALDA (NARRATION) The pioneers of flying free were the insects… They first took to the air a third of a billion years ago. One of the world's great students of insect flight is George Ruppel. Among his favorite subjects: dragonflies.

GEORGE RUPPEL Here we have caught a large dragonfly, one of the best fliers we have.

ALAN ALDA (NARRATION) And dragonflies not only have powerful wings

GEORGE RUPPEL Always, it will bite me. Ouch.

ALAN ALDA (NARRATION) We met George Ruppel a few years ago in Germany, where this marsh is one of his favorite spots for stalking dragonflies.

ALAN ALDA How do you look for them? Do you scan with your eyes or do you --

GEORGE RUPPEL Yes, I scan with my eyes and then I detect the blue and black bodies.

ALAN ALDA (NARRATION) Like most scientists who study flying creatures, Ruppel employs slow motion photography. But George shoots his movies on location rather than in the laboratory.

ALAN ALDA So what's the idea? Why come out to the pond and shoot? Why don't you take the dragonflies into the laboratory where the conditions are controlled?

GEORGE RUPPEL Yes, controlled, but the dragonflies don't behave normally. They only show here in natural conditions their full behavior. And even their full flight behavior. And therefore we have to go out. Please let, have a look. There is a dragonfly sitting on the stem. I can, I hope, film it.

ALAN ALDA (NARRATION) What fascinates George Ruppel about dragonflies is how they use their flying skills in their everyday life. For example, male and female dragonflies often fly in tandem pairs after they mate. The female has to dip her tail into the water to lay the eggs the male has fertilized. By riding shotgun like this, the male is keeping his rivals at bay. Here one of those rivals switches from hovering flight to full forward thrust in an attempt to dislodge the first male from his mate. A third male briefly joins the dogfight-- and in the confusion the first male gets dunked. The attacker switches to high power backward flight as he pulls away with the female. The aerobatics continue as the new male flips the female into a somersault, apparently expelling the eggs the first male fertilized. Now the newcomer has a chance for fatherhood. Breaking free of both land and water some 350 million years ago, flying insects became the most successful life form on the planet. Flying insects make up 60 percent of all living species known to science-- even if their flying skills sometimes fail them. But how insects came to fly is one of the great mysteries of evolution. Where did wings-- and all the complex muscles and nerves needed to operate them-- come from? As the woods and rivers of eastern Pennsylvania began waking up from their winter deep freeze, we joined biology professor Jim Marden and his student Melissa

Kramer in a hunt for clues to the origins of insect flight. One of these clues lies beneath the water, where many insects begin life as swimming larvae-- like this mayfly.

JIM MARDEN Have you seen him before?

MELISSA KRAMER No.

ALAN ALDA (NARRATION) Its gills beat in the water like miniature oars, and many biologists now see these flapping gills as the forerunners of flapping wings. But that still leaves the thorny question of just how oars became wings. If evolution proceeds in steps, with every step being useful for something, what use is something halfway between an oar and a wing? It's a question Jim Marden now believes he may have answered -- thanks to his love of fly-fishing.

JIM MARDEN Well in fly fishing you're tying some feathers and string on a hook in order to imitate an insect; but that's only half the battle. Because then you have to come out here in the stream and present it to the fish in the right way. And so fly fishing made me a real student of the behavior of insects on water.

ALAN ALDA (NARRATION) And it was while watching insects on water-- especially a group of winged but flightless insects called stoneflies-- that Jim Marden suddenly saw what good a half-wing could be. Stoneflies often emerge from their larval form in the middle of a river, and need to get to shore quickly in order to find a mate. Stoneflies are drab and uninteresting even to most biologists-- unless you're planning an experiment to find out if wings evolved first not to fly in the air, but to skim across the surface of the water.

JIM MARDEN OK, I'll see if we can get one.

ALAN ALDA (NARRATION) Back in the lab, the Pennsylvania State University biologists found their stoneflies to be highly cooperative, behaving in front of a high speed video camera just as they do in the river.

JIM MARDEN Here she is, and we've just dropped her in the water. She's struggling to get free of the surface tension. Here she's raising up and trying to get the tip of her abdomen pulled off the water there. The trick the surface skimming is, we've found, they have to really get up on top of the water. It doesn't work if any of them is touching the water, except their tips of their legs. There. Now she's ready and off she goes. And she's nice and stable and off-screen flapping. You still see her flapping into the shadow. There she goes.

