

Drones

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ABSTRACT

Drones represent the latest revolution in civilian aviation. The sophisticated miniaturized electronics, electric propulsion systems, low cost, and ability to capture close-in imagery make microdrones attractive assets for aerial activities that have never before been feasible. Larger configurations—machodrones—have longer

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endurance and range and the capability to fly at higher altitudes. They will complement manned airplanes and helicopters in missions for which their cost proves advantageous or for which manned flight is too hazardous or otherwise undesirable. Specific features of electric propulsion, control systems, and the capability of autonomous flight maneuvers will stimulate new types of missions for microdrones; in other instances, existing mission requirements will lead the design of machodrones. The Federal Aviation Administration (FAA) is seriously behind in delivering on its Congressional mandate to integrate civilian drones into the National Airspace System. Unless the FAA moves more quickly and appropriately, thousands of microdrones will operate commercially despite the FAA's current prohibition. A novel regulatory approach is desirable for microdrones, while existing regulatory approaches can be adapted for machodrones. Over the next several years, politics, labor markets, and the private supply chain will alter the shape of the aviation industry to accommodate these new small robots, stimulating economic growth.

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I. INTRODUCTION

When many people hear the word “drone,” they think of missions against al Qaeda in Afghanistan, Pakistan, and the Middle East.¹ What the armed forces and intelligence agencies do halfway

1. The fiscal year 2012 inventory ranges from the Navy’s 44,600 pound aerial combat X-47B and the Air Force/Navy 14,900 pound Global Hawk to the Army’s 4.2-pound, hand-launched Raven. UNDER SEC’Y OF DEF. FOR ACQUISITION, TECH. & LOGISTICS, U.S. DEP’T OF DEF., REPORT TO CONGRESS ON FUTURE UNMANNED AIRCRAFT SYSTEMS TRAINING, OPERATIONS, AND SUSTAINABILITY (2012), *available at* <https://www.fas.org/irp/program/collect/uas-future.pdf>. In 2010 the Air Force had 192 drones, the Army 364, the Navy 15, and the Marine Corps 28, in addition to some 6,200 small, unmanned aircraft, which require less support. U.S. GOV’T ACCOUNTABILITY OFFICE, GAO-10-331 UNMANNED AIRCRAFT SYSTEMS: COMPREHENSIVE

around the world, however, does not mean that the same thing is inevitable on US soil. It reveals something about technological capabilities, but it does not reflect the factors that will shape business and political decision-making in the United States.

What is clear is that drone technology is evolving rapidly and that microdrones—what the Federal Aviation Administration (FAA) calls “sUAS” (small unmanned aircraft system)—already have the capability to supplement manned helicopters² in support of public safety operations, news reporting, powerline and pipeline patrol, real estate marketing, agriculture, and construction. Microdrones weighing five pounds or less and priced at the \$1 thousand level are on the market now.³ They can provide crucial support in circumstances where manned helicopter support is infeasible, untimely, or unsafe. They can fly short-range missions at heights and in proximity to targets that are too dangerous for manned helicopters. Indeed, they are flying such missions legally in Europe and other parts of the world and illegally in the United States. But their commercial deployment, even for testing and demonstration, is not legal in the United States because of the FAA’s sluggish implementation of its congressionally mandated plan to integrate drones in the national airspace.

Microdrones and helicopters will not compete head-to-head with each other. Each has advantages in its respective sphere. Microdrones provide a new capability for inexpensive, close-in, aerial activities. They will carve a new sphere for aviation support, thereby benefitting industries that have not had aviation support available to them at a cost they could afford. The ready availability of microdrones

PLANNING AND A RESULTS-ORIENTED TRAINING STRATEGY ARE NEEDED TO SUPPORT GROWING INVENTORIES (2010), available at <http://www.fas.org/irp/gao/uas2010.pdf>.

2. See *infra* Part II.B.1. Rotary wing drones have the distinct advantage over fixed-wing drones in that they do not need a specially prepared place to operate from. In addition, depending on their basic design, they may have much simplified control systems. See *infra* Part II.A.2. Accordingly, this Article focuses on rotary wing drones instead of fixed-wing drones. Nevertheless, fixed-wing microdrones may be preferable to rotary-wing configurations for some missions, such as geographical mapping, powerline and pipeline patrol, and other activities benefitting from the greater range that fixed wing aircraft always have over similarly sized rotary wing aircraft.

3. Assessing the impact of drones requires differentiating between two kinds: “microdrones”—what the FAA calls “sUAS”—and “machodrones,” larger unmanned aircraft intended to be integrated into the flow of manned aircraft. Microdrones, hard to distinguish from model helicopters, are already widely available; only FAA restrictions on “commercial use” have slowed their productive deployment. See *infra* Part III. The University of Missouri’s Drone Journalism program suffered a setback when the FAA told it to stop flying its drones on news gathering missions until it obtained a Certificate of Authorization. See Scott Pham, *Missouri Drone Journalism Program to Reconfigure Goals After FAA Letter*, MISSOURI DRONE JOURNALISM PROGRAM (Aug. 21, 2013), <http://www.missouridronejournalism.com/2013/08/missouri-drone-journalism-program-to-reconfigure-goals-after-faa-letter/>.

will tempt users to deploy them even before their operational use is legal.

Larger drones—“machodrones”—are not yet widely available outside battlefield and counterterrorism spaces. Approximating the size of manned helicopters, their design is still in its infancy as designers await greater clarity in the regulatory requirements that will drive airworthiness certification.

The central thesis of this Article is that microdrones will be deployed in support of news gathering, law enforcement, and pipeline and powerline patrol activities long before machodrones will be available or cost effective. Machodrones face a much more arduous regulatory regime, considered in more detail in Sections III.A.2.a.i and IV.A, and the result of meeting regulatory requirements will drive up their price and limit their operational flexibility.

Part II evaluates drone technology and design and considers how existing and probable drone capabilities satisfy mission requirements. It draws upon the authors’ collective experience in flying news helicopters, giving helicopter flight instruction, practicing and teaching law, flying drug surveillance missions, evaluating best practices for helicopter support for public safety activities, and in practicing aeronautical engineering. Part II.B concentrates on electronic news gathering,⁴ law enforcement support,⁵ and pipeline and powerline patrol because these activities are most likely to benefit from drone operations.

Part II.B’s analysis and conclusions with respect to microdrones are supported by empirical results obtained from a series of flight tests of currently available microdrones. Its assessment of machodrone deployment necessarily is more speculative. There, the Part explains the engineering design process and identifies the strengths and weaknesses of existing technologies compared with likely regulatory requirements.

