PHOTO ILLUSTRATION BY THÉO; DRONE: ALEXEY YUZHAKOV/SHUTTERSTOCK.COM; AIRLINER: KOSMOS111/SHUTTERSTOCK.COM

DRONES IN A BUSY SKY

CAN TECHNOLOGY PROTECT AIRPLANES FROM THE NEW THREAT?

BY MICHAEL BEHAR

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.

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" aircraft, twin-engine Beechcraft turboprops (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 midday, at which point *Ikhana* gets grounded. "We're last priority," he grumbles.

The *Ikhana* project is part of a multiyear 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 aircraft systems. The project collaborates with the Federal Aviation Administration, the Radio Technical Commission for Aeronautics (RTCA), and commercial aerospace entities to develop "minimum 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 [UAVs] play nicely, just like any other aircraft," says Kim, who developed combat drones for Boeing's Phantom Works before joining NASA in 2006.

Ikhana, which has a maximum takeoff weight of 10,500 pounds, is capable of flying autonomously. Today, however, NASA pilot Herman Posada will operate it remotely, sending it commands from inside a steel-paneled ground-control station alongside an Edwards taxiway.

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.

The flight tests are designed to help the FAA develop detect-and-avoid technology requirements for drones. Nobody knows how these requirements will be applied or when: At the moment, there are no fixed deadlines by which such rules must be established. Perhaps UAV manufacturers will be asked to integrate collision avoidance systems on every unit they sell. Or drone pilots encountering manned aircraft will have to execute 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.

Jetliners, military aircraft, and many private airplanes already use a variety of detect-and-avoid avionics, but these technologies aren't practical for most drones because they're often too large, too heavy, and too power-hungry (drones are usually battery-operated). Presently, of the half-million drones registered on the FAA's UAV database—and the untold number of unregistered UAVs—the majority are essentially flying blind.

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.

TOP: NASA/KEN ULBRICH; LEFT: KAYLEE OSOWSKI/PENINSULA CLARION

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 under way 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 pilot veers right. Dan Eng, *Ikhana*'s systems engineer, who is sitting beside me nervously watching the radar, abruptly blurts 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."

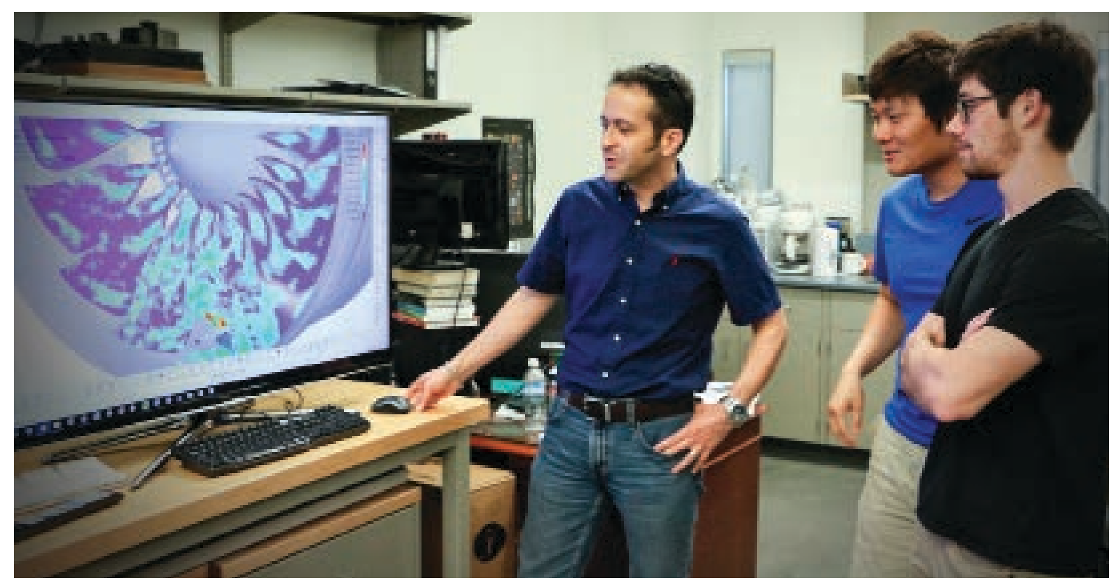
"WE'RE BASICALLY GOING TO INTENTIONALLY FLY AIRPLANES AT EACH OTHER," SAYS SAM KIM, THE LEAD ENGINEER ON THE PROJECT. KIM DEVELOPED COMBAT DRONES FOR BOEING'S PHANTOM WORKS BEFORE JOINING NASA.

