THE WORLD OF SURVEILLANCE

# HERE'S LOOKING AT YOU

*Should we worry about the rise of the drone?*

BY NICK PAUMGARTEN

One night last June, outside the town of Lakota, North Dakota, three cows, with three calves, wandered off a ranch and onto a nearby property farmed by a family named Brossart. The next day, Rodney Brossart, the patriarch, discovered the cows and calves, he claims, eating feed and hay meant for his own cattle. He put them in a pen. Before long, the neighbor appeared and asked that Brossart return them. Brossart refused, citing an old North Dakota livestock law, which, in his interpretation, entitled him to hold on to the cattle until the neighbor repaid him for what they'd eaten and whatever damage they'd caused. The neighbor, who says that Brossart offered to sell him the cattle, appealed to the county sheriff, and soon a deputy and a livestock inspector were headed out to the Brossart farm. On the way there, the officers came upon Rodney Brossart, pumping water, and asked that he turn over the cattle. Brossart refused. The officers threatened to go onto his property to retrieve them, and Brossart replied, "If you step foot on that property, you're not walking away." The deputy attempted to arrest Brossart. Encountering some resistance, he subdued Brossart with a Taser. Brossart's son Jacob, seeing his father in distress, rushed to his aid, and was handcuffed. Brossart's daughter, Abby, also attempted to intercede, and was arrested and charged with assault.

The Brossarts' ranch covers three thousand acres and encompasses an old missile silo. Later that day, the sheriff and other officers showed up with a warrant and were greeted by several Brossarts brandishing firearms. The sheriff retreated and called in a SWAT team from Grand Forks. He also requested the use of a Predator drone, like the ones that the United States has deployed in Iraq and Afghanistan. U.S. Customs and Border Patrol has a fleet of them, and had recently offered them to local law enforcement to help conduct operations on the state's vast northern plains. An unarmed Predator, finishing up its shift along the border, flew down to the Brossart ranch and circled ten thousand feet overhead, using infrared imaging to track the Brossart boys, as they moved about their ranch with what looked to be rifles in hand. The sheriff decided to wait until morning.

The next day, the Predator returned, and the police, watching on a monitor, saw the Brossarts riding around the ranch on A.T.V.s. They appeared to be unarmed. The SWAT team moved in and arrested three of them. The neighbor got back his six cows, and five Brossarts got five felony counts. The cops uncovered four rifles, two shotguns, a few bows and arrows, and a Samurai sword.

The roundup of the Brossarts was hailed at the time as the first drone-assisted arrest on American soil. There had been at least one other, it turns out, but this was certainly the first time that a four-million-dollar remote-controlled aircraft had been deployed to resolve a dispute over reimbursement for a bale of hay.

The Brossarts are said to be members of a separatist group called the Sovereign Citizens movement; they deny it, but they do favor, as their lawyer asserted last month, in a motion to dismiss the case, "the company of one another over the company of extended family or friends." This can be taken as either a justification for the use of the Predator or a kind of self-contained rebuke, since the cops' disproportionate approach seems to validate the anti-government sentiment that precipitated it. Those who most fervently decry the incursions of an Orwellian police state are often the ones who wind up provoking it to its most conspicuous excesses. Certainly, it doesn't help that the Predator is a drone known for killing people from the air. It's one thing to have misgivings about airborne surveillance and another to contemplate death from

*Flying quadrotors at Penn's GRASP lab. Photograph by Christopher Griffith.*

above. In Pakistan and elsewhere, if the Predator, during its so-called personality strikes, collaterally kills innocents, its owners risk creating more enemy combatants. Using it stateside to spy on recalcitrant rustics may have a similar effect.

The legal issue of domestic drone deployment is itself a little like a drone: it has stolen up on us and is now hovering noiselessly overhead. In February, Congress, without much fanfare or debate, passed a law that will eventually open the national airspace to unmanned aerial vehicles, or U.A.V.s, for commercial, scientific, and law-enforcement and public-safety use. President Obama, a strong supporter of drone use abroad, quickly signed the bill into law. It requires the Federal Aviation Administration to have regulations in place for U.A.V.s by 2015. Air safety, not privacy or due process, is the F.A.A.'s chief concern, and in that regard alone it has its hands full. Five years ago, the F.A.A. banned Americans from operating drones, apart from special exemptions granted to around three hundred military contractors, research programs, and law-enforcement agencies. For a while, the hiatus muffled the murmur of excitement and worry over what our lives might be like once the drones take to the air.

