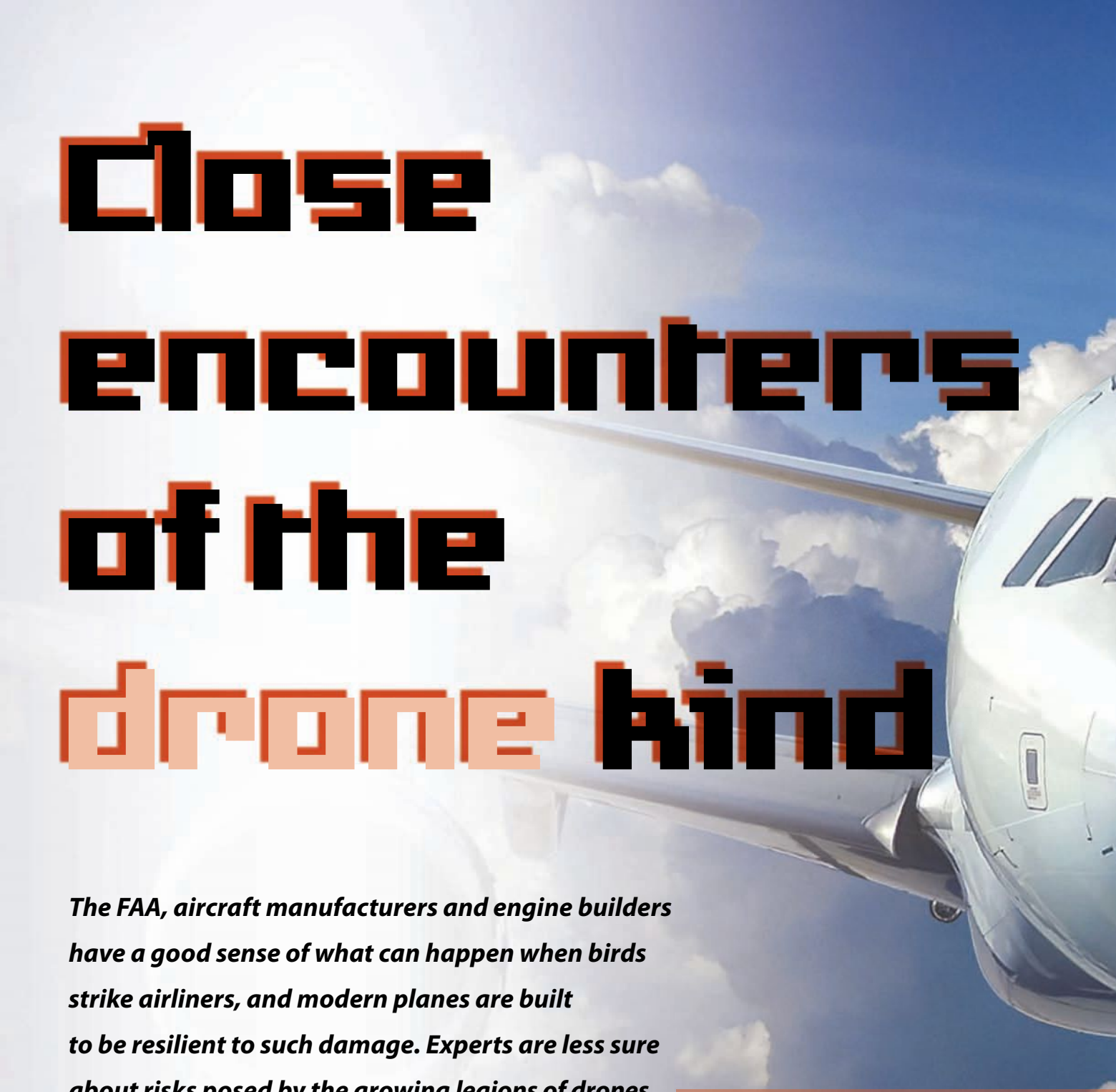
Close encounters of the drone kind



The FAA, aircraft manufacturers and engine builders have a good sense of what can happen when birds strike airliners, and modern planes are built to be resilient to such damage. Experts are less sure about risks posed by the growing legions of drones. Michael Peck spoke to researchers who are trying to answer that question.

When a 4-meter-long Shadow drone tore into a C-130 cargo plane in Afghanistan in 2011, online photos of the damage stirred lots of commentary about the risks drones might someday pose to airliners in civilian skies. The Shadow tore a ragged hole in the leading edge of the military plane's left wing. The C-130 landed safely at Bagram Airfield, but the photos published by the sUAS News website made it easy to wonder whether airliners, which store fuel in their wings, would be so lucky.

