"FLYING HIGH" -
SHOW 603

EPISODE OPEN

ALAN ALDA I've never flown a plane in my life. No problem, they said. With today's automated systems you can land a 747. On this edition of Scientific American Frontiers, we'll find out if they were right.

ALAN ALDA (NARRATION) We'll also meet a bird who's teaching a man how to fly, a sun-powered wing that one day may fly forever, a fisherman learning how life first took off, and some flying robots with minds of their own.

ALAN ALDA I'm Alan Alda. Join me now for "Flying High," our special airborne edition.

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THE ETERNAL WING

ALAN ALDA (NARRATION) Dawn in California's Mojave desert. This is the famous dry lake bed at Edwards Airforce Base. Of the hundreds of experimental aircraft tested here over the years, this has to be the strangest. It's a hundred-foot-long flying wing, powered by the sun. At the edge of the lake bed is NASA's Dryden Research Center. Bob Curtin is the solar wing project manager.

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.

NEWSREEL

NARRATION A plane of unusual interest is demonstrated at Rosemund Dry Lake in the Mojave Desert. It is the latest model of the Northrop Flying Wing...

ALAN ALDA (NARRATION) Forty years ago, the first flying wings were flown from this same lake bed. They've always been the Holy Grail of aircraft design, because lifting only the wing into the air, with no fuselage, offers the ultimate in lightness, speed and efficiency.

NEWSREEL

NARRATION ... up to 100 miles an hour. Now a preview of the flying wing transport of tomorrow...

ALAN ALDA (NARRATION) The cargo or passengers simply travel inside the wing itself.

NEWSREEL

NARRATION ... inside the wing. And future air travelers will really see something. Snug as bugs in their magic carpet, air travel...

ALAN ALDA (NARRATION) It was the high cost of development, rather than technical problems, which led to wings being abandoned in the early fifties.

ALAN ALDA These are little tiny wheels on this. It looks like the wheels that you'd find on a stroller.

BOB CURTIN Exactly. Those, they are baby carriage wheels in fact.

ALAN ALDA They're from that?

BOB CURTIN Yeah, that's right.

ALAN ALDA (NARRATION) The wing combines the ultimate in design with the lightest construction.

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 quest for super-light planes goes back to the seventies, and the vision of this man, Paul MacCready. He was struggling to win the valuable Kremer Prize for human-powered flight. There was a strong incentive -- he was seriously in debt.

PAUL MacCREADY Suddenly this light bulb just glowed over my head. Hey, that prize is just the amount of the debt. How, what a remarkable coincidence.

ALAN ALDA So all you had to do was come up with what they were giving a prize for.

ALAN ALDA (NARRATION) The Gossamer Condor did win. MacCready paid off his debt, and in the process a new kind of flying was born, tailored to very low power.

ALAN ALDA What do you think is the key ingredient here that helped you win that prize?

PAUL MacCREADY Well, the final configuration key is large and light.

ALAN ALDA (NARRATION) MacCready's next plane crossed the English Channel, and then another light bulb went off -- almost literally... Solar power. He realized that because his planes were now so efficient, maybe he could use just the sun to drive them. At first, he added solar cells to a human-powered plane. With this combination, the Solar Challenger also crossed the English Channel. But now his latest vision does away with the human component. MacCready's new idea -- the perpetual airplane, that flies forever. The flying wing is a big step in that direction, but it can't yet carry enough batteries to power it through the night, when the sun doesn't shine.

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) The Pathfinder, as it's called, has so far flown only at a thousand feet or so. Now the team is preparing for the first high-altitude flight. In this test, only three of the six motors are installed. They're running on the sunlight that's now 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. Take-offs are always timed for dawn, when the desert air is at its calmest.

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 lake bed 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 has no pilot, so it will be flown remotely from the ground. Takeoff will be 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 accelerates across the lake bed. The nineteen mile-an-hour lift-off speed is 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 spirals up from the desert floor, it's followed with cameras more used to observing the space shuttle. And that's appropriate, because MacCready's idea is that perpetual solar wings, circling at high altitude, can replace space satellites as platforms for observing the earth.

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

BOB CURTIN I hope so.

