IT'S EXACTLY 3:45 A.M. on a blustery and unseasonably cold Tuesday morning in May when an armed military guard wearing a bulletproof vest waves me through the west entrance of Edwards Air Force Base. On a typical weekday at this hour, almost everyone here would be asleep. But this isn't a typical weekday. I'm in a briefing room with some two dozen researchers—mostly aerospace and computer software engineers, along with three Air Force pilots certified to fly drones—at NASA's Armstrong Flight Research Center, which is located on this Southern California military base. We're guzzling coffee and chomping doughnuts while Dan Sternberg, a NASA operations engineer and former F/A-18 Hornet test pilot, leads the meeting, ticking through the day’s flight plan.

The Armstrong team is here to evaluate how so-called “detect-and-avoid” technologies designed for collision avoidance can prevent drones, or unmanned aerial vehicles (UAVs), from smashing into other aircraft. Today's schedule involves a series of 24 head-on passes—when two aircraft face off on a near-collision course—between a General Atomics MQ-9 drone named *Ikhana* and two piloted, or “intruder”

How can we ensure drones don't collide with airliners? NASA and the FAA are working to find the best collision avoidance systems for UAVs in the United States, soon to number in the millions.

**DRONES IN A BUSY SKY**

**CAN TECHNOLOGY PROTECT AIRPLANES FROM THE NEW THREAT?**

**BY MICHAEL BEHAR**
aircraft, twin-engine Beechcraft turbo-props (a B200 and a C90). The exercises are designed to simulate encounters between UAVs and airliners. “We’re basically going to intentionally fly airplanes at each other,” says Sam Kim, lead engineer on the project, who tells me the pre-dawn start is imperative because military flights overrun the airspace by mid-day, at which point Ikhana gets grounded. “We’re last priority,” he grumbles.

The Ikhana project is part of a multi-year NASA study called the Unmanned Aircraft Systems Integration in the National Airspace System (UAS-NAS). Launched in 2011, the UAS-NAS conducts research to enable routine airspace access by unmanned aerial systems. The project collaborates with the Federal Aviation Administration, the Radio Technical Commission for Aeronautics (RTCA), and commercial aerospace entities to develop “minimal operational performance standards”—the best mix of technologies, regulations, and protocols necessary for drones to operate safely in the United States. “We want to make sure rules must be established. Perhaps UAV pilots encountering collision avoidance systems on every unit.”

At Edwards Air Force Base in California, NASA has been conducting flight tests with a General Atomics MQ-9 UAV (foreground) and a Beech King Air (rear), which flies intrusions into the Reaper’s path.

John Parker, president of Integrated Robotics Imaging Systems in Kenai, Alaska, is working with researchers at the University of Denver to develop a radar small enough to fly on drones. His company hopes to market sophisticated detect-and-avoid electronics the size of a playing card.

specific maneuvers. More likely, any forthcoming regulations will combine both approaches: technical requirements and pilot protocols. But before the FAA can establish requirements, it needs data from actual flight experiments to know what works and what doesn’t. That’s what Kim’s team intends to provide. Posada guides Ikhana onto Runway 22R and takes off a few minutes before sunrise. I’m observing the flight with the research team, whose members track Ikhana on eight large LCD screens in Armstrong’s Live Virtual Constructive lab. From here, we monitor, among other things, radar, GPS coordinates, and real time video feed from the drone’s forward mounted turret camera. At the moment, Ikhana is doing laps above the lakebed base at 170 mph, waiting for the Beechcraft intruders to arrive.

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In July 2015, Bayandor released the results of a study that used sophisticated computational techniques and programs to simulate an eight-pound UAV quadcopter—similar to those popular with photographers and filmmakers—flying into the type of turbofan engine common on passenger jetliners like the Boeing 737. Since then, Bayandor has experimented with different parameters, altering the results of a study that used sophisticated computational techniques and programs to simulate an eight-pound UAV quadcopter—similar to those popular with photographers and filmmakers—flying into the type of turbofan engine common on passenger jetliners like the Boeing 737. Since then, Bayandor has experimented with different parameters, altering the majority are essentially flying blind.

So far, there are no reports of a drone damaging an aircraft. (Last April, one was believed to have struck a British Airways A320 approaching Heathrow.) The Ikhana team at Armstrong believes that UAVs equipped with the appropriate technology could easily avoid such a mishap. And they intend to prove it: Today’s detect and avoid encounters are part of a two month series of experiments called Flight Test 4, or FT4, which began at Edwards in mid-April. The first three series took place between 2012 and 2015.

The first flight of the morning gets underway with one of the intruders, the Beechcraft B200, closing on Ikhana at more than 150 mph.