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Photo illustration by Jane Fitzgerald

The answer is that no one knows for sure. The FAA requires tests to ensure that airliners can land safely after striking foreign objects, especially birds and ice. The FAA says it will be conducting tests beginning next year to assess the effects of unmanned aircraft hitting commercial aircraft or being ingested by their engines.

That question, largely an academic one in 2011, has taken on a new urgency with today's growing horde of hobbyist-controlled quadcopters soon to be joined by the first fleets of commercial cargo drones such as those planned by Amazon.

Until now, the FAA and researchers at NASA have handled the risk to airliners mostly by focusing on technologies for averting collisions. Sense-and-avoid technology is in development that would enable unmanned planes to detect and get out of the way of commercial aircraft. A different approach, called geofencing, is favored by Chinese drone manufacturer DJI in its popular Phantom line of small quadcopters. Software installed on the drone bars it from entering a specific GPS-defined zone, such as the area surrounding airports.

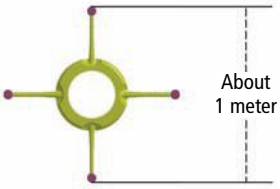
MODELING DRONE INGESTION

Researchers at Virginia Tech are using finite element modeling to predict the results of collisions between small drones and airliners. The sequence to the right models the effects on an engine with a titanium alloy casing. Researchers are now investigating composite casings.

1.5 milliseconds

The quadcopter impacts a fan blade on the right side of the engine; imbalance forces the blades into contact with the casing, creating stress indicated by the green.

A 5-kilogram quadcopter shown to scale with a jet engine.



Graphic: Modeling by Ph.D. students Yangkun Song and Kevin Schroeder of Virginia Tech's Crashworthiness for Aerospace Structures and Hybrids lab.

The damage to a C-130 transport plane after a collision with a Shadow drone in Afghanistan.

sUAS News

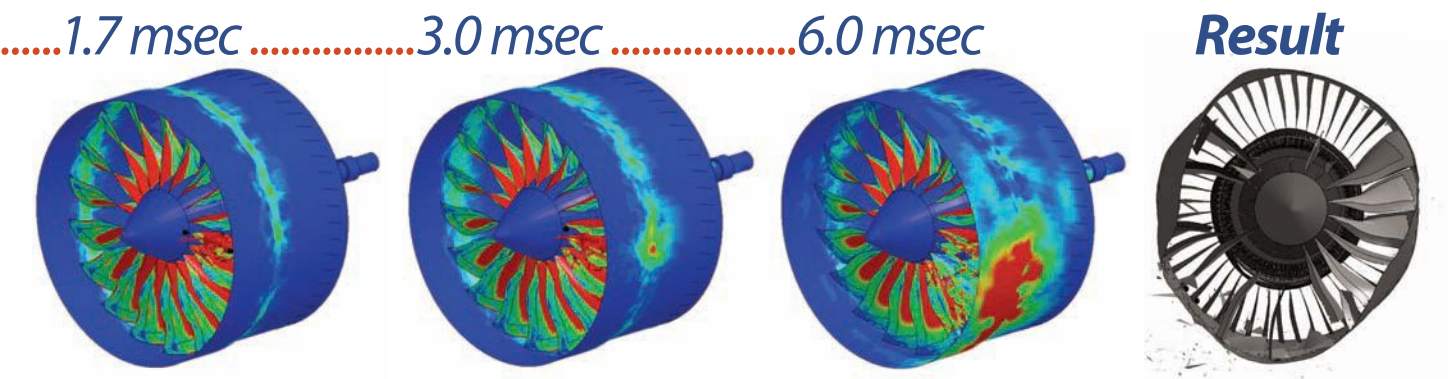
But what if all that technology fails — or if a bad actor decides to "jail break" the technology, aiming a drone or swarm of drones on a collision course with a passenger jet? Researchers are anxious to find out exactly how vulnerable planes might be.

When it comes to collisions, size matters. Most of the planes in the coming commercial drone revolution — a market that could soar to $1.9 billion by 2020, according to the firm MarketsandMarkets — are expected to be smaller than the 200-kilogram-class Shadow implicated in the 2011 collision. In July, for instance, a 5.9 kilogram quadcopter from the Australian company Flirtey made the first FAA-authorized, unmanned cargo flight by delivering 4.5 kilograms of medicine to rural Virginia. Airliners are not as rugged as military planes, and designers are beginning to incorporate new hybrid materials, which are combinations of metals and composites. This raises questions about whether those small drones might turn out to be just as potentially dangerous as the larger Shadow.

At Virginia Tech in Blacksburg, researchers are using finite-element-models of drones and aircraft to predict what could happen when small drones collide with airliners or are ingested by their engines. The models are eye opening. "If a drone hits a plane at takeoff, [the results] could be quite severe," says Javid Bayandor, director of Virginia Tech's CRASH Lab, short for Crashworthiness for Aerospace Structures and Hybrids. Bayandor founded the lab in 2012 to contribute to the design and certification of new aircraft and spacecraft through analysis.