ALAN ALDA (NARRATION) This use of wings to propel an insect across the surface of water is what Jim Marden believes to be the missing link in the

evolution of flight. Most of the experiments to test this hypothesis were run by Melissa Kramer.

MELISSA KRAMER What I'm doing is videotaping these stoneflies surface skimming from above, with a centimeter (inaudible) underneath, so that I can get their velocity. I can measure the time that it takes them to run a certain distance by getting that off of the videotape.

ALAN ALDA (NARRATION) With the slow-motion replay, Melissa can count the number of video frames it takes for the stonefly to skim a certain distance. The insects average about 1 1/2 feet per second. Then she clips the insect's wings with a pair of nail scissors, and measures the speed again. The insects are slower-- but not by much. Now here's the critical test. When she clips the wings to mere nubs-- less than a quarter of their original length-- the stoneflies can still use them to skim around on the surface of the water. So even a nub of a wing-- a wing much too short to allow flight-- can be useful. And completes an evolutionary pathway along which gills could have become oars, oars flapping sails, and flapping sails, wings.

JIM MARDEN Well the Darwinian idea of evolution is a gradual, step-wise process. And so right from the time that Darwin first proposed his ideas, he was attacked on many fronts. One front was how do you get highly complex traits that only work in their full blown and fully integrated form? "What good is a nub of a wing?" is a direct quote from one of Darwin's contemporaries. So one of the things we're out here doing with these stoneflies is showing what nubs of wings really are used for.

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FLAPPING FLIERS

ALAN ALDA (NARRATION) Most of the airplanes Paul MacCready has made in his life owe little to flapping winged insects. But not all.

ALAN ALDA Is this going to flap its wings?

PAUL MACCREADY It will flap and fly beautifully -- unless I bust it while I'm assembling it.

ALAN ALDA How many hours did it take to build this?

PAUL MACCREADY Well, there's a friend builds these, and he lets me have them because he knows I'm going to show them to kids and to people that think like kids. But I need somebody to wind. Let's see, 20 times.

ALAN ALDA So you might be able to get that to come back to you?

PAUL MACCREADY Once it's going right it goes around in circles that are about eight feet in diameter. You can practically fly it in a phone booth.

ALAN ALDA Do you ever expect that a plane that will be used for something will fly this way by flapping? Or is this…

PAUL MACCREADY Passengers on a 747 would really be irritated if it went like that. But it's virtually identical to things I was making in 1939, 1940, and if I hadn't been doing these things then as a hobby, that led to other things, there wouldn't have been a Gossamer Condor, or a 247 foot airplane. So is it practical as a device, no, it's just fun. But as a catalyst for thinking and hands on work and development and inventions it turned out to be hugely valuable. The ones I made were just about like this, but I also made some smaller ones that had much more power and would make noise, prrrr, and you release one behind your teenage sister without her knowing, it just sounds like a bat, and it would terrify her and little boys like to do that.

ALAN ALDA Well that sounds useful.

PAUL MACCREADY Yeah, it has its merits.

ALAN ALDA (NARRATION) For Paul, flapping wings may once have been more entertaining than practical.

PAUL MACCREADY Ah, give it another three or four, what the heck.

ALAN ALDA (NARRATION) But as we'll see in a moment, there are plenty of missions beyond scaring a teenage sibling that a tiny flapping flyer could perhaps one-day take on.

PAUL MACCREADY Now we'll see if this gets a turn. OK. Yeah, that's a little more like it. Of course, if a thermal comes, that's the last this will ever be seen… If it lands in the bush that could be the last it's seen, too. It doesn't get hurt.

ALAN ALDA No. It's OK. It's pollinating the flowers.

PAUL MACCREADY For some reason or other, kids like this. CEOs of billion dollar corporations like it, they all want one. And the fact that they can't have one makes it more appealing to them.

ALAN ALDA (NARRATION) One multi-billion dollar organization that wants a tiny flapping flyer is the defense department. For soldiers fighting in house to house combat, a robot able to scout ahead and peer into rooms could be a lifesaver. Wheeled or tracked robots are already being developed that can carry cameras and other sensors into dangerous environments. But a small flying robot would be faster, more versatile and harder to defeat. The same defense agency sponsoring the Black Widow we saw earlier is also supporting the development of indoor flyers -- including one at Georgia Tech.