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, windscreens, and control surfaces, such as ailerons, rudders, and leading edge flaps.

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 airspeeds, weights, and sizes of the drone and the jetliner, and ran the models. He simulated a drone carrying a camera. And he altered the material composition of the turbofan blades, testing different metal alloys used in modern jet engines. In some scenarios, it took just over 0.02 second for the UAV to shred several 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."

SIERRA COLLEY VIA DR. JAVID BAYANDOR/VIRGINIA TECH CRASH LAB



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.

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. Later this year, Tom Aldag, a member of the alliance who directs research and development for Wichita State University's National Institute for Aviation Research, will begin deliberately crashing drones into the different types of materials used in the airframes of commercial aircraft. Aldag plans to start with small quadcopters and fixed-wing UAVs, measuring the damage that they might inflict on a jetliner such as the Airbus A320. Actual airplanes are next: "We hope to expand testing to full-scale impacts on airframe structures in the next year or two," says Aldag.

SEVERAL FEDERAL agencies and international groups are involved in detect-and-avoid research. ASTM (derived from the American Society for Testing and Materials) International, which already produces technical standards for manned aircraft, has formed a committee to develop drone safety guidelines. The Association for Unmanned Vehicle Systems International is working with UAV manufacturers to determine the best approaches for collision avoidance. And the RTCA is trying to build consensus between UAV industry executives and federal regulators. At the nexus of all this is the FAA, where Earl Lawrence directs 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 says. "It's more like integrating laptops and cellphones into the national airspace system than a typical aircraft." A recent FAA survey of detect-and-avoid technologies found some two dozen entities, both 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 (100 mph), when (daylight hours only), and where (away from airports and over anyone not directly involved with the drone's operation). Commercial UAV pilots also must be at least 16 years old, able to see their drones at all times—known as maintaining "visual line-of-sight"—and yield the right-of-way to all other aircraft by following standard see-and-avoid practices: If you see another airplane, get out of the way. Commercial operators must register their UAVs, but will be able to request a waiver for most of these restrictions.

Recreational drone operators, who also are required to register their aircraft with the FAA, must follow a similar set of guidelines. Additionally, hobbyists can't fly over groups of people, over stadiums and sports events, or near emergency response activities, such as firefighting. The FAA website (*faa.gov*) has a "Fly for Fun" page that lists the rules for recreational drone users.

Drones that weigh more than 55 pounds are regulated much as ordinary manned aircraft are. But most drones are in the sub-55-pound category. The FAA predicts that by 2020, at least 4.3 million of these smaller drones will be roaming the nation's airspace.

Despite FAA guidelines for drone-flying hobbyists, Keith Hagy, who directs engineering and air safety for the Air Line Pilots Association in Washington, D.C., is concerned. He notes that consumers snapped up more than 1.1 million hobbyist drones last year alone. And it's these small UAVs—many of which can operate autonomously—that make professional pilots most nervous. The large, commercial drones, like *Ikhana*, "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 flying a small drone that violates regulations. But arresting lawbreakers 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 likely piloting their UAVs from miles away.