If the FAA wants to achieve its goal of managing the introduction of these new flight technologies into the national airspace system safely, it must accelerate the regulatory process and do a

4. See generally DAVID GOLDBERG ET AL., REMOTELY PILOTED AIRCRAFT SYSTEMS AND JOURNALISM: OPPORTUNITIES AND CHALLENGES OF DRONES IN NEWS GATHERING (2013) (assessing desirability of using drones in news gathering), available at https://reutersinstitute.politics.ox.ac.uk/fileadmin/documents/Publications/Working_Papers/Remotely_Piloted_Aircraft_and_Journalism.pdf.

5. These two uses are similar in many respects: the nature of the flight profiles, relatively low and relatively stationary; the equipment required, high-definition cameras with, for law enforcement, infrared imaging capability; and the use of a pilot and a sensor monitor, usually called a Tactical Flight Officer (TFO) in law enforcement, and a photojournalist, usually abbreviated to “photog” in news gathering. The capability to supplement or supplant these manned helicopter uses are similar for both industry sectors.

better job of matching regulatory requirements with mission reality and likely aircraft characteristics. Integration of machodrones will take longer, and the FAA has more time to work with stakeholders to evolve a framework to test the limits of remote control technologies as substitutes for pilots in the cockpit.⁶ The main questions here are not whether the FAA will be able to channel technology, but whether the ultimate cost and capabilities of machodrones will make them attractive to purchasers and operators and whether actual vehicles will be able to compete with manned helicopters.

The Article begins, in Part II, with an exploration of drone technology and what it suggests about drone design. It describes law enforcement and news gathering missions that could be performed with existing designs—if FAA regulations permitted it—and then probes particular technology developments that would enhance such missions.

Part III moves to consider legal restrictions, focusing particularly on the FAA’s congressionally mandated effort to adapt its regulations to permit drones to be integrated into the National Airspace System, and concludes with a projection of when different kinds of operations will be permitted. These regulatory initiatives necessarily are intertwined with further technology development, and this relationship is considered in some detail.

Parts IV and V project the likely future of drones, considering supply chain factors, labor markets, and politics.

The authors provide more detailed analysis of the FAA’s notice of proposed rulemaking for microdrones in two sequels to this Article.⁷

II. POSSIBILITIES

Aircraft design, like politics, is the art of the possible. But even more than politics, aircraft design is the art of making trade-offs. Howard Hughes built the impressive “Spruce Goose”—an eight-engine wooden aircraft intended to serve World War II transatlantic logistics needs that was unable to fly higher than seventy feet off the ground.⁸

6. Now, drones are flown with an operator—what the Article refers to as a “DROP” (Drone Operator). In the future, drones will be flown on their own. *See infra* Part II.A.3.

7. *See* Henry H. Perritt, Jr. & Eliot O. Sprague, *Developing DROP Discipline: Training and Testing Operators of Small Unmanned Aircraft Systems*, HASTINGS SCI. & TECH. J. (forthcoming 2015) [hereinafter Perritt, *Developing DROP Discipline*] (focusing on standards and infrastructure for qualifying DROPs); Henry H. Perritt, Jr. & Eliot O. Sprague, *Law Abiding Drones*, COLUMBIA SCI. & TECH. L. REV. (forthcoming 2015) [hereinafter Perritt, *Law Abiding Drones*] (focusing on vehicle characteristics and automation potential).

8. *The Spruce Goose*, EVERGREEN AVIATION & SPACE MUSEUM, <http://evergreenmuseum.org/the-museum/aircraft-exhibits/the-spruce-goose/> (last visited Feb. 2, 2015).

Trade-offs are a function of the technologies available when the design decisions are made. Technologies change. The question in the background for any aircraft design is how many past design decisions should they revisit. Usually, the answer is “not many.” Empirical results and customer acceptance are well-established for existing designs, and airworthiness certification is far less demanding when a proponent approaches the FAA with a modification of an existing design rather than something completely new.

Sometimes, new mission concepts lead to completely new designs, as the need for high-altitude reconnaissance led to the U-2, the need for intercontinental ballistic missiles to deliver multiple independently re-targetable warheads led to inertial guidance systems, and the goal of putting a man on the moon led to the multistage Saturn rocket with a small orbiter payload.

Other times, the practicability of new technologies causes people to dream up new missions. The helicopter, which first became practicable after World War II, is an example. It caused people to wonder what we could do if we did not need runways and could remain stationary in the air.

In a market economy, neither the new-mission-invites-new-design nor new-technologies-inspire-new-missions process is unidirectional. Engineers and entrepreneurs come up with new design ideas all the time. Operators go shopping for systems that can perform new missions. When their ideas resonate with each other, something new happens, and the market either accepts or rejects it. In the worlds of law enforcement and electronic news gathering (ENG), mission will drive design for machodrones and technology will inspire new missions for microdrones.

Mission profiles for law enforcement support and for ENG are well-established and well-accepted by the decision-makers of both communities. Although police departments and television stations are always willing to redefine their air-support missions to take advantage of new technologies, considerable inertia discourages a complete rethinking of aerial support. Accordingly, one part of the growing revolution will be shaped by interest in having drones do the tasks that police and ENG helicopters do now. ENG machodrones would look similar to current ENG helicopters. Microdrones lack the capability to support that kind of ENG.⁹ The news industry has certain expectations of news-gathering helicopters, like speed and capability. Thus, ENG drone performance would need to be similar to existing ENG helicopters. Likewise, the law enforcement community

9. Camera equipment weights would disqualify microdrones from the ENG world. Current ENG helicopters are deployed with 200–400 pounds of ENG equipment.

is comfortable with its existing helicopter designs, which look very much like ENG helicopters.

At the other end of the spectrum, however, for both law enforcement and ENG, the new microdrone technologies will stimulate the development of new kinds of missions.

The following sections survey the technologies most relevant to law enforcement support and ENG, identifying developments that can enable new design trade-offs.

A. Technologies

Designing an air vehicle that does not carry a pilot or passengers opens up design constraints that historically have driven size, weight, and power requirements. Now, the long-standing debate over the relative merits of man versus unmanned spaceflight is moving to aviation more generally. It raises the question: how can aircraft be flown safely from the ground with no one actually aboard? To do that requires sensory input for the drone operator (DROP) roughly similar to what a pilot in the cockpit has and some robust link between the DROP and the aircraft.

One can imagine a conversation about new air-vehicle designs:

An engineer says to a colleague: "We got a helicopter that weighs 2,200 pounds. What happens if we don't need to have the pilot and the photog onboard? They'll stay on the ground."

"That gives us another 400 pounds of payload."

"Wait a minute? Why was it this big in the first place?"

"To carry the people and to carry the fuel."

"But if we don't have the people, we don't need as much fuel. What could it do if we scale it way down, as much as by a factor of a hundred or a thousand?"

And so the design chase is on.

The following subsections consider the technologies central to this reconfiguration: electric propulsion of lighter vehicles, design of DROP ground stations, and the wireless links between the vehicle and the DROP.