ALAN ALDA (NARRATION) Today the crew is going to see how high they can 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'll work 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 comes a big hurdle. They have never before flown the wing through the strong winds of the jet stream. But the on-board camera shows 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's clear that because of greater than expected winds they won't make their sixty-five -thousand-feet goal. But it's still been a flight that's broken 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. The next model will store enough power to stay up here until the sun rises again. We're back on the lake bed, two hours after sunset.

BOB CURTIN 300 feet.

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

ALAN ALDA (NARRATION) MacCready's vision is back on earth. And that's where his thinking stays firmly planted.

PILOT Beautiful, that's the most beautiful thing that I've ever seen in my life.

ALAN ALDA You know I see a theme running through all the work you've done, which is doing more with less. What does that mean to you?

PAUL MacCREADY More with less is an absolutely necessary part of a future world that works. We can't just consume energy, consume materials at the rate we're doing it here in an advanced country, while at the same time there are more people around the earth all the time. And the earth isn't getting any bigger. We have to do more with less, and we can do so much more with less.

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TAKING TO THE AIR

ALAN ALDA (NARRATION) A third of a billion years ago, life on earth took a giant leap-- into the air. And it was never the same again. George Ruppel is one of the world's great students of insect flight. 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 couple of 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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COCKPIT CONFUSION

ALAN ALDA Do you have one started in there now?

ED HUTCHINS Yeah, they're flying in there now.

ALAN ALDA (NARRATION) I'm at NASA's Ames Research Center near San Francisco. Ed Hutchins and I are about to go for a spin.

ALAN ALDA So what does this represent? What kind of plane is this?

ED HUTCHINS This is a 747-400. We're ready to go.

ALAN ALDA Where should I sit here?

ALAN ALDA (NARRATION) Ed's an expert in a subject that affects every airline passenger -- computerized flying.

ALAN ALDA Is it this tight in a real 747?

ED HUTCHINS All of the dimensions are the same.

ALAN ALDA (NARRATION) To see what the computers do, I'm going to try flying this simulator without their help.

ED HUTCHINS When I say rotate you will ease back on this yoke. You'll come back about 3 inches, and that's going to lift the nose of the airplane off the runway. CONTROLLER NASA 2001, the wind is calm, you're clear for take-off.

ALAN ALDA We're moving.

ED HUTCHINS Yes. And there we go, we're going to takeoff thrust. And rotate -- Alan, bring the yoke back.

ALAN ALDA Oh, what, what? Rotate already?

ED HUTCHINS Yeah, rotate already. You're doing fine.

ALAN ALDA Too fast?

ED HUTCHINS No, that's good. Positive rate. Gear coming up. You're doing great. Bring the nose down just a little bit.

ALAN ALDA Oh no. This is making me sick here.

ALAN ALDA (NARRATION) We're still flying, but now here's San Francisco International ahead.

ALAN ALDA God, I, I hope we don't land in the water. I don't like that.

VOICE Sink rate.

ALAN ALDA What, sink rate?

VOICE Pull up.

ALAN ALDA Pull up. Pulling up, pulling up.

VOICE Pull up.

ALAN ALDA Oh, I don't like this.

ED HUTCHINS Now you can see, you've got two runways there. I'll take either one or between them.

ALAN ALDA You mean I've got to look at it by sight and pick the runway?

ED HUTCHINS Yeah. This would be a good time to start thinking about --

VOICE Sink rate. Sink rate. Pull up.

ALAN ALDA I'm pulling up, pulling up.

VOICE Pull up.

ALAN ALDA Pulling up.

VOICE Pull up. Sink rate.

ED HUTCHINS Now push forward a little bit, we've got to get down to it. Good, good. There's the runway. Now just put us on that runway.

ALAN ALDA Oh sure, easy for you to say. I'm too, I'm too far up, I've got to go down. Oh, I'm going down nose first. Oh, I don't... I've got to go down a little more, too, too much... oh, I think I'm crashing.

ED HUTCHINS No, you're on it, you're on it. Perfect. Get the wings --

ALAN ALDA I crashed.

ED HUTCHINS That's, the red means we're dead.

ALAN ALDA We're dead.

ED HUTCHINS Yeah.

ALAN ALDA What did I do wrong?

ALAN ALDA (NARRATION) After a miraculous recovery, we go around again -- this time with all the automation switched on.

ED HUTCHINS We now have the runway in sight, and we're clear to land.