Aside from the new drone database, the FAA hasn't announced any future rules to make drones more visible to other pilots or air traffic controllers. In practice, if commercial drone pilots stick to the Part 107 rule and hobbyists heed the regulations, detect-and-avoid systems aren't really necessary. The technology becomes useful only when operators obtain a waiver and subsequently fly their UAVs in airspace where they're more likely to encounter manned aircraft. Even so, aviation experts speculate 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.

BAYANDOR EXPERIMENTED WITH DIFFERENT PARAMETERS, ALTERING THE AIRSPEEDS, WEIGHTS, AND SIZES OF THE DRONE AND THE JETLINER. IN SOME SCENARIOS, IT TOOK JUST 0.02 SECOND FOR THE UAV TO SHRED SEVERAL OF THE SIMULATED FAN BLADES.

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.

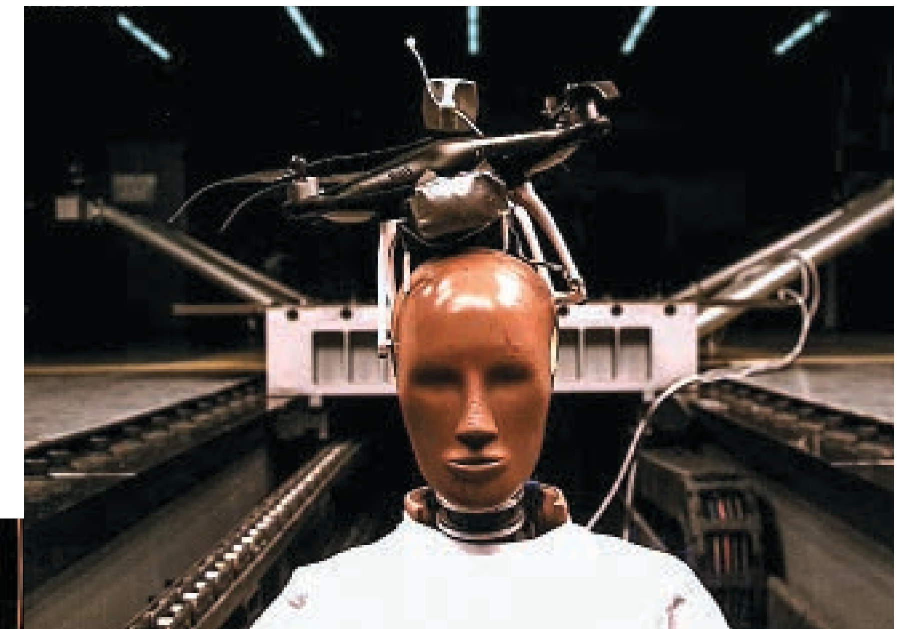
The situation today is similar. It's both dynamic and chaotic, says Lawrence. With so many players—and technology that is constantly evolving—regulations become outdated almost as quickly as they can be created. I ask Lawrence to envision our national airspace in 20 years, when UAVs will be ubiquitous. "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 role is to develop a regulatory framework flexible enough to accommodate whatever people come up with for UAVs—and that we're not a barrier to their dreams or their inventiveness."

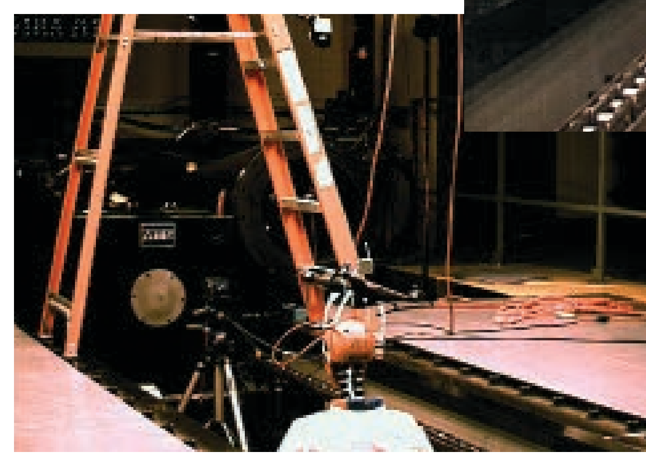
EACH TIME A PILOT REPORTS a close encounter with a drone, Lawrence receives a text on his cellphone. "I get them all day long," he tells me. "That's how we track safety." Lawrence gets about 100 incident reports every month from pilots, many of them spotting drones around congested airports, such as JFK and LAX. "The fact that we're having pilots seeing them at low altitudes, in highly populated areas, shouldn't surprise us when you look at the tremendous amount of them that have been sold."