The risky nature of the maneuver requires that the Beechcraft pilot make a visual identification when he’s within one nautical mile of the drone. If for some reason he can’t see Ikhana, the test is called off. On the radar display in the lab, it becomes evident that neither aircraft is lined up properly. Gusty winds are making it difficult for the pilots to stay on course. Mike Marston, a former F-16 pilot, leads the operations engineering team. Suddenly, he’s yelling over the radio, “Abort! Abort! Abort!”

Ikhana gradually banks left, while the Beechcraft veers right. Dan Eng, Ikhana’s systems engineer, who is sitting beside me nervously watching the radar, abruptly blurs out to no one in particular, “Don’t mess up my paint job!”

“LOOK AT A PICTURE OF AN AIRCRAFT WITH HAIL DAMAGE,” instructs Jim Blanchard, chief scientist for the Unmanned Autonomous Systems Academy in Warrenton, Virginia. “What makes you think a drone, which has much more mass, is not going to do a lot worse? Common sense tells you it will.”

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Mechanical engineering associate professor Javid Bayandor had the same thought when he founded Virginia Tech’s CRASH lab—Crashworthiness for Aerospace Structures and Hybrids. CRASH focuses on aeronautics research, examining, among other phenomena, what happens when objects like hail, rocks, birds, and more recently drones, slam into aircraft engines, propellers, fuselages, windscreen, and control surfaces, such as ailerons, rudders, and leading edge flaps.

In some scenarios, Ikhana would arrive at a set point 0.02 second for the UAV to avoid hitting a virtual ball of the simulated nine-foot-diameter fan blades. I ask Bayandor what prompted the project. “There were a lot of reports of drone sightings escalating and everyone was seeing things close to airports,” he says. “We wanted to show the FAA that there is a real danger and they need to address it.”

At the Crashworthiness for Aerospace Structures and Hybrids lab at Virginia Tech in Blacksburg, director Javid Bayandor (far left) and his team have created a model of what would happen when small drones of various weights strike airliner turbofan engines.

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Do Bayandor’s simulations match reality? That’s what engineers want to know at the newly formed Center of Excellence for Unmanned Aircraft Systems, an FAA research alliance between universities and the UAV industry. After this year, Tom Aldag, a member of the FAA’s recently announced research and development for witchita State University’s National Institute for Aviation Research, will begin deliberating with universities and inter-agencies and interdress directors of the Office of Unmanned Aircraft Systems Integration. He tells me that never before has the FAA created a bureau dedicated solely to regulating a new class of aircraft. But the complexity of trying to coordinate all the various efforts to establish safety standards for drones warranted it. “We recognize that this is different,” he explains. “It’s more like following a cell phone into the national airspace system than a typical aircraft.” A recent FAA survey of detect and avoid technology and some findings may not be relevant to the public and private, developing more than 150 systems designed to prevent UAVs from hitting things. The booming detect and avoid industry is stunning when you consider that, at the moment, the FAA imposes no requirements for collision avoidance technology on UAVs. So far, the only new UAV regulation on the books is something called the Part 107 rule, which Lawrence’s office finalized in June. Part 107 governs the commercial use of small UAVs—those weighing between 55 and 55 pounds. It’s an attempt to keep the most common class of drones away from high-risk areas. Part 107 sets limits on how high commercial operators can fly (400 feet), how fast (150 mph), and where (away from airports and over anyone not directly involved with the drone’s operation). Commercial UAV pilots are not required to carry transponders, which would enable air traffic controllers to identify their owners. It’s also tough to catch operators at the scene of a crime when they’re piloting their UAVs from miles away. Aside from the new drone database, the FAA hasn’t announced any future Part 107 rules. But a recent FAA report on tiềmantly, professional pilots might be required on UAVs around 2025. That’s when the FAA expects to complete NextGen, its sweeping overhaul of the national airspace. NextGen includes a requirement for all manned aircraft to carry a device that links them to a satellite-based tracking system. That provision would presumably encompass drones too. But unless the FAA significantly staffs up enforcement or another federal agency steps in to handle that job, the sheer number of drone violations will quickly overwhelm any efforts to prosecute scofflaws. It’s a scenario reminiscent of the early 1990s, when the record industry spent tens of millions of dollars lobbying for laws to prevent Internet users from downloading music for free. The situation today is similar. It’s both dynamic and chaotic, says Lawrence. With so many players—and technology that is constantly evolving—regulations become outdated almost as quickly as they are created. I ask Lawrence to envision our national airspace in 20 years, when UAVs will be ubiquitous. “Whatever answer I gave would be wrong,” he says. “All we can really say for sure is we’re going to have a lot of unmanned aircraft. What size and what they’re doing will amaze us all. New uses are popping up every day. Our rules to develop a regulatory framework absolutely necessary. The technology becomes useful only when operators obtain a subsonic and subsequently fly their UAVs in airspace where they’re more likely to encounter manned aircraft. Even so, aviation experts speculate, late that detect and avoid technologies might be required on UAVs around 2025. That’s when the FAA expects to complete NextGen, its sweeping overhaul of the national airspace. If and when the FAA decides to mandate detect and avoid systems on UAVs, the myriad models of the small aircraft will be required to carry transponders and other devices that make professional pilots nervous. “The large, commercial drones, like Ibana,” are going to be heavily regulated and treated just like any other aircraft,” Hagy says. “It’s the hobbyists that worry me. They’re pretty much unregulated.” The FAA has the authority to prosecute anyone going a small drone that violates regulations. But arresting law-breakers is a formidable challenge. Unlike manned aircraft, UAVs don’t have visible tail numbers. Drones aren’t required to carry transponders, which would enable air traffic controllers to identify their owners. It’s also tough to catch operators at the scene of a crime when they’re piloting their UAVs from miles away. The Armstrong Center’s Sam Kim wants to re-create the assorted interac- tions a pilot might have when approaching drones equipped with these systems. Somewhat as the in-store Posada, at Ibana’s controls, to disconnect TCAS but leave ADS B activated. In other instances, continuous broadcast their location—altitude, latitude, and longitude—along with airspeed and whether it’s climbing or descending. The information is then transmitted to pilots and air traffic control- lers. For pilots in particular, ADS-B vastly improves situational awareness, providing them with a real-time, three-dimensional picture of the surrounding airspace. 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the Beechcraft intruders charge at Ikhana with their detect-and-avoid systems designed to engage small drones.