ALAN ALDA At this point I was flopping my wings all over the place.

ED HUTCHINS Yeah.

ALAN ALDA This is, this is nice and smooth here. How close are we?

VOICE Fifty.

ALAN ALDA Fifty, oh thank you.

VOICE Thirty.

ALAN ALDA Aha. I see, it's moving here.

VOICE Ten.

ED HUTCHINS Touch down.

ALAN ALDA (NARRATION) A perfect landing. Modern jet liners are all highly automated. Computers operate the controls, run the engines, navigate the route and make the landing. Overall, these kinds of planes are far safer than the old manual types. But automation brings problems of its own. The crew of this Airbus thought the computer would protect the plane. The computer thought they were landing. When humans don't know what the computer is thinking, it can lead to tragedy. Engineers like John Hansman at M.I.T. call it "mode confusion," and it begins right here with the cockpit instrument displays. This one, from a 747, works fine. The purple line maps the course that the computer will automatically fly -- through these star-shaped waypoints. That's called "navigation mode". Or the pilot can select "heading mode", and have the plane simply fly in a set direction, represented by this dashed line. Mode confusion is possible, but not serious in this case.

JOHN HANSMAN Even if the pilot were to forget that he or she was in heading mode here, it's not a very severe case because once you flew by the turn point or waypoint you would see in the map in front of you that in fact you weren't going the way you thought. So you could very quickly catch that error and correct it.

ALAN ALDA (NARRATION) In contrast, here are the controls for what's called "vertical navigation" -- going up or down. The computer can seek a particular altitude, hold at a given height, or climb or descend at a set rate. But there's no simple visual display of what the plane's doing -- it's all knobs and numbers. In the winter of 1988, it was knobs and numbers that got one of these planes into trouble. An Airbus A320 flew into a mountain on a night approach to Strasbourg, France, with major loss of life. Just before the crash, shifting winds had led controllers to switch the plane from the normal runway to a secondary, which has no electronic landing aids. So now the pilots had to fly a standard procedure called a "non-precision approach."

JOHN HANSMAN In the non-precision approach what you do is you fly level until you reach a certain distance from the airport. And then you basically descend in a series of steps.

ALAN ALDA (NARRATION) The pilots knew that a descent angle of 3.2 degrees would line them up correctly with the steps, clearing the mountains. So now they had to program that angle into the computer.

JOHN HANSMAN The way you would do this would be you would enter 3.2 degrees in the flight control unit by turning this knob we've simulated here, and pulling that knob out.

ALAN ALDA (NARRATION) But the knob does two things. Depending on the position of this button here, it either controls descent angle in degrees, or speed of descent in feet per minute. 3.2 degrees is displayed like this, with a period. But 32 hundred feet per minute is displayed like this. The only difference is the dot. On that night the pilots thought they'd set 3.2 degrees, but in fact had called for a 32 hundred feet per minute descent.

JOHN HANSMAN So they descended at 32 hundred feet per minute, which is a much steeper angle than 3.2 degrees, and descended them basically into the mountain short of the runway. Clearly the flight crew made the mistake. They flew the airplane in the wrong mode and flew the airplane into the ground. On the other hand, this is a case of what we would call poor human factors engineering, in that the same knob and same display was used for those two modes.

ALAN ALDA (NARRATION) After the Strasbourg crash, Airbus improved the display in the A320. But the task of improving communications between pilots and their computers isn't complete. Mode confusion let to the crash of this Indian Airlines Airbus, and incidents of mode confusion are reported with all makes of planes.

JOHN HANSMAN We're on our way towards Boston, and at some point here we're going to have to start to descend to get into Boston.

ALAN ALDA (NARRATION) Here's a typical example. We're heading toward a waypoint called "Milt". It's the town of Milton.

CONTROLLER ASO 1, 2, 3; descend and maintain flight level 190 by Milt.

JOHN HANSMAN OK. The air traffic controllers just told us that we have to descend to 19,000.

ALAN ALDA (NARRATION) John Hansman dials in the new altitude, then tells the computer to stop holding at our cruise height, and start descending at a particular rate. He dials in the rate that will get us down to nineteen thousand at Milt. We start to descend. Here's the altitude dropping through thirty four thousand. So far, so good. But, we're just about to get into trouble.