The prospect of unmanned flight has been around—depending on your definition—since Archytas of Tarentum reputedly designed a steam-powered mechanical pigeon, in the fourth century B.C., or since Nikola Tesla, in 1898, demonstrated a radio-controlled motorboat at an exposition in Madison Square Garden. (Ten years later, Tesla pronounced dirigibles, not airplanes, to be the future of flight.) The actor Reginald Denny, a First World War ace and model-plane enthusiast, designed remote-piloted target drones for the United States Army in anticipation of the Second World War (he eventually sold the business to Northrop), and by the sixties the Air Force was deploying unmanned reconnaissance jets over Southeast Asia. Still, it was the advent, in the mid-nineties, of the Global Positioning System, along with advances in microcomputing, that ushered in the possibility of automated unmanned flight.

Model-plane hobbyists began adapting their toys to suit a range of tasks, in some cases mounting them with cameras and seeking out customers—farmers, fishermen, wildlife managers, meteorologists—who might benefit from having pictures, videos, or other data taken from the air. The Department of Defense, meanwhile, developed a keen interest. With the wars in Iraq and Afghanistan, and manhunts in places like Yemen, the military applications, and the corporations devoted to serving them (Lockheed Martin, Northrop Grumman), came to dominate the skyscape. Many of these manufacturers had one client: the Department of Defense.

In 2001, the military had just a few U.A.V.s. Now it has more than ten thousand. With the wars winding down, the drones, field-tested at taxpayer expense, are coming home and looking for jobs. The same, presumably, goes for the humans who operate them.

Later this month, the F.A.A. will present a regulatory regimen enabling law-enforcement departments (among other public-safety agencies) to fly small drones, and the military contractors will suddenly have some eighteen thousand potential new customers. As of now, only a tiny percentage of municipal and state police departments have any air presence, because most can't afford helicopters or planes. Small camera-loaded U.A.V.s are much cheaper. Police tend to have a fetish for military gear, which the purveyors of U.A.V.s seem to recognize. In pitches to police departments, Vanguard Defense Industries, in Texas, has been touting the ability of its drones to carry shotguns and grenade launchers. Patrick Egan, the president of the Silicon Valley chapter of the Association of Unmanned Vehicle Systems International, told me, "If you don't have unmanned aircraft, or if you don't have plans to get them, you're seen as a caveman." The police have noted the military using hand-launched lightweight electric drones and now covet them. The manufacturers see an opportunity for diversification and a hedge against declining military budgets. Together, they persuaded Congress to act.

Still, military innovation usually assimilates itself into civilian life with an emphasis on benign applications. The public proposition, at this point, anyway, is not that drones will subjugate or assassinate unwitting citizens but that they will conduct search-and-rescue operations, fight fires, catch bad guys, inspect pipelines, spray crops, count nesting cranes and migrating caribou, and measure weather data and algae growth. For these and other tasks, they are useful and well suited.

Of course, they are especially well suited, and heretofore have been most frequently deployed, for surveillance. "The nature of technology is that it is introduced for one role and then it slippery-slopes into unintended roles," Peter W. Singer, a fellow at the Brookings Institution and the author of "Wired for War," a book about military robotics, told me. Singer believes that drones will be as transformative as the advent of gunpowder, the steam engine, the automobile, or the computer. "Their intelligence and autonomy is growing," he said. "It used to be that an aerial surveillance plane had to fly close. Now sensors on a U.A.V. can detect a milk carton from sixty thousand feet. The law's not ready for all this."