1. Electric Powerplants

While electrical propulsion systems are not as common in manned aircraft and larger drones because of battery weight, they are the predominant system in microdrones. Manned helicopters must be big enough and have enough power to carry a human pilot. On the other hand, unmanned helicopters can be much smaller. And, at smaller sizes, electric propulsion systems become practicable, as

multiple rotors can be driven by small electric motors. Changing revolutions per minute (RPM),¹⁰ rather than changing the pitch of the blades, varies the thrust and thus eliminates the complexity of pitch-change mechanisms.

Electrical propulsion systems are desirable because they simplify drive-train and control-system requirements and features.¹¹ Electrical propulsion systems do not require mechanical gearboxes or mechanical shafts, all of which are sources of energy loss in piston engine or turbine-powered aircraft. Instead, appropriately sized wires transfer electrical power from the battery or generator to electric motors powering the rotors. In addition, because electrical motors have more favorable torque output over a wide range of RPM, rotor thrust can be varied efficiently by changing RPM, obviating the need for blade-pitch variation, with its associated mechanical complexity.

2. Control Systems

Well-trained human beings are extremely good at integrating very fine and rapidly changing sensory inputs and responding appropriately, as anyone knows who can fly a helicopter or play tennis, golf, or the piano. Robots have been around for a long time, but it is only recently that robotics has gained the capability to replicate very fine human coordination.¹²

Designing systems for controlling aircraft from the ground requires attention to three cooperating subsystems: the ground control station, the subsystems aboard the aircraft for collecting data that the pilot would otherwise sense directly and for applying his control inputs to hardware on the aircraft, and connecting the two. Each influences the others. For example, a high-resolution video display for the DROP does not assist him in flying unless cameras aboard the aircraft feed the displays with the requisite high-definition imagery. Even if the DROP is highly skilled in responding to sensory inputs, his

10. The torque available from piston and turbine engines peaks at a particular RPM and falls off sharply at higher and lower RPMs. See *Power and Torque*, EPI INC., http://www.epi-eng.com/piston_engine_technology/power_and_torque.htm (last updated Mar. 11, 2011) (explaining why torque falls off at lower and higher RPMs in piston engines and providing graphs). The torque available from an electric motor is greatest at zero RPM and falls off gradually as RPM increases, over a much wider RPM range than for piston and turbine engines. *Electrical Motors—HP, Torque and RPM*, ENGINEERING TOOLBOX, http://www.engineeringtoolbox.com/electrical-motors-hp-torque-rpm-d_1503.html (last visited Feb. 2, 2015).

11. See Part II.A.2 for a fuller explanation of control system simplification.

12. See TED, *Raffaello D'Andrea: The Astounding Athletic Power of Quadcopters*, YOUTUBE (June 11, 2013), <https://www.youtube.com/watch?v=w2itwFJCgFQ>.

fine control movements have to be transmitted to the aircraft quickly and change its flight orientation.

The following subsections consider the ground station, the onboard data collection subsystem, and the link. Any piston- or turbine-engine aircraft has a means for translating the control inputs received from the human operator into mechanical forces applied across control surfaces to the pitch rods for the main and tail rotors in helicopters. The same means used in simple systems to reduce pilot effort or in more sophisticated autopilots to maneuver helicopters are a straightforward way to do this. Servo mechanisms convert small pilot forces on the controls into larger forces on rotors and control surfaces.¹³ “Fly-by-wire” systems convert pilot control inputs to electrical signals that drive mechanical servos.

Electrically powered multirotor aircraft use on-board computers to translate control inputs into differential electrical currents that vary rotor RPM asymmetrically.

a. “Cockpit” Design

If the analysis in this Article is correct, then machodrone DROPs will need visual information comparable, insofar as practicable, to what they would have if they were in the cockpit. Microdrone DROPs do not need this, because they keep their vehicles and the vehicle’s surroundings in sight. For machodrones, one can envision a ground station layout with a multiplicity of high-definition video screens that provide real-time imagery captured from multiple cameras on the drone. The images on the screens would replicate a field of view roughly 270 degrees laterally and 90 degrees up and down.

13. See Ivan A. Getting, *Servo Systems*, in *THEORY OF SERVOMECHANISIMS* 1, 1 (Hubert M. James et al. eds., 1947), available at <http://www.jlab.org/ir/MITSeries/V25.PDF> (“[A] servo system involves the control of power by some means or other involving a comparison of the output of the controlled power and the actuating device. This comparison is sometimes referred to as feedback.”).

In a typical remotely controlled model helicopter, for example, a small electric motor rotates or otherwise moves a shaft to a position set by the user and holds it there until the user commands a different position. *How to Choose the Right Servos for your RC Helicopters*, RCHELICOPTER, <http://www.rchicopter.com/category/rc-helicopter-servos/> (last visited Feb. 2, 2015). The source of power—the actuator—can be hydraulic as well as electrical, and typically is on larger, manned helicopters.

The Piccolo II is a 7.7-ounce avionics package that offers a full-featured automatic pilot and data link channels for drones. UTC AEROSPACE SYS., CLOUD CAP TECHNOLOGY PICCOLO II: EXPANDED CAPABILITY FOR ADVANCED APPLICATIONS 1–2 (2014), available at <https://www.cloudcaptech.com/Sales%20and%20Marketing%20Documents/Piccolo%20II%20Data%20Sheet.pdf>.

This requirement will be mitigated to the extent that machodrones utilize electronic sensors, radar, and Automatic Dependent Surveillance-Broadcast (ADS-B)¹⁴ for traffic and terrain avoidance.¹⁵ Ensuring adequate field of view is possible with the multiplicity of cameras and video screens. Zoom lenses theoretically would give the DROP greater visual acuity, but it takes longer to zoom a lens, even with the best human-factors design, than it does to swivel your head and focus on a particular object.

Providing depth perception, however, is a challenge without an obvious solution. Depth perception is important in spotting other traffic. For example, the FAA's standards for pilot medical certificates require depth perception, even in pilots with serious visual deficiencies in one eye.¹⁶ But depth perception is not possible with even the best two-dimensional image produced by the best monocular camera. Three-dimensional movie and medical technology, both of which use two cameras aimed from slightly different angles and special viewers, might address the depth perception problem.¹⁷

The complexity of two cameras, however, which would require shooting each angle with the correct aiming points and fields of view, would complicate the sensors on the drone and would be collateral to mission equipment. Therefore, they would be necessary only for control and traffic separation, thus adding weight and power consumption unnecessary on a manned helicopter. Likewise, the DROP might find it cumbersome to wear 3-D goggles to look at his display.¹⁸

In addition, the human perceptual apparatus has the capacity to focus instantly and concentrate on a particular object within the field of view. Cameras, of course, can pan and zoom, but they cannot

14. See *infra* Part III.A.2.b.

15. Current research and development suggests other capabilities that might be necessary to replicate what is available to a human pilot in today's cockpits. A combination of radar, visual imaging, and GPS-based geographic positioning could allow a camera or radar sensor to be directed precisely at the position where ADS-B reports conflicting traffic.