JOHN HANSMAN This is actually a very rapid descent. In flying terms it's what we call a slam dunk, where the controllers dunked us right down on top of the airport.

ALAN ALDA (NARRATION) As our plane drops down, it naturally speeds up. Here's our speed displayed, as we approach three hundred and thirty miles an hour. Watch what happens. At three thirty the computer reacts. Let's see that again, just as the speed gets up to three thirty. Did you get it? One more time. Watch the box at the top right. As we hit three hundred and thirty miles an hour, the computer automatically goes into high-speed-protect mode. That levels the plane out to keep our speed within the safe range. But now we're going to come in above our assigned altitude, maybe where there's other traffic. And we might not have noticed.

JOHN HANSMAN Most pilots will catch that type of situation very quickly and will in fact anticipate that the airplane would switch modes. The issue really comes in more complicated real world situations, where you're not just sitting looking at the screen, but in fact you're trying, maybe trying to get weather information. You may be dealing with a passenger in the back having a problem. You may have, be worried about fuel or things like that.

ALAN ALDA (NARRATION) John Hansman is developing a new cockpit instrument, to help pilots understand the vertical situation. In the descent to Milt, for instance, his new instrument alerts the pilot that the plane will automatically ease-up in the descent, and that it will be too high when we reach Milt. It's generally agreed that automated cockpits need this kind of vertical display. Compared to the old days, computers have made flying a lot safer. But they've also made being a pilot a different kind of job.

JOHN HANSMAN It used to be that if you were very good and smooth on the stick you, you were a safer pilot. Nowadays safe pilots are pilots who really know how to manage the systems and manage the automation.

ALAN ALDA (NARRATION) Back at NASA Ames, Ed Hutchins is showing me his version of a new vertical display. And it was here during this night simulation that I suddenly understood what an amazing challenge flying is.

ALAN ALDA I've been in the cockpit of a plane once or twice because the pilot invited me up. It was always in the daylight.

ED HUTCHINS Right.

ALAN ALDA And this is the first time I get a sensation of what it must be like for a pilot to fly through this inky darkness. And I realize how totally dependent you are on, on all this information here. There's nothing to, no possible way, is there, to guide yourself visually?

ED HUTCHINS No.

ALAN ALDA (NARRATION) Automation has made flying safer. And to make automation safer, pilots and their computers are learning to understand each other better.

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BIRD MAN

ALAN ALDA (NARRATION) People wanting to fly have long drawn their inspiration from birds. Not that it's done them much good. Only when we swapped flapping wings for fixed ones-- and not always then -- did we finally get off the ground. In the almost 100 years since those earliest flying machines, planes haven't changed much in their basic design. Fixed wings, powerful engines, wheels-- all very un-birdlike. But pilot and biologist Ken Dial continues to look to birds for inspiration.

KEN DIAL What turns me on about flight is that I get to pretend to be a bird at least once in a while. But I realize that I do it in a very stilted fashion and nothing as beautiful and as elaborate as a bird can fly.

ALAN ALDA (NARRATION) To understand better how a bird can fly, Ken watches them closely while they do it-- here in a wind tunnel at the University of Montana. This is a magpie flying at cruising speed-- about 12 miles per hour. A muscle sensor reveals how much energy the bird is using.

KEN DIAL OK, let's give it a little more speed.

ALAN ALDA (NARRATION) When the wind speed is cranked up, the magpie flies faster-- but according to the muscle sensor, with very little extra effort. Even approaching 30 miles an hour-- its maximum speed-- the magpie uses energy with great efficiency. The bird's secret is that it's able to adapt its whole body to the faster flight.

KEN DIAL When the bird's flying very quickly, the tail will pretty much take the form of the body to reduce drag. When it wants to maintain a high speed, it will become horizontal with the air flow. Its feet will go and retract, beautiful, retractable gears underneath the feathers. You'll see that it opens its mouth when it flies faster. We believe that it's actually ramming air down into the respiratory system and blowing up like a balloon.

