De-icing with nanotubes

U.S. military drones were rushed into service during the wars in Iraq and Afghanistan, sometimes with known technical compromises, one of them being a lack of in-flight d -icing equipment. Michael Peck spoke to scientists who say they have an "elegant" solution.

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In Battelle's HeatCoat system, a thin layer of carbon nanotubes thaws ice on the wings of unmanned aircraft, as shown in this rendering.

The U.S. Air Force's MQ-9 Reapers, the terror of the Taliban, are vulnerable to an unlikely foe: Frozen water. In fact, the Air Force advises Reaper pilots in ground control stations to avoid steering the planes into icing conditions "to the maximum extent possible." The service's RQ-4 Global Hawks, which eavesdrop and take images from high altitudes, also cannot shed ice. It's not just an Air Force problem. The Army's RQ-7 Shadow tactical intelligence drones aren't equipped for de-icing, either.

Among those vying to potentially retrofit these and other military drones with de-icing technology are the materials scientists at Battelle, a private, nonprofit research organization in Columbus, Ohio. Battelle wants to coat the most vulnerable areas of airframes with carbon-nanotube molecules and heat them to melt ice. Lots of lab and wind tunnel work lies ahead toward flight tests planned for 2018. If all goes as Battelle hopes, a frustrating constraint for commanders and drone operators could be lifted.

Innovating with nanotubes

Weight is the first enemy for any technologist working on drones. As the Air Force told the industry in December, the Reaper "is operated with zero excess power and weight for stores. Whenever anything is added to the platform, something must be removed (i.e., fuel, sensors, stores)." The Air Force is open to ideas, but it's safe to say that proposals to sacrifice cameras, computers, missiles or fuel would not go over well.

Nanotubes are lightweight, but their possible role as a de-icing solution for drones wasn't immediately obvious.

"This story starts in the way that it is often not recommended to do product development," jokes Amy Heintz, the Battelle materials scientist who conceived HeatCoat and in May received an award as Battelle's 2015 Inventor of the Year.

Rather than waiting for a requirement from the Pentagon, as is often done, Battelle developed HeatCoat on its own about 11 years ago, after the organization began delving into the emerging technology of carbon nanotubes. While looking for potential applications, it occurred to Heintz that nanotubes, which have a diameter 10,000 times narrower than a human hair, could be used to de-ice aircraft.

These carbon molecules can form corrosion-resistant materials stronger than steel, but most important for Heintz was their remarkable thermal conductivity, which meant they could convey heat to surfaces vulnerable to icing.

Heintz originally envisioned HeatCoat as a de-icer for commuter aircraft, but in 2006 she concluded that there was more of a demand for de-icing unmanned aircraft, and there would be fewer regulatory hurdles to fielding the technology. Indeed, Battelle started receiving research dollars in 2010 from several Air Force unmanned aircraft program offices.

No moving parts

Engineers and scientists refer to an efficient design as elegant, and the de-icing systems that Battelle saw on the market were anything but.

"We knew a lot of the systems being used had a lot of moving parts, had poor reliability, and people didn't want to use them," Heintz explains.

She and her colleagues got to work designing a system that would eliminate moving parts.

Placing de-icing gear on the surface of an aircraft, especially the wings, is usually a nonstarter, because anything protruding into the air flow could rob lift and create drag. Heintz reasoned that lightweight connectors could feed power to heating wires (similar to those in a toaster or baseboard heater) that could be installed under the skin of a drone. These would radiate heat to nanotubes applied as a layer of paint or film. The nanotube layer would have to be thin enough that aerodynamic effects would be minimal and light enough that nothing would have to be removed to compensate.

The next question was how to suspend nanotubes in a paint so that they would conduct heat effectively. It would not be easy. "Nanotubes are just like carbon soot," Heintz says. "Imagine taking carbon soot and putting it in water."

The soot wants to clump up, but the microscopic tubes must be evenly dispersed and they must be close to each other. "We knew that the junctions between the CNTs [carbon nanotubes] and the spacing between the junctions were the limiting factor for the conductivity, so we sought to minimize these junctions and achieve tight connections," Heintz says.

The solution was to mix the nanotubes with a dispersing agent to maintain the right concentration.