In 1971, Paul MacCready, a champion glider pilot, aeronautical engineer, and model-airplane enthusiast, founded AeroVironment, in Southern California, with the idea of using aerospace technology and design to solve environmental problems. Later in the decade, he developed the first human-powered aircraft capable of controlled sustained flight, the Gossamer Condor; to keep the plane aloft, the pilot pushed bicycle pedals in the cockpit. In 1979, a cyclist flew a successor, the Gossamer Albatross (seventy pounds, with a wingspan of ninety-six feet), across the English Channel. The AeroVironment team also developed the first directly solar-powered aircraft, as well as, in collaboration with NASA, ultra-light planes that could fly into the stratosphere. MacCready imagined a new era of space planes that could serve as communication nodes. In August, 2001, Helios, with a wingspan of two hundred and forty-seven feet, reached an altitude of nearly a hundred thousand feet; no plane

had ever flown higher. A month later, the September 11th attacks occurred, and the Pentagon came calling.

Some years before, Ted Wierzbanowski, a retired Air Force colonel and experimental test pilot, had joined AeroVironment. With the onset of the wars in Afghanistan and Iraq, Wierzbanowski, as one of the few military men at the company, was tapped to work on AeroVironment's expansion into selling U.A.V.s to war fighters.

AeroVironment won a succession of contracts to make small, lightweight drones that could be carried in a backpack and launched by hand, primarily to see things from the air. (It does make one weaponized drone, the Switchblade, a guided kamikaze the size and shape of a baguette.) The company became, first and foremost, a military contractor.

AeroVironment now supplies the military with eighty-five per cent of its drones. Since AeroVironment's drones are much smaller and cheaper than the other drones in the fleet, they account for just two per cent of the Pentagon's drone budget. AeroVironment makes the Puma, the Wasp, and the Raven—each system costing hundreds of thousands of dollars. Among the other mainstays in the United States fleet are the Predator, from General Atomics, which costs four million dollars; the ScanEagle (three million for a set of four); and, the biggest of all, Northrop Grumman's Global Hawk, which weighs thirty thousand pounds, pulls thirty-hour sorties, costs thirty-five million dollars without dealer ops, and requires a small army of people to operate and service each plane.

AeroVironment's drones are sized and priced in a way that may appeal to police departments. This is the company's hope, anyway, as it tries to expand into the domestic market. Wierzbanowski serves on the Unmanned Aircraft System Aviation Rulemaking Committee, a group of industry representatives and policymakers that is charged with offering recommendations to the F.A.A. as it devises its new rules. He was also co-chairman of an earlier rulemaking committee.

Patrick Egan, of the U.A.V. trade group, has questioned AeroVironment's regulatory influence. "They seem to be crafting the standards to suit the Raven," he told me. But an AeroVironment spokesman says that that is not the case. Egan, a construction contractor, got into the drone business when, ten years ago, he began attaching still cameras to remote-controlled aircraft to take photographs of building sites. The 2007 F.A.A. ban put him and other people like him out of business, and he has been lobbying since then to get back into the conversation about what the skies will look like in the future. "It's hard for someone working out of his garage to compete with the military," he said.

*"Did you realize that every woman here is Cindy Sherman?"*

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AeroVironment's production and research facilities occupy two factories, in Simi Valley, California, on a street called Enchanted Way. As a visitor, you must present your passport and surrender your phone, which is a shame, because you come across skunk-work marvels that make you itch to text smartphone snapshots to gadget-geek friends. The shop floor, overseen by a former operations manager from Boeing, is an immaculate fairground of tinkerers' open-air garages, bordered on one side by a low wall of outgoing product—dozens of Puma drones in black caskets the size of guitar cases. AV can turn out as many as a hundred drones a day.

Each one, before it's crated, undergoes two flight tests. AeroVironment has arrangements with property owners in the area, who allow the company to fly on their land, with the standing permission of the F.A.A., in the form of a "certificate of authorization." (Whether you are a military contractor testing your product or a weekend hobbyist, you cannot fly a U.A.V. any higher than four hundred feet, and it must always remain within view.) The day I visited, some flight testers were flying drones at a beet-and-pepper farm, ten minutes from the plant. Steve Gitlin, an AV executive, drove us there. We turned off the road at a strawberry stand and came upon two testers, Mike Reagan and Matthew Shemenski, who'd parked on a dirt road that bisected the fields. They had a laptop opened on a folding table, and an array of AeroVironment drones lined up in the dust.

