# FUTURISTIC FLOW CON

**For the history of fixed-wing flight, pilots have controlled their aircraft by moving flight control surfaces into or out of the air rushing by their craft. DARPA thinks there's a better way, and with help of aerodynamicists and an X-plane it aims to prove it. Jan Tegler tells the story.**

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# TROL


**Small devices called** sweeping jet actuators appear as red dashes down the center of the vertical tail on Boeing's ecoDemonstrator 757. The flight test was part of NASA's Active Flow Control Enhanced Vertical Tail Flight Experiment.

Boeing

Replacing flaps, rudders, elevators and ailerons with electrodes or other devices to create targeted currents of air could give aircraft designers new flexibility and enhance fuel efficiency. Over the decades, researchers in the U.S. and abroad have tested a variety of such concepts in labs, wind tunnels and cautiously on aircraft.

Now DARPA is searching for a team to build an X-plane that will maneuver primarily with this kind of control.

The program is called CRANE, short for Control of Revolutionary Aircraft with Novel Effectors. Announced by DARPA last August, the goal is to fly a conventionally piloted or unmanned X-plane by fiscal 2024. Later this year, competitors from industry and academia will hear whether they have been selected to participate in a $21 million conceptual design phase. One or two of those winners will be invited to continue working beyond this initial phase, and in 2022 DARPA plans to select a single team to build and fly the X-plane.

The new control technology could empower designers to create aircraft with seamless outer mold lines, meaning without moveable flight control surfaces and the gaps, hinges and rivets that come with them. These create drag, hamper fuel economy and increase the radar cross section.

DARPA doesn't want to push the competitors toward a specific design for the X-plane, however. "I purposely haven't shown cartoons of a nominal airplane because I didn't want people to lock into a picture or concept," says DARPA's Alexander Walan, the aerodynamicist who directs the CRANE program.

**▼ A closeup of the** Magma experimental drone on the runway.
BAE Systems

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As far as the public record shows, no one has flown a full-sized aircraft with one of the new technologies as its primary means of directional control. Doing so in four years will be a big challenge, and Walan says that's the point.

"I would argue that if it had been done, DARPA wouldn't be interested," he says. The word "Revolutionary" in the CRANE name refers partly to the fact that flying without mechanical control surfaces "allows you to think about shapes that aren't necessarily classic aircraft shapes," he adds.

The trick for CRANE will be demonstrating the effectiveness of the new approach in the real world, not just in wind tunnels, on small scale models or in cautiously orchestrated flight tests.

DARPA would not identify the competing teams, but aerodynamicists and engineers affiliated with some competitors agreed to speak to me about technologies that could end up on the X-plane.

### Basic principle

The new approaches have come to be collectively known as active flow control, or AFC, although technically speaking conventional flight control surfaces also perform active flow control. The various technologies distort the flow around the vehicle to achieve control without changing the shape of the vehicle. Fundamentally, the techniques "generate forces and moments that can help maneuver the vehicle," explains Michael Amitay, director of the Center for Flow Physics and Control at Rensselaer Polytechnic Institute, who is on one of the teams.

Consider, for example, how a conventional aircraft performs a roll. Traditionally, that would be done by employing ailerons. Raising an aileron on one wing decreases lift while lowering the aileron on the other increases lift. The difference in lift causes the airplane to roll. "If you want to do that with AFC, on one side you can accelerate flow and on the other side you can decelerate flow," Amitay explains.

With AFC, momentum might be added to the airflow at a specific location on a wing or fuselage by blowing air into the flow out of orifices in the fuselage. Conversely, momentum could be subtracted by sucking air out of the flow. Blowing and suction can also create or shape aerodynamic wakes that Amitay describes as virtual control surfaces.

"On one wing you blow a jet of air that moves the wake downward," Amitay says. "On the other side you blow a jet to move the wake upward — virtual ailerons."

Blowing can create virtual elevators and flaps too. If the wings have rounded trailing edges, air will follow their curvature, a tendency known as the Coanda Effect. Blow air over the top of a rounded trailing edge and you create a downward wake. Blow

air from below and you create an upward wake. The wakes can change the pitch of an aircraft, raising or lowering its nose just as flaps and elevators do.