I GET MY FIRST PEEK at one of these miniaturized systems when I meet John Parker on a hot summer morning at the Hilton in downtown Denver. Parker, who lives in Kentai, Alaska, is founder of a UAV called Integrated Robotics Imaging Systems, and a former accident investigator for the airline and insurance industry. He’s in Colorado to meet with researchers at the University of Denver who are helping him develop the world’s smallest radar. Over breakfast at the hotel’s Café, Parker opens a shiny yellow plastic case to show me a prototype radar, which is about the size of a playing card. Several companies like Parker’s are developing and marketing detect-and-avoid systems for small UAVs. Among them is Sagetech, based in White Salmon, Washington, where Jim Davis directs business development. “Non-cooperative aircraft are the thing everybody is worried about,” Davis says. His firm sells ADS-B units that operate identically to the much larger systems commercial jetliners carry. But Sagetech’s device is the size of an apricot and weighs just over 1 kg. It is designed to be compact and light enough for even the tiniest drones.

When I propose the idea of an ADS B on every drone to the FAA’s Lawrence, he quickly points out that such an extensive installation would wreak tiny blips on displays, making it almost impossible for pilots and air traffic controllers to distinguish legitimate threats from clutter. “It would overwhelm the system,” he says. “It’d just be too many [UAVs] in the air.” In other words, drones would become the span of the skies.

Not long after controllers warn Marston about an F/A-18 Hornet and an F-35 Lightning II stealth fighter doing high-speed maneuvers in the vicinity, I hear sonic booms exploding over the airfield. Since dawn, Marston has been on the radio relaying communications between Posada and the military air traffic control at Edwards. Now Marston needs a break. “It’s all yours,” he says, removing his headset and handing off his duties to a colleague. “I’m going to grab another cup of Joe.” I interdict him at the coffee maker to find out what’s going on. “We’re gonna get booted out of here in 15 minutes,” he tells me.

A logical approach might be to regulate drones like firearms: give each unit a unique digital fingerprint embedded in its hardware that the owner at the time of purchase. For UAVs, that serial number would be in the form of a digital fingerprint embedded in a lightweight transponder attached to the UAV’s motherboard. Every drone could then broadcast a unique identifier, or squawk code, over a pre-assigned radio frequency. Air traffic controllers and pilots could monitor this frequency around airports or wherever they’re concerned about UAV encounters. But much like regulators of firearms, drone companies aren’t keen on the government telling them what to do, especially when it comes to mandating extra hardware, which will drive up the price of their product.

In the aviation industry, it has often taken a major catastrophe to spur change. Following 9/11, airlines redesigned cockpit pits. And in response to Malaysia Airlines Flight 370, the FAA is developing live flight tracking requirements. Sadly, unless UAV collision damages or possibly brings down an airliner, most drones won’t be flying with detect-and-avoid systems anytime soon.