ALAN ALDA (NARRATION) While birds can fly fast very efficiently... slow flight is much harder work... as the muscle sensor shows. But here again, the bird adjusts its whole body, flaring its tail for extra lift, dropping its feet and steepening its body angle to increase drag. Airplane designers have adopted a few bird tricks-- flaps for extra lift on take offs and landings--a retractable landing gear. But by comparison with a bird's ability to use its whole body, pilots have only a few moving surfaces to work with-- like ailerons for turning. To study how birds turn, Ken Dial's students are setting up a slalom course for pigeons in a corridor of their University of Montana laboratory. The pigeons first have to learn the course. A couple of practice flights, and they skillfully weave between the barriers. Once again the birds are equipped with sensors to see how their muscles perform... And the flight is recorded on slow-motion video.

KEN DIAL One wing beat goes from straight and level to about 120 degree, bang, in one wing beat, which happens in about 100, 120 milliseconds, tenth of a second. In the next wing beat it rights itself. Now that's pretty impressive for a bird as big as a pigeon to be able to turn that fast and recover in two wing beats.

ALAN ALDA (NARRATION) The information he gets from the video and the muscle sensors inspires Ken to don a pair of wings himself.

KEN DIAL If a bird is going to make a left turn, it's going to supinate or increase its angle of attack on the outside wing. And it's going to pronate or decrease the angle of attack on its inside wing. And it would be able to then develop the proper angular momentum to make this turn. What complicates this unfortunately is that it begins all of these twisting actions of the entire wing to make this turn when the wings are fully extended up above the bird's back. And so that now I'm going to make my right turn, I'm going to actually decrease the angle of attack on this wing, increase the angle of attack on this wing. And go through my wing beat to make my right turn.

ALAN ALDA (NARRATION) Recently, Ken Dial has begun literally peering inside his birds as they fly.

KEN DIAL What's interesting this tape (laughter) is first of all you're looking at x-ray. You're looking through the feathers, the skin, and seeing some of the outlines of the muscles. With the retractable gear of his legs really hidden by feathers, and then its neck which is entirely hidden by feathers and skin. We think it's a fabulous area of research to, I'm trying to understand this independent suspension system that birds have. Now watch the head. Watch how it can sit pretty much still in space as the body oscillates up and down, providing the lift and propulsion that this locomotion machinery has to, while the cockpit has to keep literally an eye on where it's going and what's it, its intentions are.

ALAN ALDA (NARRATION) Ken's research is now moving into a third dimension. Pigeons equipped with tape that reflects infrared light fly in front of an array of infrared cameras. The simplified, computer-generated 3-D images of the flight--

along with the X-ray images of flying birds-- will give an unprecedented insight into how birds achieve such mastery of the air.

KEN DIAL I think once we put the feathers on this it's going to move right off the screen.

ALAN ALDA (NARRATION) Ken Dial's research into bird flight leads him right back to what separates birds from airplanes. When plane designers long ago abandoned birds as practical models for human flight, they did so because of one huge advantage rigid planes have over flexible birds: stability

KEN DIAL We're really in a very stable airplane right now. That is I could pull the power, I could let me hands off of the controls, and we won't go spiraling out of control. So here goes the power, here go my hands. Now we're not spiraling out of control; we're about a mile above the ground so I have time to recover if I want to. The power is effectively off right now, I'll pull it a little, even more. And I'm not touching the plane. Now a bird, if he decided to just shut the computer off, that is the controls and the thrust, it would tumble and fall and crash and burn, much like when a hunter shoots a bird, hits it squarely, the computer is out, and so are all the flight surfaces. But now I can go take control of the plane, put in some power, climb back up to altitude, and you can see we didn't go through any great discomfort or any uncontrolled flight.

ALAN ALDA (NARRATION) For most of aviation's history, the un-birdlike but stable airplane has been the only way to fly. But today's newest planes are very different. The X-29 experimental aircraft, for instance, is so unstable that it simply cannot be flown without a computer -- but just like a bird it's extraordinarily agile in the air.

KEN DIAL We're moving into this new arena with fantastic computers, with sensory receptors. With aircraft that are being built inherently unstable, but with computers to keep the upright. Well that's what a bird does but it's got a hundred million, 150 million years head start on them, and I still think we have a tremendous amount to learn from our feathered friends.

ALAN ALDA (NARRATION) It's taken almost a century-- and our most sophisticated technology-- but at last we are learning how to fly like the birds.