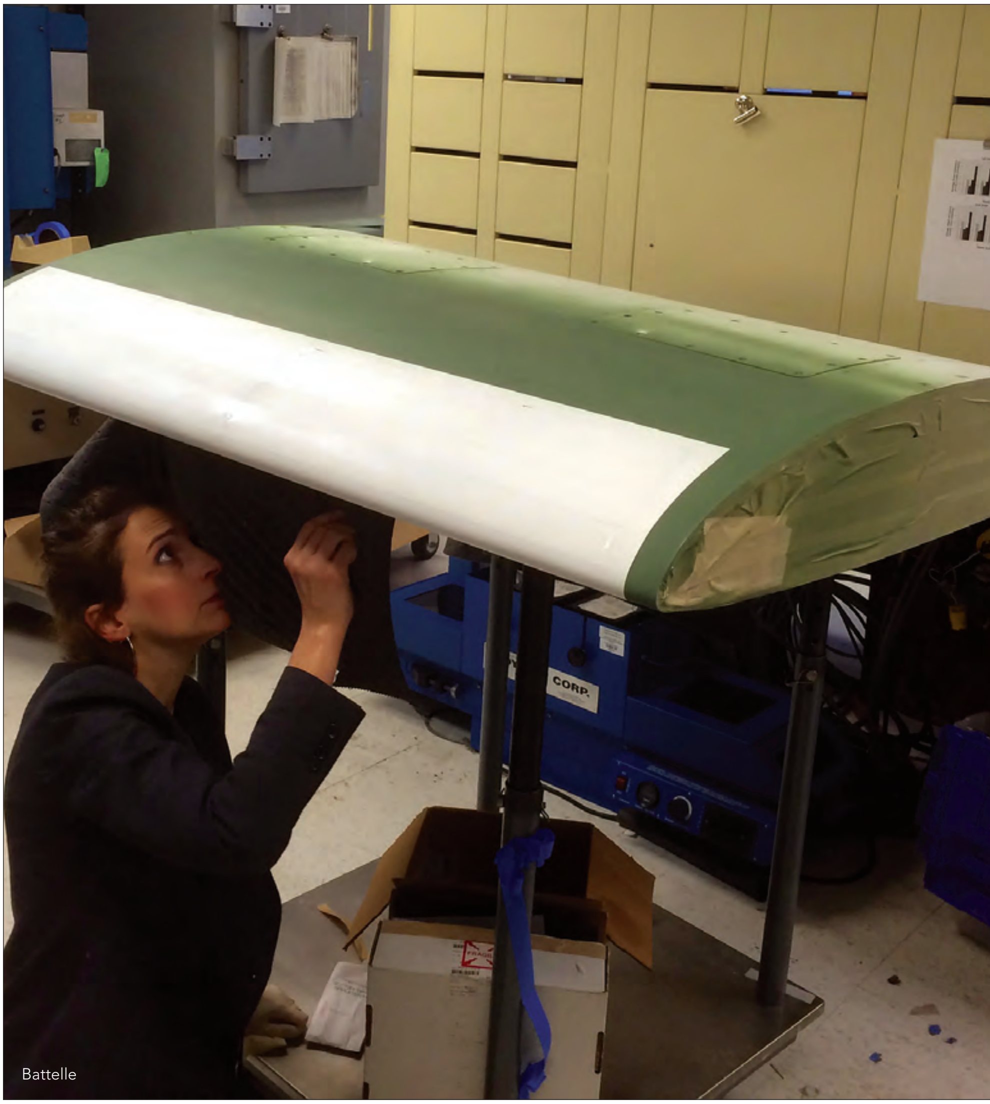
"The total thickness of the coating stackup applied to the aircraft surface is less than 0.51 millimeters, including the original paint layers," says HeatCoat Program Manager Brett Burton, who co-developed the technology with Heintz.

Battelle's HeatCoat brochure shows a plane retrofitted with a five-layer surface. At the bottom is the aircraft's skin, then the regular primer. On top of the primer is the layer of nanotubes, and then a barrier coating of commercial paint is applied to keep moisture out, and a top coating of regular paint is applied. Small electrical leads affixed to the surface of the aircraft are hooked through pass-through connectors to the aircraft's existing wiring system.

Another hurdle was power consumption.

"If you were to take that watts per square inch and multiply it over the whole aircraft surface, you would find that you need way too much power," Heintz says.

Materials scientist Amy Heintz examines a layer of conductive coating applied on a wing for de-icing.



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The team conceived of a solution. The nanotube material would be applied only on locations that are vulnerable to icing, and they would not conduct heat all the time.

A control and sensor system on board the aircraft would detect weather conditions that could create icing. Nanotube heating elements on the wings, engine inlet and tail would be cycled on and off as a preventive measure (HeatCoat will eventually include ice sensors for even more precise heating).

"The heaters are applied as an array, with multiple individual heaters situated along the leading edges of the wings, engine inlets, and tails as required," Burton says.

Enough heat would need to be conducted to melt the ice, but not so much as to cause wear or damage the surface. HeatCoat applies just the appropriate amount of power depending on the weather.

Battelle employees attach an alignment drill jig to a wing section in an engineering lab in Columbus, Ohio. Holes were drilled to run wires to carry current to melt ice.

Real-world considerations

HeatCoat's designers needed to keep in mind that the technology would have to be retrofitted to existing aircraft and serviced by military personnel.

"Have we affected how they do routine maintenance? People don't want to have to do anything differently," Heintz says. Rather than stripping the aircraft and removing the primer, HeatCoat will be applied by removing the top coat of paint, putting down the nanotube paint and barrier layer, and then reapplying the top coat.

Mindful that other de-icing products are on the market, Heintz's team resolved to show "as fast as we could" that the HeatCoat concept worked.

"It was a challenge to think a little bit differently; to not solve every problem and risk we thought might be there, but to push it through as a beta test, so to speak," Heintz recalls.

The gamble paid off. In 2009, Battelle tested a small HeatCoat-equipped airfoil in United Technologies Corp.'s Goodrich icing tunnel. The team met its goal of showing that the air foil could be de-iced to FAA standards for light and moderate icing and within the power budget of the Army's Shadow. After that, Battelle received HeatCoat funding from several Air Force program offi es.

Heintz's team is still refining HeatCoat, including how to efficiently manufacture the nanotube components. There are also discussions with manufacturers about applying the technology to manned aircraft, though there is not yet any experimentation along those lines.

Battelle declines to say which Air Force offices are funding HeatCoat, but the company's HeatCoat brochure is printed with a drawing of a drone firing a missile. The drone looks remarkably like an MQ-9 Reaper.

Michael Peck
michael.peck1@gmail.com
@Mipeck1