In theory, this wave of drones shouldn't be a problem. To qualify as a model aircraft, and thus avoid the need for FAA certification, an unmanned aircraft must fly below 400 feet, stay at least 8 kilometers from an airport, and it cannot be flown for commercial purposes.

In reality, drones are sometimes flown commercially and hobby craft at times stray into airspace near airports because of technical malfunctions or pilot error. Today's quadcopters are typically flown by amateur enthusiasts with little training and no certification, unlike the case of the Shadow near



The remaining half of the quadcopter is ingested and is struck by a second blade; stress increases as parts of the blade hit the casing; loss of blade mass exacerbates the imbalance and stress.

Damage spreads to a third blade; the imbalance worsens; pieces of the drone are now impacting the casing.

The quadcopter is obliterated; three fan blades are catastrophically damaged; the remaining blades contact the casing; stress grows, shown in red, but the casing holds.

The titanium-alloy casing is significantly deformed.

Bagram Airfield, which presumably was flown by a well-trained soldier.

"Anyone can go on Amazon.com and buy a small quad or aircraft, and then decide they want to fly it near the airport," says Vince Pujalte, who heads the unmanned aircraft program at Embry-Riddle Aeronautical University in Prescott, Arizona. "The greatest concern should be on landing and takeoff."

There have been reports of numerous near-misses between small drones and manned aircraft. A Washington Post story in August detailed a dozen FAA-reported incidents — in a single day — of drones either flying too close to civilian and military planes, or too near airports.

Birds versus drones

Drones are often made of relatively soft materials compared to conventional planes, but they are not as soft as birds, which are notable for their delicate skeletons. Do-it-yourself websites show how to make drones out of plywood, fiberboard and only a bit of aluminum. Drones contain some heavier components, the densest and most potentially damaging parts being their battery packs and engines. Bayandor, for instance, is concerned that batteries could explode on impact. Masses of drones can be similar to birds: A quadcopter weighs about 1.4 kilograms, while the largest gull — the most common culprit in bird strikes, according to an FAA database — weighs about 1.8 kilograms. Canada geese are another threat, because they tend to gather and fly in flocks, and an individual specimen can weigh as much as 6 kilograms, according to the hunting and conservation website, ducks.org.

Birds are soft, but still a hazard. The Wright Brothers ran into a flock in 1905. The most famous recent incident was the US Airways "Miracle on the Hudson" case of 2009. Both engines on an Airbus A320 flamed out after ingesting geese at about 2,000 feet, forcing the pilot to make an emergency landing

A red-tailed hawk penetrated the wing of a Boeing 747 after the jet touched down at the Dallas/Fort Worth International Airport in February 2013.

Cathy Boyles, Dallas/Fort Worth International Airport

A plane taking off from Canandaigua, New York, disturbs a flock of birds. According to a 2014 FAA report, wildlife strikes have killed more than 255 people and destroyed over 243 aircraft around the world between 1988 and 2013.

When birds and airplanes collide

Between 1990 and 2013, 138,257 strikes between wildlife (mainly birds) and civil aircraft were reported in the U.S., nearly 10 percent of which resulted in damage.

Aircraft components hit

	Number of cases	Percentage of total
1. Windshield	20,302	16 percent
2. Nose	17,654	14 percent
3. Wing/rotor	16,743	14 percent
4. Engine(s)	15,814	13 percent
5. Radome	15,415	13 percent

Aircraft components damaged

1. Engine(s)	4,321	29 percent
2. Wing/rotor	3,508	24 percent
3. Radome	1,433	10 percent
4. Other	1,156	8 percent
5. Windshield	926	6 percent

The identity of the bird species or species group is known in about half of the strikes.

Strikes by bird species

1. Mourning dove	6,124
2. American kestrel	3,593
3. Killdeer	3,369
4. European starling	3,348
5. Barn swallow	2,863

Source: FAA National Wildlife Strike Database Serial Report Number 20, July 2014

on the river by Manhattan, miraculously without serious injuries or deaths. Another flight decades earlier did not end with a miracle. In 1960, an Eastern Airlines L-188 ran into a flock of 20,000 starlings over Boston Logan International Airport, damaging two of the four turboprop engines and causing a crash that killed 62 people.

Bird Strike Committee USA, an advocacy group for addressing the bird strike problem, estimates that birds cause more than $900 million a year in damage to U.S. civilian and military aircraft. Airports plagued by birds devote much effort to driving them away through a variety of methods, from clearing bird-friendly habitats near runways to using noisemakers or even shooting them.