On the left was the Puma, with an eight-foot wingspan and a weight of thirteen pounds, a propeller on the nose and a gimballed camera in its belly. Gray and sleek, like a mini glider, it can land on water. Next was the Raven: 4.2 pounds, 4.5-foot wingspan, one prop behind the wings. The military has more than five thousand of them. "People say, 'Wow, they just look like model airplanes,' but that belies the technology these things have aboard," Gitlin said. "They have as much tech as a small piloted plane." The Qube, AeroVironment's first U.A.V. for nonmilitary

use, was a quadcopter the size of a lunch tray, with "POLICE" written on the side, in black-and-white. There was a fourth drone, in a briefcase.

"What's that one?"

"Actually, we can't show that one to you," Gitlin said. He and the others looked at each other. "Secret project."

Instead, Shemenski went about preparing the Raven.

"Ready to launch."

"Throttle up."

"Hold on, we got traffic." A few hundred yards to the west, a single-engine plane had taken off and was buzzing the fields. They watched it fly westward and turned their attention back to the Raven. "Throttle up." The prop revved to a fiendish whirr, and Shemenski heaved the aircraft forward, like a javelin. It didn't seem to mind that there was a stiff breeze. "Twenty knots is easy for it," Reagan said.

It flies autonomously. You program a flight path—point and click waypoints on the laptop screen—and it manages all the details of flight on its own. It adjusts to the wind and navigates by G.P.S. It can stay aloft for sixty to ninety minutes and travel as far as nine miles. You can program it to follow a target, or to loiter, and, if it loses its link to the ground-control unit, to return home or to climb higher, in a spiral, until it regains contact. It can be deployed as a link to a platoon of ground robots.

In the air, bobbing on the wind, the Raven had a rinky-dink look, like a cheap special effect in a Godzilla picture. As it rose, it blended into the sky. On the screen, where you control the camera, you could see beet fields, corrugated sheds, and palm trees. There's something intrinsically menacing about live bird's-eye surveillance video; its ordinariness seems to foreshadow a sudden flash of violence and carnage, or what's known in the trade as a "bug splat." But there'd be no splats today. After a few minutes, the Raven appeared to the south, having completed a big ring. It flew slowly into the wind and prepared to land. A hundred feet above the edge of the beet field, it seemed to stall; it plummeted toward the ground, smashed into the furrows, and broke into half a dozen pieces. Parts were strewn about the soil.

It turned out that the Raven is supposed to crash-land and break apart. It comes in ten pieces, made of lightweight composites. In some respects, its greatest asset is its durability—its ability to crash-land on hundreds of missions and still be operational. Shemenski reassembled the pieces and let me launch it. Throttle up: it leaped easily into the air—idiot-proof. "We have had people dork it," Shemenski said. You could see a hawk—or, at least, what appeared to be a hawk—wheeling on the updrafts. On top of a hill a mile or so south was a building complex—the Ronald Reagan Presidential Library and Museum. A car came hurtling up the dirt road toward us and then skidded to a halt, did a U-turn, and sped off, as though it hadn't expected to see us. Teen-agers on a joyride? It was tempting to tail them with the Raven.

Even now, many piloted planes—commercial jetliners, fighter jets—almost fly themselves; the pilot is essentially a chaperone, and the autopilot, you might say, a kid with a learner's permit. It will soon be technically feasible, if culturally unimaginable, to deploy passenger and cargo planes with empty cockpits. This would take some getting used to, but, as Singer said, "there was a point in history when no one would ride in an elevator without someone driving it."

Drones do crash. In 2010, a drone from Mexico crashed into a back yard in El Paso, and a Navy drone went out of control on a test flight and wandered into restricted airspace over Washington, D.C. Last month, an MQ-9 Reaper went down in the Seychelles. They also kill: the U.S. government has used them to kill American citizens abroad who are considered to be terrorists.