16. See *Guide for Aviation Medical Examiners*, FED. AVIATION ADMIN., https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/aam/ame/guide/app_process/exam_tech/et/31-34/mv/ (last modified Aug. 31, 2011).

17. Research on laproscopic surgery using two-dimensional flat-panel displays compared with three-dimensional simulation with da Vinci cameras and polarizing glasses showed significant improvements in performance times and surgeon satisfaction with the 3-D simulation. It also showed, however, that experienced surgeons use monocular cues to compensate for lack of depth perception, including motion parallax by shifting the camera, relative position and size of instruments and anatomical structures, and shading of light and dark. Kazushi Tanaka et al., *Evaluation of a 3D System Based on a High-Quality Flat Screen and Polarized Glasses for Use by Surgical Assistants During Robotic Surgery*, 30 INDIAN J. UROLOGY 13 (2014), available at <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3897045/>.

18. Co-author Sprague is dubious about whether this is a relevant concept at all.

do it as quickly as a human eye can focus its visual concentration.¹⁹ The latency in image shift is a function of the DROP (a) moving a mechanical controller of some kind, (b) letting the servomotors in the camera to respond, and (c) allowing for latency in the connection. Even in hardwired systems, such as those installed in ENG helicopters, the latency is appreciable. It will be even greater when the video camera control inputs must traverse the uplink, depending on the bandwidth of the uplink and computer processing time on both ends.

In sum, empirical work should precede any commitment to 3-D photography or any conclusion that there is a serious inherent problem with providing good visual information to the DROP.

The elaborate hardware and software required to replicate the cockpit view, while not challenging technologically, suggest that a more promising approach is to take the DROP out of the collision avoidance loop and rely on sensors and collision avoidance algorithms as the primary means of traffic separation.

b. Cameras

Law enforcement support and ENG depend on good imagery. Accordingly, drones must be equipped with stabilized video cameras similar to those installed on ENG helicopters.²⁰ These camera systems have gimballed mounts to neutralize helicopter vibration and servo motors that permit quick changes in azimuth and elevation relative to the helicopter's heading as well as quick zooming.

The FAA's plans for drone integration into the National Airspace System (NAS) reinforce this need. As Part III.A.2.d explains, traffic separation in the NAS depends on a see-and-avoid philosophy. This is not likely to change until well after 2020. That means that machodrone DROPs must have real-time video imagery captured from the drone—and it must be good imagery. But one camera is not going to be enough. A human pilot has a nearly 180-degree horizontal field of view—95 percent away from the nose on each side—and 60 degrees

19. If the video display available to the DROP exactly replicates what he could see from the cockpit, he can use this perceptual flexibility just as he could in the cockpit.

20. For example the FLIR Ultramedia HD system contains a Sony HDC-1500 camera, a 3-chip, 2/3-inch CCD device. It has 2.2 effective megapixels and 14-bit bit depth. The greater bit depth, compared with the HDR-AS10 consumer camera, permits greater precision in representing the brightness of each color. A competing product from Cineflex uses the Sony HDC-2400 camera. See *Cineflex Media*, CINEFLEX, <http://www.cineflex.com/Our-Products/Cineflex-Media> (last visited Mar. 1, 2015).

upward.²¹ He can shift his field of view in an instant by rotating and inclining his eyes and turning his head.

Replicating this visual perspective for the DROP is challenging. It will require multiple cameras, as many as five—one pointing forward, one pointing left, one pointing right, one pointing up, and one pointing down—and a multiplicity of display screens arranged so that the DROP can see what he would see from the cockpit.

Infrared imagery, in addition to color imagery, is desirable for law enforcement applications but not for ENG applications. Infrared imaging equipment is available for machodrones and is beginning to be available for microdrones. For full-sized manned helicopters, infrared equipment weighs about one hundred pounds and consumes about 350 watts of electrical power.²²

Night vision equipment may be more necessary for a DROP to fly a machodrone at night than for a pilot in a helicopter cockpit. When microdrones are flown, for line-of-sight the DROP will simply use the boom orientation lights. Even the best cameras have limitations on low-light image capture compared with the human eye. If the camera cannot capture an image, the DROP cannot see it on his screens. Night vision equipment may be desirable for law enforcement applications, but it is not relevant to ENG operations, unless news organizations develop a demand, not yet evident, for night-vision photography.

Any useful drone must have transceivers and antenna systems to downlink video imagery. Such systems are widely available for microdrones and their installation on machodrones is no more problematic than it is for manned aircraft.

The technology for video imaging is changing rapidly, fueled in large part by consumer demand for lighter, higher-resolution cameras that spare battery power. The weight, cost, and power consumption of cameras for law enforcement and ENG will fall dramatically over the next several years.

c. High-Bandwidth Wireless Data Links

Drones do not have a human pilot onboard; thus they must have a data link capable of transferring information about the drone's

21. *Resolution of the Human Eye*, BOUNDLESS (Nov. 14, 2014), <https://www.boundless.com/physics/textbooks/boundless-physics-textbook/vision-and-optical-instruments-25/the-human-eye-172/resolution-of-the-human-eye-621-6294/>.

22. See FLIR, STAR SAFIRE 380-HD (2012), available at http://www.flir.com/uploadedFiles/flirGS/Surveillance/Products/Star_SAFIRE_HD_Family/Star_SAFIRE_HD_Family/380-HD/flir-star-safire-380-hd-datasheet-ltr.pdf.

position and flight profile down to the DROP and of transferring control inputs up to the drone.

Remote control of flight vehicles is not a new undertaking. Space probes fly to Mars and collect samples on the ground²³ and deep-space probes penetrate the outer reaches of the galaxy, sending photography back to Earth.²⁴ None of these activities can be successful without robust control links and other data links.²⁵ In comparison to the demands of space-vehicle-control technology, the requirements for terrestrial drones are modest—well within the capabilities of existing technology.²⁶

Such data links comprise radio transceivers both on the ground and in the drone, operating on the same frequency, using compatible modulation²⁷ schemes and exchanging compatible data structures.

Data-link design involves determining frequencies, transmitter power, receiver sensitivity, and standardizing data structures²⁸ so that the transmitting and receiving units can understand each other. Depending on the distance from the DROP to the drone, relay stations may be necessary. The greater the demands on drone radio links, the greater the bandwidth and processing power in both on-board and

23. See *Mars Exploration: Investigating the Red Planet*, NAT'L GEOGRAPHIC, <http://science.nationalgeographic.com/science/space/space-exploration/mars-exploration-article/> (last visited Feb. 2, 2015) (describing Mars exploration by unmanned vehicles).