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ROBOFLYERS

ALAN ALDA (NARRATION) Dawn in Atlanta. And competitors-- many exhausted from working all night-- are gathering at Georgia Tech for a contest that has never been won. It's a contest between flying robots. Here's the task. With no one at the controls, each robot must take off from one corner of a 60 by 120 ft. field, then find and fly to a ring containing 6 metal disks. Still without human control it must pick up the discs one at a time and carry them over a 3 ft. barrier to a second ring, where the discs are deposited. In five years of competition, no robot has even come close to completing the mission. First on the field this year is a blimp from the Technical University of Berlin, Germany.

ALAN ALDA Have you tried this out on a field back home?

MARION FINKE Yes, but inside.

ALAN ALDA Inside?

MARION FINKE Yeah, it's working very well inside. We still have some problems with the (inaudible).

ALAN ALDA (NARRATION) Like all the robots here, once it starts, it's on its own.

GERMAN STUDENT OK, and we are autonomous.

ALAN ALDA (NARRATION) And at once the Berlin blimp demonstrates why the contest is so difficult-- especially for blimps. Its six battery-powered propellers try hard to steer it toward the ring - but the gentle dawn breeze wafts it away.

ALAN ALDA Has it lost control, do you think it's --

ROB MICHELSON No, not completely.

ALAN ALDA (NARRATION) As Marion dashed off to help rescue her balloon, I sought out the contest organizer, Rob Michelson.

ALAN ALDA What do you think happened there?

ROB MICHELSON They had the props going as hard as they could down, and they were able to catch it before it went into the power lines. But that's the problem with a blimp.

ALAN ALDA (NARRATION) Taking a radically different tack is the next robot. This is the fifth consecutive year the University of Texas at Arlington has entered what amounts to a flying propeller.

ALAN ALDA Just from your previous years' experience, what's it like once you throw the switch and the thing starts to go on its own, you can't do anything? All the work you put into it matters, but you can't do anything at that point.

TEXAS STUDENT 1 This, this year different from the previous years, I'm really, really nervous because this is the closest we've ever been.

ALAN ALDA (NARRATION) The first year of the contest, the Texas tailsitter was one of the few machines even to get off the ground-- briefly. Last year-- after 3 years improving its control systems-- the tailsitter flew beautifully. The problem was still the landing.

JUDGE First thing I need you to (inaudible) show me is how your emergency set up --

ALAN ALDA (NARRATION) This year, the contests' judges are taking no chances.

JUDGE I want to see the emergency set up first thing --

ALAN ALDA He said he wants to see the emergency procedures. I want to see your emergency procedures too. I'll be over here.

ALAN ALDA (NARRATION) What had caught my attention was what looked like a giant inflatable pig. It turned out to be another blimp, this one from the University of British Columbia.

ALAN ALDA Are you about to take off for the first time now?

CANADIAN STUDENT We were flying earlier. What we're going to try is a manual flight just to see that the system is working, which isn't.

ALAN ALDA Do you know what the problem is?

CANADIAN STUDENT No, I don't, engine trouble.

ALAN ALDA (NARRATION) The engine got fixed. But the navigation system-- involving a video camera watching the size and shape of the black spots-- got confused by a glint of sunlight, and the Canadian robot waltzed off the field. Meanwhile, last year's best performer-- a helicopter from the University of Southern California-- was also having a bad morning.

JIM MONTGOMERY We crashed last night about 4 in the morning. It was flying great, things were looking good. We were, we crashed and something mechanically is wrong with it. The craft is not functioning right.

ALAN ALDA (NARRATION) Despite improvised repairs...

JIM MONTGOMERY -- let's reset, start again.

ALAN ALDA (NARRATION) ...and last minute adjustments, the USC 'copter simply couldn't get off the ground.

JIM MONTGOMERY Aagh! Man! You look at this, you know, you think "Gees". You go pick up a disk, you carry it across the barrier and drop it off. That's so simple, what's the problem? But they don't realize that, you know, what's very easy for humans is much more difficult for robots. You have sensing problems, you have to deal with variables such as wind and such and it's not a very trivial problem at all. It just shows you just how flexible and adaptive humans are.

ALAN ALDA (NARRATION) I really liked this little device, designed to pick up the discs when dangling from its helicopter.

TEAM MEMBER Pick it up, and we have --

ALAN ALDA That works really smoothly.