Privacy is another concern. In December, the American Civil Liberties Union concluded, in a report on drones, "The prospect of cheap, small, portable flying video surveillance machines threatens to eradicate existing practical limits on aerial monitoring and allow for pervasive surveillance, police fishing expeditions, and abusive use of these tools in a way that could eventually eliminate the privacy Americans have traditionally enjoyed in their movements and activities." Supreme Court decisions in the eighties upheld the use of manned aerial surveillance in drug arrests on private property without a warrant, but it is surely inevitable that, with a proliferation of drone-assisted police work, such precedents will come up for review.

Drone people, for their part, seem universally to have accepted the fact that the era of privacy ended a while ago. ("You have zero privacy anyway," Scott McNealy, then the C.E.O. of Sun Microsystems, said in 1999. "Get over it.") Cameras on every corner, Google, Facebook, cell phones: the data-mining regime is well entrenched, for good or ill, and a few aerial shots, the thinking goes, aren't about to change much.

The surrender of privacy can lead to a rise in transparency, which, on a good day, can have a mitigating effect. Drones have been deployed at Occupy protests in Warsaw to monitor the police, in Texas to uncover violations at a slaughterhouse, in Indonesia to keep an eye on loggers. Aid workers have discussed using them in Africa to deliver medicine to remote villages.

The prospect of a vigorous domestic drone industry has also given rise to a budding drone protest movement—a ragtag collection of prankster John Connors. Several tech entrepreneurs started a drone service in San Francisco called the Tacocopter, a quadrotor which theoretically delivers tacos to your door—theoretically, because current F.A.A. regulations forbid commercial droning, and because the enterprise is in some respects a piece of protest theatre. "Honestly, I think it's not totally unreasonable to regulate something as potentially dangerous as having flying robots slinging tacos over people's heads," one of the founders told the Huffington Post. "On the other hand, it's a little bit ironic that that's the case in a country where you can be killed by drone with no judicial review." In March, the Pirate Bay, the Swedish BitTorrent site, announced plans to load its servers onto drones and have them be permanently airborne, to protect them from law enforcement. An artist in Barcelona made a mock proposal to the "United States Armed Forces" for the production

of a "peace drone," designed for "hovering over hostile settlements or cities playing loud clown music, smiling around, and delivering clouds of OxyContin."

And then there is the fear that drones, in the wrong hands, pose an especially insidious threat. If they are relatively cheap and easy to obtain, then the bad guys can get one. The acuteness of this anxiety hinges on one's definition of bad guy. Last year, the F.B.I. charged Rezwan Ferdaus, a Massachusetts man, in an alleged plot to fly a remote-controlled plane loaded with C4 explosives into the Pentagon. (He already had the plane but was arrested trying to procure the C4.) In 2003, border vigilantes in Arizona began testing two drones to track illegal immigrants. Iran claimed last month that it had managed to crack encrypted codes from a Sentinel drone that crashed there in December. And what if drones fell into the hands of Hollywood paparazzi? Laurel Canyon would become Waziristan.

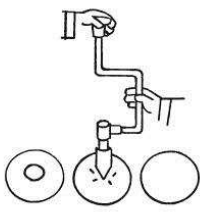
The most fearsome wrong hands may be those of a malevolent regime, be it one of men and women, using the information they have gathered to subjugate a powerless populace, or one of machines possessing superior artificial intelligence—Skynet, a tyranny of the robots. It is often said that technology, on its own, is neither good nor bad—merely a tool in the hands of a moral animal. When I asked Colin Angle, the chairman and C.E.O. of a company called iRobot, about a war with the drones, he said, "The world's going to be wildly stranger than that," and began to talk about the integration of robot parts into people's bodies.

Patrick Egan told me, "Even my family, we're watching 'The Terminator' and my fifteen-year-old son asks me, 'Can drones do *this*?' The public perception is that a U.A.V. is a flying machine killing people. And yet the best use for it may be upping the yield on onions. The technology has been hijacked by people in the military." He went on, "If you get the tech out there and use it to find a lost kid, people will accept it better. If you sell it as tech that you use to kill or to spy on people, people will resist it." He mentioned that there had been talk of mounting Tasers on drones. "The first time a drone Tases the wrong dude at a Phish concert, you're going to have problems."