24. See *Voyager: The Interstellar Mission*, NASA, <http://voyager.jpl.nasa.gov/> (last visited Feb. 2, 2015).

25. See *Basics of Space Flight: Telecommunications*, NASA, <http://www2.jpl.nasa.gov/basics/bsf10-1.php> (last visited Feb. 2, 2015) (describing frequencies, signal strength, coding, modulation, and ground and airborne equipment); *Basics of Space Flight: Typical Onboard Systems*, NASA, <http://www2.jpl.nasa.gov/basics/bsf11-2.php> (last visited Feb. 2, 2015) (describing typical onboard systems); see also *Laser Telemetry from Space*, NATURE (July 26, 2002), <http://www.nature.com/news/2002/020726/full/news020722-8.html> (describing how the demands of high-quality video from space probes threaten to overwhelm available radio bandwidth); *NASA's Deep Space Network . . . Communicating with Interplanetary Spacecraft*, SPACE TODAY ONLINE, <http://www.spacetoday.org/SolSys/DeepSpaceNetwork/DeepSpaceNetwork.html> (last visited Feb. 2, 2015) (describing generally the network for communicating with space systems).

26. Obstructions to line-of-sight are not a problem, however, for space communications. Unmanned space vehicles also can tolerate much lower data rates in the control link, because they, unlike terrestrial drones, do not need to maneuver quickly. That means that the bandwidth required of drone data links is higher than that required for space communications.

27. Modulation is the combination of information with a basic radio signal, known as a “carrier.”

28. “Data structure” is the term used by computer scientists to refer to standard ways of exchanging information between computers or between different parts of the same computer system. The data structure for positional information transmitted to the DROP by a drone might have altitude in the first field, latitude in the second field, longitude in the third field, and so on. Each field must be defined in terms of its length and how the information is coded. The data structure for commands transmitted by the DROP to the drone could have collective position in the first field, cyclic longitudinal position in the second field, cyclic lateral position in the third field, and yaw position in the fourth.

ground equipment must be. At some point, trying to put a machodrone DROP in the same position as an on-board pilot will become infeasible because of limitations on bandwidth and processors. Moreover, greater range means greater latency, which introduces delays in control responses.

Each end of the link listens continuously to the other.²⁹ The sending side sends the pertinent data structures repeatedly, with changed values if the operator has moved one of the controls or the drone has changed position.

This technology is not without its challenges, however, as a variety of things can happen to corrupt or interrupt the data link. For instance, a burst of static from a lightning strike can cause a bit to be missed or a bit to be inserted. In addition, another radio signal on or near the data-link frequency for the drone can overpower the drone control signal.

When this happens, both ends of the data link must have a strategy for re-establishing communication if possible.³⁰ Or, if it seems hopeless to re-establish the link, the drone should go into an autonomous state and perform some maneuver that ensures safety, such as climbing to improve line-of-sight signal reception or autonomously returning to “home.”

Data links can be encrypted for security, using well-understood and widely available encryption algorithms.

Nevertheless, as drone use becomes widespread, and as the demand for higher quality video increases, the limitations on available radio spectrum will become a constraint. Wireless spectrum is already crowded with voice and data communications related to manned aircraft operation. Widespread drone use will crowd the spectrum further, although the FAA Roadmap assumes that the “communications spectrum is available to support UAS operations.”³¹

Most microdrones presently assign both their controlling and video downlink frequencies to the unlicensed WiFi bands. The availability of spectrum is not likely to be a problem as long as only one drone is flying within the range of the WiFi transceivers on the drone in the DROP station.

29. It does this by programming the computer algorithm on each end to run in the loop. It looks for new information, then processes it, and then asks for new information again.

30. They might step back for a short time interval and restart, looking for the beginning of a packet, in an attempt to resynchronize. Digital data structures have markers for the beginning of packets of data.

31. FED. AVIATION ADMIN., U.S. DEPT OF TRANSP., INTEGRATION OF CIVIL UNMANNED AIRCRAFT SYSTEMS (UAS) IN THE NATIONAL AIRSPACE SYSTEM (NAS) ROADMAP § 4.1 (2013), available at https://nppa.org/sites/default/files/UAS_Roadmap_2013.pdf.

But it will not be long before multiple drones are flying in the vicinity of a public safety incident or newsworthy event, which in turn may be located in an area where multiple residents and businesses are using WiFi in their ordinary activities. In such a situation, frequency congestion will occur, degrading performance for everyone and possibly interfering with effective drone control.

But the wider use of drones will stress spectrum availability only if it stimulates more demand for aviation support of law enforcement and news gathering. If the total amount of video downlink—the biggest user of spectrum—remains about the same as collected by manned helicopters now, supplemented by drone-collected video, video downlink spectrum requirements will not increase. The spectrum requirements for control links and ADS-B Out³² are relatively modest.

3. Autonomous Drone Flight

In the near to medium term, both microdrones and machodrones will be piloted in the sense that they will be controlled by a DROP at a ground facility who has, controls, and makes essentially the same sensory inputs that he would have if he were aboard.

Yet, technology permits drones to be autonomous: to fly some or all of their missions without a DROP.³³ Some can automatically navigate a pre-programmed flight plan defined as GPS coordinates marked on a map. The boundary between autonomous and piloted is not dichotomous. Current microdrones, for example, have autopilots that are capable of hovering without operator input, and many of them have a return-to-home feature that permits them to navigate back to the launching point if the control link is lost. At the other end of the autonomy spectrum, even if a drone is authorized to fly most of its mission autonomously, a DROP might make the takeoff and landing or might fly certain parts of the mission.

Microdrones with autonomous features are already on the market and cost well under \$1 thousand.³⁴ These microdrones have the capability of flying from waypoint to waypoint, programmed by the DROP on a movable map using familiar GPS mapping capabilities. With software that is currently available, the DROP can assign

32. See *infra* III.A.2.b.

33. But see FED. AVIATION ADMIN., *supra* note 31, § 4.1 (“Autonomous operations are not permitted. . . . Autonomous operations refer to any system design that precludes any person from affecting the normal operations of the aircraft.”).

34. See *infra* Part II.B.1 for an analysis of microdrones now on the market.

altitudes for each waypoint, direct the drone to hover or orbit at particular waypoints, and then to return to the launching point.

These autonomous features could give particular industries new capabilities. An autonomous drone assigned to a law enforcement formation, for example, could be programmed to fly a grid, or more complicated patterns, of particular streets in particular parts of the city, sending imagery back to a DROP and tactical flight officer. A drone assigned to a search-and-rescue mission could be automatically programmed to fly a standard search grid. In either case, the DROP and systems operator could concentrate their energies on looking for anomalous situations that might indicate the target of a search effort or criminal activity rather than flying the aircraft.

Possible roles for autonomous drones in news gathering are less clear. ENG helicopters, unlike police helicopters, do not engage in routine patrol according to predictable patterns; they fly ad-hoc to cover newsworthy events. An experienced traffic reporter and pilot, however, could conceivably program autonomous drones to perform a routine duty, such as traffic surveillance.