ALAN ALDA (NARRATION) The problem was it wasn't quite so smooth once its helicopter was carrying it. But now the Texas tailsitter was taking off, guided by scanning laser beams. It seemed to be flying very nicely, but made no attempt to go pick up any discs. Everyone seemed very pleased when it landed without toppling over. I was a bit puzzled by all the excitement.

ALAN ALDA What happened?

TEXAS STUDENT 2 That was a completely autonomous flight and we took off, hovered, and landed completely autonomously.

TEXAS STUDENT 3 That's world history for this competition; that's the first time that's ever been done in this competition and I've been here for five years.

TEXAS STUDENT 2 We're pumped now. The next step is a disk.

ALAN ALDA (NARRATION) But now Stanford University was taking the field. These guys looked like pros. And they had a navigation system to prove it, employing the Defense Department's Global Positioning Satellite System.

ALAN ALDA What is that thing over there?

STEVE ROCK That is a GPS antenna. That is our ground station. That GPS antenna sees satellites in the sky and we basically fly to that reference station. We have four of those little antenna on board the helicopter. And the thing that's neat about this is that with this new GPS technology we're able to tell you where each one of these little antenna is to within a centimeter.

ALAN ALDA A centimeter?

STEVE ROCK A centimeter.

ALAN ALDA (NARRATION) Once the helicopter locked on to the satellite...

ANDREW CONWAY The flashing red lights on the back of the helicopter means that everything is working.

ALAN ALDA (NARRATION) The Stanford robot took off without a hitch.

STEVE ROCK This is flying under complete computer control right now.

ALAN ALDA (NARRATION) And unlike the other teams, didn't bother with preliminaries.

ALAN ALDA Are you just going for autonomous flight now? Or are you going to try to go over and get a disk?

STEVE ROCK We're going to try to pick up a disk right now. We're flying the whole trajectory.

ALAN ALDA (NARRATION) To pick up a disc, the machine simply trawls with a magnet.

STEVE ROCK Whoa! We're close. We're going to, he goes into a search pattern so there'd be a little random motion here where we'll try to drag it around, hoping that we'll bump onto a disk.

ALAN ALDA (NARRATION) It looked to me as if the helicopter was flying too low to drag the magnet around the whole circle. I found myself making an acute observation..

ALAN ALDA So the problem here is that you need to make the string shorter.

STEVE ROCK Maybe we need, yeah, high tech solution. (laughter) Make the string a little bit shorter. Whoa, it got one. The robot had finally got a disk-- but then it picked up another one-- and that's against the rules. But the Stanford team still had plenty of time. For the Texas team, though, time was running out-- and their tail-sitter was heading the wrong way.

JUDGE Four minutes guys.

TEXAS STUDENT 1 Think quickly.

ALAN ALDA What are you trying to come up with?

TEXAS STUDENT 1 We're just trying to adjust the gyros as the instruments warm up.

ALAN ALDA (NARRATION) But the drift problem affecting the tailsitter proved unfixable. At least this year, the Texas robot didn't scatter itself across the field. The German team was also coming down to the wire.

ALAN ALDA So you made it up.

MARION FINKE Yes.

ALAN ALDA You got up just barely. You have to be up off the ground before you leave that square, huh?

MARION FINKE Yes.

ALAN ALDA (NARRATION) Sailing serenely-- and autonomously-- the blimp headed in the right direction... Only to overshoot.

ALAN ALDA If it just gets a little calm air it might be able to settle into that - oh no. Outside.

GERMAN STUDENT OK. So we can put it again --

ALAN ALDA 45 seconds left. Watch out! Watch out!

ALAN ALDA (NARRATION) The blimp had begun its day battling the breezes.

ALAN ALDA 20 seconds.

JUDGE You want to get it restarted.

STUDENT Yes.

ALAN ALDA (NARRATION) And it was the breeze that finally defeated it.

MARION FINKE I think one could see that we could manage with a little luck and with less wind.

ALAN ALDA Yeah. Congratulations.

MARION FINKE Thank you.

ALAN ALDA (NARRATION) Another blimp was having similar problems. But this one-- with a distinctly home-made look-- turned out to be the work not of a college team but of students from the Thomas Wooten High School in Rockville, Maryland.

ALAN ALDA When you have school to worry about, how much of your day can you spend on this?