Left or right yaw motion, produced by rudders on conventional aircraft, is harder to create with AFC, but it can be done by vectoring the thrust of an engine. “Picture exhaust gases coming out from a jet engine,” Amitay says. “You can blow or pull the exhaust gas to one side or the other side and manipulate it.”

Imagine a plane flying at an angle steep enough to cause the air flowing over it to separate from its wings or body. This can lead to a stall, but “if you can activate something that is a local disturbance, like a jet of air that adds momentum, that can cause the flow to reattach. That’s active flow control,” Amitay says.

Also, air flowing around a vehicle exhibits variations in density, pressure, velocity and temperature.

▲ **Tufts to indicate wind** flow are attached to the surface of a full-sized tail from a 757 commercial aircraft that has been equipped with tiny jets called “sweeping jet actuators” that blow air across the rudder surfaces.

NASA

Engineers are learning to tap these instabilities with their AFC technology. “We can change lift and drag significantly by amplifying or diminishing natural instabilities,” says aerospace engineer Mo Samimy of Ohio State University’s Aerospace Research Center, which is also part of a team proposing for CRANE.

An example would be the transition from laminar flow to turbulent flow caused by instabilities. An aircraft might trigger or suppress this transition with synthetic jets, depending on what the pilot wants the aircraft to do. Suppressing instabilities on one wing, but not the other, would induce a roll or cause the nose to rise, depending on the combination of jets that were fired, says Matthew McCrink, a colleague of Samimy’s and a research scientist at Ohio State.

### The options

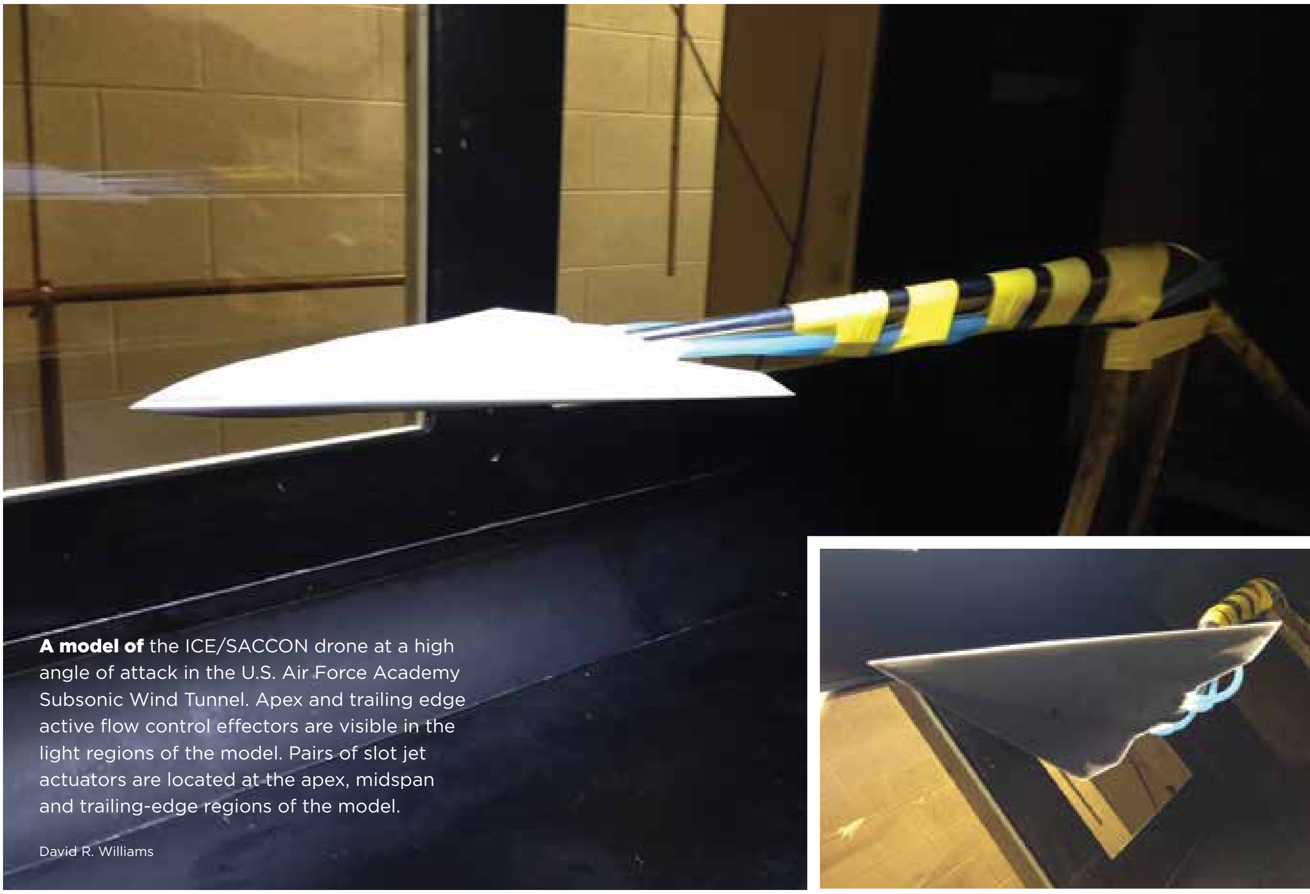
Fluidic oscillators are one kind of active flow control actuator. Small quantities of air are funneled internally from the aircraft’s engines to orifices — slots, trapezoids or other shapes — in a process known as bleed air extraction. This air is injected into the flow at various locations on an aircraft.