The implications of greater autonomy on performance, safety, and acceptance are hard to predict with any confidence. Labor costs would not necessarily be reduced, since it is quite unlikely safety considerations would permit an autonomous drone to operate without close human monitoring and control by personnel having the same skills required for non-autonomous operations. Autonomous drones will engender more opposition because of the perception that a human pilot can deal with unanticipated problems better than an autopilot. Indeed, only an anticipated problem can be programmed into autopilot software. Moreover, the greater capabilities of the software and the electronics necessary to perform autonomous missions safely undoubtedly will increase weight, cost, and power consumption.

B. Matching Mission and Design

Conventional mission concepts for law enforcement and ENG will drive design for machodrones, while new technologies will inspire new missions for microdrones.

Microdrones capable of performing useful missions are already available. While current regulatory requirements for their commercial use are presently cumbersome and, in some respects, irrational, the FAA projects eventual relaxation of the requirements.

The next two sections analyze designs and mission capabilities for the two basic categories of drones. Because machodrones are not yet widely available, the section on machodrones probes the design process more deeply than the section on microdrones, utilizing basic

aerodynamic principles and rules of thumb while speculating about cost.³⁵ The final section of this Part speculates about the possibility of combining manned helicopter operations with microdrones.

1. Microdrones

Microdrones provide an example of new technologies driving new mission concepts. The point is not that microdrones can do the same job that manned helicopters can. They cannot. But they can supplement helicopters.

a. Description of Authors' Flight Tests

Microdrones capable of useful missions already exist. The authors have flown several of them for educational purposes. The microdrone featured prominently in most press and media stories is the Phantom 2 Vision,³⁶ a quadcopter³⁷ with battery life of about a half-hour that flies as high as 500 feet at thirty to thirty-five knots. Priced at \$1,200, it weighs about 2.5 pounds and has a built-in high-definition video camera that is controllable in elevation by the operator, using an iPhone. The operator can see camera imagery while he flies and can download the video recording while in flight or after the vehicle lands. The aircraft also has an autopilot that keeps it stable in a hover when the operator makes no control inputs. If the control link is lost, the aircraft automatically flies back to its point of departure on that flight and lands.³⁸

Based on their experience with the Phantom and similar microdrones,³⁹ the authors assembled, through their drone research

35. One rule of thumb, for example, says that one horsepower is required for each ten to twenty-five pounds of weight and that the figure of merit (FOM) is 60–80 percent. FOM is a parameter used in helicopter design to represent the percentage of engine shaft power reflected in rotor torque. Sometimes FOM includes gearbox losses; sometimes it excludes them. These figures are validated by the descriptive facts for the Robinson R22 Beta II, which has a maximum gross weight of 1,370 pounds and a maximum continuous power rating of 124 horsepower. For a FOM of 60 percent, the weight per unit of power is 18.4; for a FOM of 80 percent, the weight per unit of power is 13.8, both well within the range of ten to twenty-five pounds per unit of horsepower.

36. *Phantom 2 Vision: Your Flying Camera*, DJI, <http://www.dji.com/product/phantom-2-vision/> (last visited Feb. 2, 2015).

37. A quadcopter is a rotorcraft with four main rotors, obviating the need for a tail rotor.

38. The authors have flown the Phantom 2 Vision for some ten to fifteen hours and confirmed its advertised capabilities. The camera does not have azimuth control, nor does it have a zooming lens, but there is no reason to believe that these features will not be added in future models or offered in competing products.

39. The DJI Inspire, introduced in late 2014, offers autonomous flight regimes beyond those offered by the Phantom and can accommodate bigger cameras with better gimbals. *See*

and development firm,⁴⁰ the Movonator,⁴¹ a microdrone they will use for recreational and educational purposes until FAA approval is obtained for commercial deployment.

The basic design has a lightweight carbon fiber body sized to accommodate upgrades. The flight control system has a magnetometer and GPS tracking. It is an octocopter, with eight booms and eight brushless electric motors with fixed-pitch rotors. It has range capabilities greater than the Phantom and, like the Phantom, comes with GPS, first-person view (FPV), and Bluetooth for iPad support. It also has a built-in Intelligent Orientation Control (IOC) to avoid control reversal as the orientation of the drone changes.

Typical microdrones have a fixed FPV camera mounting point and built-in regulators to convert the higher voltage of the main drone battery to the appropriate voltages to power FPV equipment and a gimbal. The drones also offer room for additional mission equipment such as higher quality video cameras, FPV gear, OSD, sonar sensors, telemetry radios, infrared cameras, and other devices. Bolt-on mounting points make it straightforward to mount sensors, cameras, and other devices.

All of these have built-in, high-definition cameras, capable of streaming real-time imagery back to the ground. They all have some level of automated hover and return-to-home capability and vary in

Inspire 1: Creativity Unleashed, DJI, <http://www.dji.com/product/inspire-1> (last visited Feb. 2, 2015). The DJI S900 offers still greater capabilities. See *Spreading Wings S900: Highly Portable, Powerful Aerial System for the Demanding Filmmaker*, DJI, <http://www.dji.com/product/spreading-wings-s900> (last visited Feb. 2, 2015). The Aerialtronics Altura is a larger entry, with a gross weight approaching ten pounds, endurance of up to fifty minutes, and a correspondingly larger payload. See *Payload Options*, AERIALTRONICS.COM, <http://aerialtronics.com/altura-zenith/payload-options/> (last visited Feb. 2, 2015). It is configured as a hybrid between a quadcopter and an octocopter, with two rotors on each hub. Dutch in origin, it is being marketed in Europe but not yet in the United States. Some European vendors quote a price of €8,000, approximately \$11 thousand. The IRIS+ Custom “Spec Ops” Package, priced at \$1,669, offers longer endurance, approaching an hour, and flexibility to configure according to user requirements, for example, by installing different cameras in the gimbal system. See *IRIS+ Custom “Spec Ops” Package*, AEROWORKS PRODUCTIONS, <http://shop.aeroworksproductions.com/IRIS-Custom-Spec-Ops-Package-ISpecOps.htm> (last visited Feb. 2, 2015). The 3DR Y6 Copter ARF (Special Order), priced at \$1,100, offers lower endurance, but flexibility in GPS waypoint autonomy. See AEROWORKS PRODUCTIONS, <http://shop.aeroworksproductions.com/3DR-Y6-Copter-ARF-Special-Order-3DRY6.htm> (last visited Feb. 2, 2015). The Turbo Ace X830-D RTF, one of several options priced at \$1,297, offers flight times of up to thirty minutes and payloads approximating two pounds. See *Turbo Ace X830-D*, WOW HOBBIES, <http://www.wowhobbies.com/turboacex830-dquadcopterrtfwdevo10rx1002gps4x35aescandbrushlessmotorsmgpower5300mah3s35cbatterytxbatteryxc-b601strap.aspx> (last visited Feb. 2, 2015).