WOOTEN STUDENT Oh, we would spend until midnight a lot. We would spend 5, 6 hours a night on it. And, I mean that bag, everything here is home made. We didn't buy anything, you know, bought.

WOOTEN STUDENT Go that way.

WOOTEN STUDENT I'm going, I'm going.

ALAN ALDA The wind is too strong for you, huh?

WOOTEN STUDENT Yeah, too strong, too strong. Just a slight wind throws everything off for the blimp at least. That's why a lot of these college teams have helicopters.

ALAN ALDA Yeah.

WOOTEN STUDENT And you can see the other two blimps have the same problems we do.

ALAN ALDA Yeah.

ALAN ALDA (NARRATION) Under direct radio control, the high school blimp wasn't even trying to fly autonomously.

ALAN ALDA You're in, you're in.

WOOTEN STUDENT No, OK. Concentration people. It's not working Mr. Best.

ALAN ALDA (NARRATION) But just by being here and flying, the Thomas Wooten students have led the contest organizers to consider a high school version of the contest in the future.

ALAN ALDA What do you think you've learned here?

WOOTEN STUDENT The biggest thing I've learned is that, you know, even though we're a high school team we can overcome whatever challenge we need to overcome. It's amazing. I came here thinking, "Wow, we're out of our league." And coming and see that they have the same problems we do, it, it's, it's kind of a relief, you know?

ALAN ALDA Yeah, yeah. It gives you confidence.

WOOTEN STUDENT Right.

ALAN ALDA (NARRATION) The high schoolers had devised from a cylinder and magnet a clever device for picking up and dropping the discs -- a system that made Stanford's method for snagging discs look primitive.

STANFORD STUDENT How much do we want to shorten the string?

ANDREW CONWAY Oh, about that much.

STANFORD STUDENT About half, about half a meter?

ANDREW CONWAY Yes.

ALAN ALDA (NARRATION) But now that they'd taken my advice and shortened their string, Stanford took off again.

STEVE ROCK Hands off.

ALAN ALDA Oh you've got it, you've got it, you've got it. (applause)

STEVE ROCK OK, let's not get another one. If we can just move it to the center fence we can get points.

ALAN ALDA (NARRATION) The helicopter, all on its own, did everything it could to complete its mission.

STEVE ROCK All right, that's it whew!

ALAN ALDA (NARRATION) But the one thing its designers didn't have time to include was a way to drop the disk once it had reached its target. Ironically, what they'd planned to use was a device using a magnet and a cylinder.

ALAN ALDA Using that cylinder seems to be the way that the high school team solved that problem too.

STEVE ROCK It's almost an identical solution to the high school team; I was looking at that earlier. And they've got a real neat little system and it's the same kind of an idea that we had.

ALAN ALDA Is that as well as that's ever been done?

ROB MICHELSON That's the best it's ever been done in the history of the competition. And if they just had an intelligent device to let go of the dog gone thing, they would have totally completed the mission.

ALAN ALDA (NARRATION) In the final scores, the Texas tailsitter took third place, the Berlin blimp was second, and the Stanford helicopter-- so close to completing the mission-- came in first. Five years ago, the mission seemed impossible. Next year it will probably be achieved. And in the future?

ALAN ALDA Do you think 20 years from now there will be some aerial robot that will be working --

ROB MICHELSON I think so, yes.

ALAN ALDA -- and out there doing something? What do you think it will be doing?

ROB MICHELSON It will probably be doing what we call D-cubed, which is Dull, Dirty and Dangerous jobs. The dull jobs are jobs where you've got to go out and inspect things for hours on end. They're very expensive to put a man in a helicopter to go look for beetle damage in pine trees.

ALAN ALDA Yeah.

ROB MICHELSON But you can send one of these vehicles out and let it fly all day long, taking data, looking for dead pine trees. The dirty part has to do with going into places where you don't want to send a man; say into a, an area like Three Mile Island or Chernobyl to get air samples.

ALAN ALDA Or to rescue somebody.

ROB MICHELSON Or to rescue someone. That's right. And you would never want to do this with a manned vehicle because you'd put two people in jeopardy then if it's a rescue mission. So Dull, Dirty and Dangerous I think embodies the kind of missions that we'll see unmanned aerial vehicles doing in the future.

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