A short walk from AeroVironment's manufacturing plant is the company's Advanced Development division. "Our nanoworks," Gitlin called it. "This is where all the people who are focussed on coming up with new things live." We came around a corner into a big open space, where a man stood underneath a whirring, airborne piece of machinery that brought to mind a flying water bug. "Is something flying, Carl?" Gitlin asked. "Is it O.K. to be seen?" The bug whirred into Carl's hand and went silent, and Carl, mumbling an apology, darted through a door, on which a sign read, "Nano Lab—Turning Giant Dreams Into Tiny Realities."

We followed him through it, and encountered Matt Keennon, the Nano Lab's director, who was busy testing a small motor. Asked what he was working on, he replied, "Unrelated work I can't talk about." His workstation was cluttered with model airplanes and helicopters, and tiny parts and tools: "Look at my tweezer collection. I use all of them, which is kind of absurd."

Keennon, an engineer, physicist, and all-around gadgeteer, was the leader of the team that created the Nano Hummingbird, a mechanical ornithopter that looks almost exactly like a real hummingbird. In 1994, the RAND Corporation put out a paper about the feasibility of micro-aircraft; in 1996, Keennon helped set up a lab at AV to build prototypes, among them a propeller-driven vehicle called the Black Widow, elements of which were fundamental to the development of the Raven. In 2005, the Pentagon's Defense Advanced Research Projects Agency, better known as DARPA, asked for a three-inch biologically inspired flying machine, with video capacity—say, a tiny spy drone disguised as a bird—and Keennon set to work.



He had derived some inspiration for the Hummingbird from drawings of flapping-wing aircraft designed in the nineteenth century by Victor Tatin and Alphonse Pénaud. For its flight mechanism, he relied, as most micro-drone makers do, on microprocessors and gyroscopes taken from smartphones. "All I did was take a two-hundred-year-old design and attach cell-phone parts to it," he said jokingly. "Of course it will fly!" It wound up being six inches, not three—anything smaller couldn't carry enough battery to power itself. He experimented with three hundred and ten wing designs. A display of a few dozen of them brought to mind an array of sail shapes at a mouse yacht club.

"This was not a billion-dollar program," Keennon said. It was a four-million-dollar program, and took almost five years. "We fly as soon as possible with whatever we have," he added. "Paul MacCready's thing was to slap stuff together, test it, get feedback. Don't spend months analyzing it. Test stuff quickly." (MacCready died in 2007.)

Keennon removed the Hummingbird's dappled magnetic shell to show off the innards: tiny cables and pulleys and pushrods. He turned it on, and the wings started to whirr at thirty flaps per second, despite being powered by a tiny 2.7-watt motor—about one three-hundredth of a horsepower. "Look at that—aww, that's so cool," Keennon said. He reattached the shell, and the hummingbird leaped into the air with a pleasing buzz, bobbing around our heads, hovering and darting. Keennon had once set it free among some real hummingbirds, and one of them, apparently mistaking it for a real bird, had relentlessly attacked it. You could easily imagine that human beings, discussing military secrets in a palace garden or a love affair in a park, would have a hard time telling the difference, too.

One of the early U.A.V. pioneers was a Canadian aeronautical engineer named Tad McGeer, who, in the early nineties, helped design a drone that collected meteorological and atmospheric data. McGeer and a fellow highly educated and Pynchonesquely named tinkerer named Andy von Flotow—both

Stanford Ph.D.s living in the Columbia River Gorge, east of Portland—started a company called Insitu. Weather being less lucrative than warfare, they decided to get some attention for their drones by being the first to send an unmanned plane across the Atlantic. Their Aerosonde, with a ten-foot wingspan and a price of fifteen thousand dollars, was up against the Global Hawk, the hugely expensive giant military drone. The Aerosonde made it first. McGeer soon realized that drones could be a boon to tuna fishermen; U.A.V.s were cheaper, more portable, and less dangerous than the helicopters they'd been using to search the sea for pods of fish. He and von Flotow developed a launching and landing apparatus and designed a system called the Seascan. The military took note, and Boeing, a collaborator, pushed a variant called the ScanEagle, for the battlefield.