40. See MOVO AVIATION, <http://www.movoaviation.com/> (last visited Feb. 5, 2015).

41. The Movonator is basically a Cinestar 8 HL octocopter. See *Cinestar/Freefly, QUADROPTER*, http://www.quadrocopter.com/CinestarFreefly_c_84.html (last visited Feb. 5, 2015).

their ability to accept different equipment. Several of these microdrones can fly a pre-programmed flight plan comprised of GPS waypoints at specific altitudes. They can hover near or orbit waypoints. Geofencing and robust fail-safes ensure safe operation.

Each has the capability of operating at or near the anticipated ceiling for sUAS operation under anticipated regulations.⁴²

Each can fly at twenty-five to thirty-five knots, which is adequate for ENG, law enforcement support, search and rescue, and pipeline and powerline patrol. Even the most expensive ones cost much less than a patrol car or ENG van.

b. Conclusions From These Flight Tests Revealed Need for Improvements, and Technology Has Bridged the Gap

The authors' flight tests revealed several shortcomings that suggested enhancements to mission capabilities, many of which are included in newer models. First, and most significantly, the DROP's controls were reversed when the Phantom's orientation was not aligned with the DROP's line-of-sight. Compounding this problem, as the aircraft flew further away, it was difficult for the DROP to see which way it was aligned. In one flight test that resulted in loss of the aircraft, the authors were doing speed tests at a height of about 150 feet above the ground. As the Phantom reached the outer boundary of the test range, the DROP was unable clearly to determine its orientation and also was unable to determine whether the Phantom was flying away or back toward the test team as he manipulated the controls. The Phantom flew out of sight before control could be regained. Shortly thereafter, the control link and the video link were lost as well.

For reasons yet undetermined, the Phantom's return-to-home feature did not work, although it had worked on three occasions previously. The authors hypothesize that the ten to twelve knot wind pushed the Phantom further away while its return-to-home feature was calculating the course it needed to fly.⁴³

42. See *infra* Part III.A.1.c.1.

43. In the February 1, 2014 flight test, control was lost when the Phantom was at 600 feet above the ground and about 600 feet slant range away from the DROP. The on-board video shows that it took approximately three minutes for the Phantom to return to its launching point and that much of this time was spent in a very gradual descent and relatively low forward speed, probably not exceeding ten knots over the ground. Assuming that is what the Phantom did on the last test flight, the wind may have overwhelmed its slow forward speed on its return flight and kept it in the air until its batteries were exhausted. What happened after that is unknown. A ground search, including one attempting to regain the Phantom's WiFi signal, was unsuccessful.

Any practicable microdrone must be indifferent to the orientation of the aircraft with respect to the DROP or, at a minimum, must provide the DROP with information about the aircraft's heading and direction of flight. Microdrones on the market now, including newer models of the Phantom, have addressed these deficiencies, demonstrating how rapidly technology develops to improve functionality of microdrones.

The video imagery available from the Phantom's forward-looking camera, displayed on an iPhone mounted on the control console, is insufficient to permit the DROP to fly the Phantom by looking at the video screen.⁴⁴ The larger screen of an iPad used to control the aircraft provides better guidance, but sunglasses and the limited angle of view are still problems. The DROP easily gets disoriented, requiring visual contact with the drone to re-establish navigation.

The loss of the Phantom on the February 22 flight test and the authors' inability to recover it were also due, in part, to the lack of positional information when control was lost. Any operational microdrone must provide latitude and longitude information at the point that the control link is lost. That would facilitate recovery.

In sum, for a microdrone to be useful for law enforcement, ENG, or powerline and pipeline patrol, it must have better features. A police officer or photojournalist attempting to obtain video imagery from the backyard of a residence, an alley, or an angle of a fire would certainly lose sight of the microdrone's orientation, and might lose the control link as well. For the return-to-home feature to work only in zero- or light-wind conditions would exclude conditions likely to exist in most real-world incidents, when the stress on both the aircraft and the DROP would be significantly higher than in the relatively relaxed atmosphere of the authors' flight test activities.

Practicable application requires longer endurance, better control, and more robust return-to-home features. It should not be difficult to evolve existing products to offer these enhancements. Longer endurance is available simply from increasing battery capacity. As a general matter, basic airframe weight, exclusive of battery, motors, and control systems, scales linearly. As power

44. On one part of the February 22, 2014 flight test, the DROP was attempting to fly the Phantom with reference only to the video image, while the other member of the team kept the Phantom in sight and provided oral cues about its position, orientation, and flight path. The intended flight path took the Phantom some fifteen or twenty feet over some electric power lines towards the roof of a school. The DROP was able see the rooftop on the video display but not the power lines. The video display also was inadequate to enable him to determine the orientation and direction of flight except at the grossest level. He would have lost control of it without the oral cues provided by the other member of the team.

requirements increase, motor weight increases linearly. Likewise, as battery capacity increases, battery weight increases linearly. There is thus a trade-off, and successful engineering design ensures that performance increases offset the battery-weight increase.

Extending the range of the control link is mainly a matter of increasing transmitter power and receiver sensitivity. Some gain also might be achieved by putting a directional antenna on the control unit. Because the microdrone is designed to always be operated within the DROP's line-of-sight, it is reasonable to assume that he will always keep the control console pointed at the drone. Mainly redesigning circuits, perhaps adding an amplifier stage, resulting in greater power consumption, can increase transmitter power. It is not likely to increase weight by much.

Microdrones similar in basic design to those already on the market, but with the improvements outlined in the preceding paragraphs, would enable the following kinds of new missions for both law enforcement support and ENG.

c. These New Improvements Would Enable New Missions

Law enforcement microdrones would be deployed and controlled by ground personnel to augment their tactical situational awareness. For example, a unit searching for a suspect might launch a microdrone to search rooftops and backyards in a residential area or to search side streets and alleys in a commercial district. In many situations, one or more microdrones might be launched to enforce a perimeter. In the case of foot- or vehicle-pursuits, microdrones might be launched to keep the suspect or his vehicle in sight and reduce the risk of surprise threats to personnel pursuing on foot or of vehicle collisions.

News gathering microdrones would be standard equipment on ENG ground trucks, enabling the journalists to launch them to obtain different perspectives of a newsworthy scene. As more ordinary citizens acquire them, their use would accelerate the trend toward television station use of amateur-captured imagery, as is already common with iPhone video. Intermediaries are beginning to emerge that link mainstream broadcasters with ordinary citizens who post news, including videos, to social media.⁴⁵

45. Leslie Kaufman, *Seeking a Lead on the News, Network Turns to Data-Mining Media Group*, N.Y. TIMES, Feb. 24, 2014, http://www.nytimes.com/2014/02/24/business/media/teaming-with-data-mining-security-firms-to-get-a-lead-on-news.html?_r=1 (reporting on deal between MSNBC and Vocativ, a startup that mines social media for patterns identifying news leads, and identifies video footage not available on larger sites like YouTube that are scrubbed by Google and other search engines).