ROBERT MICHELSON If you're flying in close quarters you've got to be able to fly slow. If we were to make this same vehicle with a fixed wing, it would have to fly very fast and we'd have difficulty landing and taking off again. Open rotors present a problem because if you touch anything the rotor will literally explode. But a flapping wing is a very robust device. Most people have seen a beetle or a bird that may have gotten into their home and even though they may bounce off the walls, they get up again, shake it off and take off.

ALAN ALDA (NARRATION) This simple wind-up model has the twin flapping wings of the machine Rob Michelson ultimately hopes to build. But like others tackling the same problem -- including Professor Yu-Chong Tai at Caltech in Pasadena -- designers of flapping wing flyers a difficult problem. Making a wind-up flapper -- as Paul MacCready proved almost 70 years ago -- is child's play. But toys like this weigh almost nothing. And even the most miniaturized cameras, sensors and computer controls -- not to mention motors and power supplies -- weigh something -- even if no more than a key.

YU-CHONG TAI So we may run into a dead end. I mean, more weight you require more power, but in order to have more power you have to put more weight. And there is an engineering boundary where we can achieve. And that's where we're exploring. You have to design more efficient wings that would generate the lift to carry the weight.

ALAN ALDA (NARRATION) In their search for more efficient wings, the Caltech researchers have linked up with scientists at UCLA -- hoping to learn the heavy lifting secrets of insects.

UCLA STUDENT This is a cicada wing I'm about to mount. It's one of the larger insect wings. It's also one of the stiffest wings we have.

ALAN ALDA (NARRATION) The UCLA researchers have been flapping a variety of insect wings in a wind tunnel. Strobe lighting and smoke reveal the way air flows around the wings. The idea is to see how insect wings generate lift, and then try to replicate their key features in the lab. Actually making the wings involves the latest in high-tech manufacturing methods. In the sort of super-clean

environment usually used to make microchips, the wing design is photographically transferred to a thin sheet of titanium. The pattern is then placed in an acid bath to etch out the wings' metal skeleton. Finally the skeleton is covered with a thin plastic film. When it came to making the wings fly, the Caltech/UCLA engineers turned to the experience of Paul MacCready's Aerovironment team -- specifically to Matt Keennon, the builder of the Black Widow.

MATT KEENNON That looks fabulous. What's the projected weight for these wings after they're cut out?

CALTECH GUY Perhaps about a few hundred milligrams.

ALAN ALDA (NARRATION) We joined the group one-day in 1999, when the insect-inspired wing was undergoing flight tests… And when it was quickly obvious that insects still know a thing or two that aeronautical engineers don't.

MATT KEENNON 3, 2, 1, launch. It's trying.

YU-CHONG TAI We really like to fly at the end of the project about one minute. And it should fly maybe a couple hundred meters away. So that's what we think we can do. But we still have about one and a half years to go. And this is a very exciting project. We see it can fly now.

ALAN ALDA (NARRATION) Almost-but-not-quite flying is another entry in the flapping wing derby, built by a team at SRI International in Palo Alto. They too know that somehow they've got to find an extra source of lift

DAVID LOEWEN In order to achieve that extra lift we've employed an aerodynamic effect called clap-fling, which is used by insects and birds of various sizes.

ALAN ALDA (NARRATION) In the slow motion effect produced by a strobe light, the wings can be seen folding together and peeling apart.

DAVID LOEWEN As they come together, they're twisting. And as they come together quite closely they actually touch and they squish the air out down, which helps in the generation of lift. And then as they come apart they peel, and this effect is called clap-fling or clap-peel. And when they peel apart you're creating a vacuum in here which forces the air to suck in between the wings. And that is very beneficial. You get on the order of 1.5 to 2 times the lift.

ALAN ALDA (NARRATION) The wings' complex motion may be based on biology, but he gears and wheels and rods that produce the motion aren't. In

nature, muscles both generate and deliver the power to fly, with no need for motors or transmissions. So several teams attempting to make micro-flyers - including the SRI team -- are trying to develop artificial muscles. Most work by contracting or expanding when an electric current is applied. These experimental artificial muscles are still too slow and weak to power a working flying machine, so these flappers are strictly for demonstration only -- including a butterfly made entirely from artificial muscle. So far it hasn't left its perch. Meanwhile, over at Paul MacCready's Aerovironment, Matt Keennon has replaced the insect-inspired wings that looked so promising eighteen months ago in favor of wings that look uncannily like the ones his boss used to make 65 years ago. It may seem unlikely that the MacCready philosophy of testing and tweaking, testing and tweaking, will ever produce a machine that can fly like a bird. But that's what they said about a plane powered by a person.