Two separate teams of researchers within the NATO Applied Vehicle Technology Task Group tested this technique on experimental drones for directional control. In 2018, Lockheed Martin Skunk Works flew a drone called ICE, short for Innovative Control Effectors. Last year, BAE Systems and the University of Manchester flew its Magma drone. Each blew air through slots in the trailing edges of their wings to maneuver. Magma also blew air into its engine exhaust nozzle from small jets to vector thrust for maneuvering.

The only full-sized aircraft known to have tested modern AFC was the Boeing-NASA ecoDemonstrator 757 that was flown in 2015. Devices called sweeping jets blew compressed air from the auxiliary power unit in the rear of the fuselage in arcs across the plane’s vertical tail in an attempt to improve aerodynamic efficiency. “You have steady air coming into these orifices that are shaped almost like a trapezoid. They’re designed in a way that it causes the flow to move side to side at high frequency, sweeping a larger area than a steady jet will, and that makes it more efficient,” Amitay says.

The concept is similar to the windshield fluid nozzles on cars, says Jim Gregory, director of Ohio State University’s Aerospace Research Center. “Instead of emitting a steady stream, they spread the fluid out over a much wider area. We can use the exact same geometry and apply that to flow on an aircraft.”

Then there are synthetic jets, so called because they create streams of air artificially with electronics, rather than with air bled from an engine or another source of compressed air. The design details vary, but millimeter-wide holes would be arrayed



**A model of** the ICE/SACCON drone at a high angle of attack in the U.S. Air Force Academy Subsonic Wind Tunnel. Apex and trailing edge active flow control effectors are visible in the light regions of the model. Pairs of slot jet actuators are located at the apex, midspan and trailing-edge regions of the model.

David R. Williams

on the surface of the aircraft, and those holes open into centimeter-wide cavities, each with a thin metallic diaphragm at the bottom. Voltage can be turned on and off rapidly to each diaphragm, or in some designs the polarity can be reversed. This makes the diaphragm oscillate inward and outward. When the diaphragm shifts inward, the vacuum effect draws air in through the hole, and when it shifts outward, air is expelled into the flow. "These really do work almost exactly like your lungs and diaphragm," says McCrink of Ohio State.