If and when the FAA decides to mandate detect-and-avoid systems on UAVs, the myriad models of the small aircraft will preclude a blanket solution. "It's not about integrating one thing," Lawrence says, "it's about integrating a lot of different aircraft. There won't be just one way to operate in the airspace. It's going to be a combination of things."

This is why *Ikhana* is testing a mix of technologies during its flights. These include TCAS (traffic collision avoidance system); a new technology based on airborne radar that emits audible warnings at the ground station like "Descend" if another aircraft gets too close; and the satellite-based ADS-B (automatic dependent surveillance broadcast)—the new emerging standard mandated for implementation by 2020 in all aircraft, including UAVs operating above 2,500 feet in controlled airspace. An aircraft equipped with ADS-B continuously broadcasts its 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 controllers. For pilots in particular, ADS-B vastly improves situational awareness, providing them with a real-time, three-dimensional picture of the surrounding airspace.

The Armstrong center's Sam Kim wants to re-create the assorted interactions a pilot might have when approaching drones equipped with these systems. Sometimes he instructs Posada, at *Ikhana*'s controls, to disconnect TCAS but leave ADS-B activated. In other instances,





NATIONAL INSTITUTE FOR AVIATION RESEARCH (2)

If a UAV falls out of the sky and crashes into a person's head, what injuries could result? Researchers at Wichita State University's National Institute for Aviation Research are trying to find out by dropping drones onto test dummies.

the Beechcraft intruders charge at *Ikhana* with their detect-and-avoid systems disengaged to simulate what a UAV operator might experience when it's too close to a "non-cooperative" aircraft—aircraft that currently aren't required to carry TCAS or ADS-B, and whose pilots sometimes switch off their radios, rendering them invisible to air traffic control. "It's all these mom-and-pop pilots who just don't want the government knowing where they are," Marston explains.

Only a UAV carrying a detect-and-avoid system would be able to recognize a non-cooperative aircraft. "It's a huge issue," says Todd Lester, a UAV operations manager at Near Space Corporation in Tillamook, Oregon, who piloted the Boeing Insitu ScanEagle drone in Iraq in 2009. "You've got these weekend warriors in the general aviation aircraft not talking on the radio." For this reason, the Armstrong Center's Kim has designed most of the *Ikhana* exercises around the belief widely held in the aviation community that avoiding collisions between manned and unmanned aircraft is largely the UAV's responsibility. But that's going to require detect-and-avoid devices compact and light enough for even the tiniest drones.

The National Institute for Aviation Research is also investigating the damage potential of collisions between UAVs and airplanes by crashing quadcopters (above) into the materials used to build airframes.

NATIONAL INSTITUTE FOR AVIATION RESEARCH

I GET MY FIRST PEEK at one of these miniaturized systems when I meet John Parker on a hot summer morning at a Hilton in downtown Denver. Parker, who lives in Kenai, Alaska, is founder of a UAV firm 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 in 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 smaller 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 three ounces. A UAV equipped with it would be visible to almost all commercial aircraft and air traffic controllers.

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 create a swarm of 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 spam of the skies.