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WALKALONG GLIDER

ALAN ALDA He's got it. He's got it on his head!

ALAN ALDA (NARRATION) We're going to end our visit with Paul MacCready's flying circus by meeting his son Tyler -- who, with his two brothers, helped build the Gossamer Condor 25 years ago.

TYLER MACCREADY We'd chase it like this for hours.

ALAN ALDA (NARRATION) When they got bored with their father's project, they invented an extraordinary little plane of their own.

TYLER MACCREADY And I can control it by putting the lift on one side of the wing or the other.

ALAN ALDA (NARRATION) They called it their Walkalong Glider.

ALAN ALDA I've never seen anything like that. How old were you when you invented that?

TYLER MACCREADY Oh, 10, 11, 12… something like that.

ALAN ALDA That's amazing. You've got to teach me how to do it. Let me see if I can do it.

TYLER MACCREADY So what you need to do is you need to be moving at a walking speed before you let go of it so that basically you don't throw it, you just let go of it and it's already flying…

ALAN ALDA Excuse me.

TYLER MACCREADY The launch is the most difficult part.

ALAN ALDA (NARRATION) Well, maybe the part right after the launch -- though Tyler is politely encouraging.

TYLER MACCREADY Excellent. You're getting it. Now the second challenge is, what you did there was to get your hands behind which actually puts lift near the trailing edge and that makes it dive.

ALAN ALDA You need to get your hands under it, huh?

TYLER MACCREADY Yeah, it's like a balancing act.

ALAN ALDA You need to get your hands right under it?

TYLER MACCREADY To get your hands just in the right area, so that the lift is lifting the wing.

ALAN ALDA Oh I see, not behind. And this way it keeps the air going up into the wings, so I want to get them like that. I see, I couldn't see that's what you were doing.

TYLER MACCREADY But also if they're too far forward it will stall and slow down.

ALAN ALDA Right.

ALAN ALDA Got it, got it. Had it for a few seconds.

TYLER MACCREADY That was great. Now the next challenge is to get it flying up in front of your face, and you can actually take your hands away.

ALAN ALDA That thing with the head must be very hard to get.

TYLER MACCREADY Did you see how it jumped up as soon as your head got under there?

ALAN ALDA When my head got under it it really picked up.

TYLER MACCREADY Young kids can pick this up pretty quick, because it does involve a bit of balancing, so you have to learn the skill for it. But you did a fantastic job. I was amazed, especially even getting it up on your head some.

ALAN ALDA Well I just got a couple of seconds. But it's amazing to see you control it with your head. It looks almost magical. And the most amazing thing is that you figured this out when you were ten years old. That's incredible. There's all this brainpower that other ten-year-olds must have that we're not making use of.

TYLER MACCREADY Absolutely. All we did…we didn't actually set out to invent something; all we did was keep pushing the limits of what we were capable of doing, which is very common with any kind of child.

ALAN ALDA You were just playing, and it looks like your Dad keeps playing no matter how old he gets.

TYLER MACCREADY And pushing the limits of what his toys are capable of.

ALAN ALDA (NARRATION) Pushing the limits of what his toys are capable of. That's what Paul MacCready has been doing with his toys for over 65 years now. And not just pushing the limits -- often going far beyond the limits of conventional airplane design. Lighter…bigger… slower… higher…smaller… quieter… all the time inspired by his boyhood dream of flying with the birds -- a dream that even at the age of 75, is still very much alive.

PAUL MACCREADY I want to make a stable silent airplane that I can fly around in and look at scenery and have a good time that's as quiet as my car inside and out. And have them fly with the birds would be a delight.

ALAN ALDA (NARRATION) It was in the still air of another early California morning that I came to say goodbye.

ALAN ALDA What are you working on?

PAUL MACCREADY Well, playing with may be more of the right word, though some of these silly things eventually result in something fairly important…

ALAN ALDA (NARRATION) And on this morning what Paul happened to be playing with was a model of the very plane in which, some day, he hopes to fly with the birds.
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