"The biggest hazard [from birds] would be an impact that would result in the loss of multiple blades on a fan, so that the imbalance in the engine could make the airplane uncontrollable," says MIT aeronautics professor R. John Hansman, who did a probability analysis for the FAA on the risk of collisions between manned and unmanned aircraft.

To test civilian and military aircraft for survivability against bird strikes, manufacturers shoot birds at them.

"Did you ever have a Daisy BB gun?" asks Lockheed Martin's Steve Owens, an airframe certification engineer in Fort Worth who has conducted bird strike tests on aircraft such as the F-35 strike fighter. "We have a big Daisy BB gun, with a 4-inch diameter barrel. In place of your BB, you load up your anesthetized or recently deceased chicken."

A bird (Owens says it has to be a bird, and not a gelatin substitute, for a valid test) weighing about 2 kilograms is shot at a prescribed velocity at an aircraft on the ground. In the case of the F-35, tests showed that the preliminary canopy design needed to be changed to meet bird strike requirements. On the other hand, shooting chickens at the aircraft's vertical-lift fan inlet door showed that the door would remain intact, while the amount of bird remains falling into the lift fan was deemed acceptable.

The hard components inside drones could pose a special challenge. The battery for a Phantom 3 quadcopter weighs about .4 kilogram. That may not sound heavy, unless it happens to be in a quadcopter flying at 30 knots, which then hits an airliner landing at 180 knots, producing a potent punch of mass and velocity.

"Think of throwing the battery of the UAV at an airplane at 200 miles per hour," says MIT's Hansman. "What would happen if your car windshield was hit by a baseball at 200 miles per hour?"

A likely impact area would be the canopy or windshield. Other likely points are the forward-facing zones of the wings, engine inlets and empennage [tail] structure, according to Owens of Lockheed Martin. Commercial engines must pass FAA-mandated bird strike tests. Engine maker Pratt & Whitney, for example, said its commercial engines pass FAA-required impact and ingestion tests for birds, ice and hail.

For all the furor over drones, it's actually birds that appear to be foremost on the minds of pilots.

"I can honestly say we take the threat of birds a lot more seriously," says airline pilot and retired Air Force Lt. Col. John Varljen. The FAA has a panoply of regulations regarding bird strikes, including a requirement that aircraft be capable of safe flight and landing after colliding with a 3.6-kilogram bird, as well as mandating that windshields be able to withstand a 1.8-kilogram bird.

The regulations seem to be working.

"I've certainly hit birds," Varljen says. "You may end up with a dent, but it's generally no problem. Unless it's a big bird like a turkey buzzard, the engine will generally eat it."

Experts suspect that, barring an unlucky hit on a sensitive area like the cockpit, commercial aircraft are rugged enough to survive a collision with a small drone. Or if an engine is knocked out, a twin-engined aircraft could probably continue to fly on one engine.

"Most of the commercial airliners they would hit, it wouldn't be a big deal," Hansman says. "They would make a dent, but the aircraft would fly fine."

But these analyses assume that the drone danger is inadvertent. What if terrorist groups strapped a couple of dynamite sticks to a quadcopter, or steered a flock of small drones into the path of an aircraft?

The U.S. Department of Homeland Security reportedly issued a warning to law enforcement agencies in August that terrorists might use unmanned aircraft to attack the U.S., although the bulletin reportedly made no specific mention of them being aimed at airliners.

AP/Matt Smith/Show Low Regional Airport

The pilot of an Ameriflight Beech C-99 cargo plane suffered facial lacerations and other minor injuries after his aircraft struck a bird on descent to Show Low Regional Airport in Arizona.

How hard would it be to maneuver a drone into the path of an airliner? Not very, says Pujalte of Embry-Riddle, who trained thousands of drone operators for the Army.

"In a few weeks, you absolutely could train somebody to do it," he says. "All you have to do is go to the airport, get some distance away when the aircraft are on descent, park your car there on some perimeter road, and as soon as you see an aircraft approach, you launch one straight up."

MIT's Hansman isn't so sure.

"How are you going to get the UAV in the right position? There is a 99 percent probability that if the UAV goes through the engine, it will just get chewed up and shot out the back. It's not an efficient way to take down an airplane."

Actually, Hansman says, it's the operators of another kind of aircraft who should worry.

"The aircraft that are more vulnerable than commercial aircraft are helicopters," he says. "Helicopters tend to operate at those altitudes where UAVs fly, and the helicopter is very vulnerable in the tail rotor. If you were to take a hit in the tail rotor, you would probably lose control."

The question of a terror attack aside, experts say it seems more than likely that there will be a mid-air collision between a commercial aircraft and drone at some point. It is a test of strength that both would rather avoid. ⍋

Ben Iannotta contributed to this article.