But Lawrence doesn't entirely discount ADS-B for UAVs. Perhaps it's a system that would be operated only when UAVs are flying in remote areas, or when pilots are flying their drones beyond line-of-sight and require ADS-B for flight planning. In highly congested zones, technologies that don't interfere with manned aircraft would be preferable, he surmises. A promising and "simple" solution, says Lawrence, is something called geofencing. UAVs with geofencing use software and an integrated onboard GPS navigation to prevent them from entering restricted airspace—"no-drone zones." Right now, only a handful of UAV manufacturers are incorporating reliable geofencing into their units—and they're doing so voluntarily.

***IKHANA*'S ENCOUNTERS** are mapped out weeks in advance, with altitudes prescribed within certain blocks of airspace. But by 8 a.m. on the day I'm visiting, heavy air traffic above Edwards forces the Armstrong team to frequently rejigger their schedule. At one point, Marston relays over the radio, "F-15 operating at 15K block to 40K," which means *Ikhana* must now remain beneath the lower altitude.

Kim is furiously scribbling notes on the day's printed flight plan, crossing out altitudes and penciling in new ones, and trying to keep tabs on who and what is vying for the airspace over Edwards. I suppose that Kim's experience at Edwards is a microcosm of the national airspace. When Edwards gets busy, *Ikhana* has to share the skies like any other aircraft. The only difference is that *Ikhana* doesn't have a set of physical eyeballs in the cockpit. But should that matter? Technology is rapidly closing the gap between flesh-and-blood pilots and drones that can fly without them. Indeed, with its million-plus dollars' worth of detect-and-avoid avionics, *Ikhana* can already dodge things in the sky better than most manned aircraft.

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 intercept 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. *Ikhana*'s eight remaining exercises have been canceled due to military air traffic with higher priority.

Flight Test 4 culminates this phase of the UAS-NAS project, with *Ikhana* logging a total of 98.1 flight hours over 11 weeks, performing more than 325 mid-air encounters with intruder aircraft.

"The big takeaway from the FT4 series is the contribution it will make to developing detect-and-avoid standards," says Debra Randall, chief systems engineer for the *Ikhana* project. "It will provide the [drone] community with the right foundation to fly UAVs in the national airspace." There is also a legal requirement in the federal aviation code that instructs pilots to see and avoid other aircraft. As part of FT4, the Armstrong team will recommend to the FAA and RTCA the kinds of detect-and-avoid systems drone pilots will need in order to comply with this rule.

Outside Armstrong, Christian Gelzer, the facility's chief historian, is waiting in an electric golf cart. He shuttles me three miles across the base to a taxiway adjacent Runway 22R, where *Ikhana* has been assigned to land. A ground crew arrives with a pushback tug for towing the UAV to the hangar. After about 20 minutes, it appears in the northeast sky, like a sleek white condor in the desert haze. It gently touches down, then turns 180 degrees to make its way toward us. While the ground crew hitches *Ikhana* to the tug, an F-35 pulls up, and its pilot gives us a friendly wave.

The nation's airspace is already filled with millions of UAVs smaller and simpler than *Ikhana*, and the skies are only going to get more crowded. Ensuring that all these drones are operated safely—and kept away from manned aircraft—is a job far too big for a single agency like the FAA. Ultimately, enforcement will require a joint effort that involves federal, state, and local agencies.

UAVs WITH GEOFENCING USE SOFTWARE AND AN INTEGRATED ONBOARD GPS NAVIGATION TO PREVENT THEM FROM ENTERING RESTRICTED AIRSPACE, OR SO-CALLED "NO-DRONE ZONES."

A logical approach might be to regulate drones like firearms: give each unit a unique serial number that is registered to 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 firearms manufacturers, 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 doors. And in response to Malaysia Airlines Flight 370, the FAA is developing live flight-tracking requirements. Sadly, unless a UAV collision damages or possibly brings down an airliner, most drones won't be flying with detect-and-avoid systems anytime soon.

Earl Lawrence directs the FAA's effort to integrate UAVs into U.S. airspace. As a private pilot, he has a personal interest in fostering law and order in the skies.

ALLEN PHOTOGRAPHY