"Our private investors viewed the wars as opportunities for making money," McGeer told me. McGeer left the company and started a new one, not only because he was opposed, on principle, to making war machines but because, for someone eager to devise civilian uses, the economics didn't add up. "Military contracting is socialism," he said. "Military contractors often work on a cost-plus basis, and there's no incentive to be efficient. A drone might cost the taxpayer a couple of thousand dollars per flight hour. But in civilian applications, in order to compete with manned aircraft, flight time needs to cost hundreds of dollars an hour. What incentive does Insitu have to build a civilian business at that price? Let's say it offers drones to the police or to some farmers for a couple of hundred an hour. Then the military guys will say, 'We want that price, too.' The incentive to be efficient is not very high."

McGeer doesn't blame the F.A.A. for the fact that drones aren't everywhere; Canada and Australia have liberal drone rules, and yet drones have been slow to catch on in those places. Nor does he blame technology: "The technology to do all this stuff has been around for two decades." Rather, he blames simple supply and demand. For most purposes, manned flight is still relatively cheap.

He went on, "The market is small and not attractive to industrial giants. It's not like cell phones. So there's room for guys like me to have some fun technically, do some good, maybe make a living. Frankly, I don't see many applications for the aircraft I'm developing. It's useful in remote areas. Alaska, the Northwest Territories. Offshore, for weather research or finding fish." He added, "The skies are not going to be dark with unmanned aircraft. I wish it were otherwise. One likes to see one's work put to use."

There are inexpensive and remarkably agile drone toys already on the market. A French company called Parrot sells a popular remote-controlled video-enabled quadrotor drone, controllable by iPhone. It costs just three hundred dollars. It is not very difficult or expensive to tweak technologies like this one to suit banal but potentially lucrative purposes. Chris Anderson, the editor of *Wired* and the godfather of the do-it-yourself U.A.V. movement, told me about one that you can deploy as a kind of personal robo-videographer. You go surfing or skiing, and the drone follows you around, logging footage. One could imagine each of us having our personal paparazzo—every life a reality show, with an audience of one.

"The Internet was once a military thing, but we colonized it and took it away from them," Anderson told me. "Right now, drones are scary. I'd like to make them unscary." He added, "What if all the U.A.V.s in the air don't say 'L.A.P.D.' and, instead, say 'Pizza Hut'?"


What if they don't say anything at all? What if they are unmarked, unregistered, unseen? In mechanical terms, Keennon's Nano Hummingbird is at the cutting edge, but several labs around the country are working on tiny drones that can fly autonomously and in swarms. These are known as micro aerial vehicles, or M.A.V.s. Researchers at Harvard are trying to develop "robobees," which would mimic the mechanics and the hive behavior of real bees, whether in the service of pollination or of stealth surveillance. So far, no

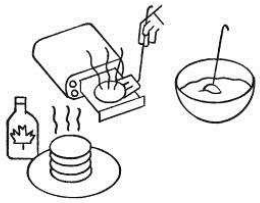
one has been able to solve the problem of delivering enough power to keep them aloft; the power itself, in the form of a battery, is too heavy. The payload problem—a camera, computing power, or anything that would make them useful in some way—is still quite far off. Then, there's the challenge of autonomy. "You might as well talk about training birds and bees to do what we want them to do," McGeer said. "We don't have any idea how to do either; they are equally feasible."

The engineers and computer scientists in the universities play a funny game of trumpeting their progress—the Harvard group says its robobees are two and a half years away—and downplaying the implications. One afternoon a few weeks ago, I paid a visit to Vijay Kumar, a mechanical-engineering professor at the University of Pennsylvania's General Robotics, Automation, Sensing & Perception lab (GRASP). Kumar and a team of graduate students from multiple disciplines and departments have developed an array of small quadrotors that can fly autonomously, pull flips, dart through moving hoops, seek out their own power supply, and fly in formation. YouTube videos of this last feat—sixteen quadrotors spreading out like a squadron and then weaving in the shape of a figure eight, like a Russian hockey team, or a band of them playing the James Bond theme on an array of prepared instruments—have gone viral, and have given rise to widespread wonder (or terror).