Yet another option are plasma actuators that discharge pulses of electricity into the air through electrodes. Heat from the electricity turns the air into plasma that interacts with the instabilities in the flow. "We generate perturbations with [the] right frequency range and let the instabilities amplify the perturbations so that we can manipulate the flow and change it the way we desire," explains Samimy of Ohio State in an email. He has been experimenting with two types of plasma actuator, one that pulses up to 20,000 times a second and another that pulses up 200,000 times a second. "Higher frequency doesn't mean it's better," he cautions.

**"Initially we tried using as many actuators as we could. One of the Boeing people asked what happens if one of the [actuator] jets fails in flight? So we turned every-other jet off and performance went up! This knowledge helped us minimize the number of jets and save power."**

— Michael Amitay, Rensselaer Polytechnic Institute

### Time to fly

DARPA believes the time is right for the boldest AFC test yet.


▲ **An engineer braces** himself against strong winds inside the National Full-Scale Aerodynamic Complex at NASA's Ames Research Center in California. He is holding a wand emitting smoke to visualize "in flight" air flow across the tail the full-sized airliner tail.

NASA

Researchers have managed to create AFC actuators that require less electricity or bleed air to achieve the same effects. "You simply could not integrate an AFC system onto most aircraft when you're using 10% [of available aircraft electricity or bleed-air]," notes Daniel Miller, senior fellow for Air Vehicle Systems and Sciences at Skunk Works. "As we're now looking at 1%, things are starting to snap into place quite nicely."

Amitay of Rensselaer recalled his participation in the Boeing-NASA ecoDemonstrator project: "Initially we tried using as many actuators as we could," he says. "One of the Boeing people asked what happens if one of the [actuator] jets fails in flight? So we turned every-other jet off and performance went up! This knowledge helped us minimize the number of jets and save power."

The newest techniques for AFC, including synthetic jets and plasma actuators, have only been tested in wind tunnels or computer simulations. AFC enabled by bleed-air extraction has flown but only on relatively small unmanned aircraft. Researchers don't yet know how effective AFC will be when incorporated on larger aircraft that must fly with a range of aerodynamic loads in varying atmospheric and electromagnetic conditions.

Samimy notes that electromagnetic interference from plasma actuators could interfere with aircraft electronics and that heat, cold, rain, ice or snow can affect the orifices that most actuators employ.

With these and other challenges to be overcome, Walan acknowledges that a CRANE X-plane might only demonstrate AFC in specific portions of the vehicle's flight envelope. "Some of the potential benefits of AFC on a tailless airplane, for example, might be significantly reduced takeoff or landing roll. That might be part of a demonstration. Or perhaps someone wants to do a combat drone approach at a higher Mach number. They may have conventional surfaces for takeoff and landing and use AFC to enhance maneuverability up and away."

Miller of Skunk Works says an attention grabber would be "something done on a next-generation tailless platform demonstrating appropriate levels of directional control power in a mission scenario."

The prospect of a tailless aircraft with a seamless outer mold line and its stealthy advantages are never far from a conversation about the CRANE program. But Miller points to the importance of redundant flight control systems for a demonstration's flight safety. "My feeling is that AFC will provide

the directional control power but you'll have on board some kind of redundant conventional flight control system present for a back-up mode."

He adds that efficient actuators paired with sensors and control algorithms capable of managing their operation will be needed to create designs that incorporate AFC for full-spectrum maneuvering.

Walan describes this challenge as closing the flight control loop, and he says more work lies ahead to achieve that. "Every time you deflect a traditional control surface 2 degrees it always has the same effect and we have decades of experience with them," he notes. "With AFC, if you have multiple controllers, the order in which you turn those on and off, and the flight conditions — there's a lot more variability,"

DARPA has stressed the use of existing subsystems such engines, wheels, and brakes to simplify the design of an AFC X-plane, noting that the 2024 first-flight goal doesn't leave much time to invent new ideas or refine actuators. Walan suspects the X-plane will be subsonic due to the complexities of shock waves that come with supersonic flight.

Ohio State's McCrink concludes that the expression "DARPA hard" applies to CRANE and active flow control but says it's the "right type" of ambition. "If you shoot the moon on this one, I think you'll hit it." ★

▲ **The Magma** experimental drone flies with a type of active flow control called fluidic oscillators.

BAE Systems