"I would feel a sense of accomplishment for the field if I could advise you to be frightened," Kumar told me. "Yesterday, I watched 'I, Robot,' with Will Smith, and I was thinking, How ridiculous this whole thing is. We are nowhere close to it."

Kumar was sitting in his office, dressed in a leather jacket and Dolce & Gabbana eyeglasses. He held out a prototype of the smallest quadrotor, known as a Nanoquad. It was designed by his students Daniel Mellinger and Alex Kushleyev, who had also made the videos that went viral. It was about the size of a 45-r.p.m. vinyl record and was basically a computer board attached to four rotors. It weighed fifty-two grams.

"In terms of mechanical ingenuity, the Hummingbird is amazing, but I'd argue that, pound for pound and dollar for dollar, this is superior and much simpler," he said. "We are the only people to bring the physical design, the algorithms, the software for autonomous operation together in a holistic approach." He added, "Robobees—they are smaller and in theory more agile and, in my mind, cooler. But you can't put stuff on them. And so they're harder to commercialize. And if you don't make something commercially viable you can't make it useful."



(Angle, the iRobot C.E.O., who is in the commercial-viability business, didn't yet see the use of the bees, either. He felt similarly about the Nanoquads: "They're very, very cool, but you have to ask yourself, 'So?' Is there a there there beyond the cool? It's high on the cool, low on the useful." He called them "solutions in search of markets.")

Kumar's work, for the most part, is funded by the Pentagon, but Kumar says that he isn't interested in the potential military applications. The quadrotors are ideal for teaching physics and math, he says, and they have many potential peaceful uses: search and rescue, emergency response, monitoring chemical and gas leaks. He imagined a scenario where sensor microphones in a Philadelphia neighborhood might be able to triangulate the exact location of a gunshot, and within moments a swarm of small drones could arrive on the scene, to suss it out for the cops.

The lab, next door, was a big high-ceilinged room, with half a dozen grad students busily fiddling with flying machines. One end was cluttered with desks, remote-control modules, and model helicopters in various states of dismemberment. The other end was an open space, a kind of stage of white sheets, encircled by what looked like red spotlights. These were infrared lights, part of a motion-capture system that the Penn guys called Vicon, after the company that makes it. "The quadrotors have reflectors on them, like Gollum, in 'The Lord of the Rings,'" a grad student named Justin Thomas said. "They tell us where they are in that space." The quadrotors manage the act of flight—pitch, yaw, and so forth—on their own, but they can't navigate without the Vicon. It's hermetic robotics, you might say. The idea is that at some point they won't need the Vicon.

The students set a larger quadrotor aloft—a Pelican, outfitted with a laser scanner and an Xbox 360 Kinect, for depth perception. This one could navigate on its own, without the Vicon, and seek out its own charging station. "You could envision it perching on power lines to recharge," one of the students said.

Another, Shaojie (Frank) Shen, had designed software that enabled the Pelican to enter a building and build a map of its environs. The map appears on a remote screen, a blueprint gradually materializing as though out of thin air. "It constructs the world around it," a student said. Programmed to be curious, it seeks out new territory on its own. "That is our most sophisticated automated robot," Kumar told me. It zigzagged about the lab, and the dimensions of the room gradually appeared on a laptop.

Thomas had been working on getting a quadrotor to swoop in and, while plotting its own trajectory, pick up an object without stopping. He showed a video, from the week before; outside, the drone grabbed a ground robot called the Octoroach, carried it in through a window, and deposited it inside, then perched on a nearby window sill, to wait for the Octoroach to do its job, whatever that might be. I recalled a conversation with a warfare expert and robotics Cassandra who'd told me that robots now had the intelligence of insects, and that, according to Moore's Law, in seven years they'd have the intelligence of rats. Kumar may not be interested in the military, but the military is surely interested in him.

Another student showed up and pulled a Nanoquad from his backpack. "Which version is that?" Thomas asked.

"The current final version," the student said. He mentioned that he was going out to California the following week for an interview with AeroVironment. ♦

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**NEWYORKER.COM/GO/OUTLOUD**
A conversation with Nick Paumgarten.