Still, many law enforcement and ENG decisionmakers will resist widespread use of microdrones. They will likely object to any line-of-sight restriction: the DROP must be in the same general vicinity as the drone. Moreover, microdrone assets will have to be widely distributed, with one in each patrol district, for example, for law enforcement, and one in each ENG truck for news gathering.⁴⁶ Moreover, widely distributing them still does not fulfill the requirements for effective news gathering. ENG trucks cannot make it through traffic delays to get to a scene faster than a helicopter and cannot cover hundreds of miles worth of roads in a single news broadcast. One of the advantages of helicopters is that they can be dispatched from a central location and be on the scene in a matter of minutes.

For pipeline and powerline patrols in rural areas, inspection personnel could carry a microdrone in their truck. They would launch it, and it would patrol twenty miles or so of a pipeline or powerline.⁴⁷ The DROP and his console would be in the truck. The truck would follow the microdrone and retrieve it when its battery is exhausted. Then, the crew would plug in a fully charged battery and repeat the process. The drone would capture video, downlink it to the crew, and record it.

This scenario, however, presents a number of problems. The body of the truck would weaken the control data link signal and limit the DROP's view of the microdrone. In remote areas, the full right of way often is not accessible by ground vehicle; that is one reason helicopters perform the patrol function. If WiFi carried the control and video downlink signals, the drone would quickly fly out of range. Finally, the truck cannot maintain speeds of forty miles per hour over unimproved roadways under powerlines or beside pipelines.

This analysis raises significant doubts about whether this microdrone scenario would provide any benefits over manned helicopter patrols. On each mission, a helicopter can fly several hundred miles, with no need for a ground crew to follow it. It can rely on visual observation by the flight crew rather than video to be reviewed after the fact. Indeed, a microdrone-centered operation might cost more than a helicopter-centered operation and be less effective.

In conclusion, microdrones can play only a limited role in search operations, essentially supporting ground personnel when manned helicopters are unavailable.

46. *But see infra* Part II.B.3 (considering the possibility for launching and controlling microdrones from a manned helicopter).

47. Assuming endurance of a half-hour and speed of forty miles per hour.

2. Machodrones

Machodrones will be late arrivals in the civilian world, although some adaptations of military machodrones are flying civilian missions now. The novelty of microdrone applications and their limitations compared with familiar manned helicopters will cause many potential purchasers to focus their interest on machodrones, which will have altitude, speed, endurance, and imagery capabilities now required of ENG and law enforcement patrol helicopters.

a. Development, Design, and Deployment

Two alternative approaches exist for machodrone design to meet these requirements: adaptation of an existing type or bottom-up conceptualization of something new. The second approach is far more ambitious and risky, but more likely to produce an aircraft that matches technology to mission.

The first, more cautious, approach would take an existing light helicopter model and make modifications so that it can be flown remotely to meet mission requirements for ENG or law enforcement support and to satisfy FAA regulations for NAS integration.⁴⁸ The central advantage of this approach is that much of the design and fabrication of the base aircraft could remain intact, saving much engineering effort. There would be no need to change the fuselage, the engine, or the drivetrain, including the gearbox. Further, main and tail rotors and their hubs would remain the same. The seats for pilot and passenger and the instrument panel would be removed and mission equipment would be installed in their place. Cameras and an antenna assembly would be installed on the outside of the fuselage.

A system—basically the backend of an autopilot⁴⁹—would move the control rods and the throttle linkage according to DROP inputs

48. This has already occurred in the defense context. Boeing developed an unmanned version of the Robinson R22 in 1999, which became the Renegade. The effort evolved into the A160T Hummingbird, a turbine-engine adaptation of the R22, and the Unmanned Little Bird, a modified MD 530F. See *Unmanned Little Bird*, BOEING, <http://www.boeing.com/boeing/rotorcraft/military/ulb/index.page?> (last visited Feb. 2, 2015).

49. The baseline autopilot would have more capability than the typical two-axis commercial system for light helicopters. See R. Randall Padfield, *Cobham HeliSAS Brings Viable Autopilot to Light Helicopters*, AINONLINE (Mar. 6, 2013, 6:10 PM), <http://www.ainonline.com/aviation-news/hai-convention-news/2013-03-06/cobham-helisas-brings-viable-autopilot-light-helicopters> (reviewing performance of autopilot marketed for Bell 406, Bell 407, and Eurocopter AS350). The machodrone's on-board system would need to be capable of flying the helicopter in coupled mode. See generally Frank Lomardi, *Automatic Flight Control Systems*, ROTOR & WING (June 1, 2013), http://www.aviationtoday.com/rw/commercial/technology/Automatic-Flight-Control-Systems_79368.html# (explaining differences among stability-augmentation systems, stability-and-control-augmentation systems, and true, fully-coupled autopilots).

received over the control link.⁵⁰ Existing technology would couple flight-director features to the autopilot. The flight director, in turn, would be controlled remotely by the DROP, almost certainly modified to allow fine adjustments by the DROP around or along any axis as well as the typical gross controls of heading, altitude, and speed found on manned autopilot interfaces. Systems for remote control of lights, electrical systems, and engine start also would have to be installed.

The second, more ambitious, approach would not depend on any existing type of helicopter; it would aim at creating an entirely original design.⁵¹

Such an original design would likely result in an electrically powered quadcopter with the size and capability of a manned light helicopter. This aircraft would avoid the 30 percent purely parasitic power consumption of the tail rotor by its counter rotating multiple rotors. It would further avoid the weight and complexity of mechanical linkages necessary to control blade pitch by relying on electric propulsion and varying RPM rather than pitch to adjust thrust.⁵²

The cost side of the design equation is not zero, however. Every basic system—structures, airfoils, rotors, electric motors and their control systems, batteries, flight control systems, and sensors—must be redesigned from basic principles. Theory would produce drawings and models. Then wind tunnel aerodynamic testing and static and destructive structures testing would provide iterative adjustments to basic design concepts. Materials alternatives would be identified and choices made, and flight control algorithms would be conceived and debugged. Then full-scale prototypes would be fabricated, and flight testing would result in further design changes. At every step of the process, performance would be traded off against weight; performance and weight would be traded off against raw materials costs and manufacturing costs, and everything would be tested against marketability.⁵³

50. Electrical, hydraulic, or electro-hydraulic servos would move the cyclic forward and aft, left and right, to move the tail-rotor pitch control left and right and to position the collective up or down. A combination of mechanical correlator and electrical governor, already installed on many helicopters, would manage the throttle setting in accordance with collective position.

51. A similar approach has been followed by AgustaWestland in its Project Zero, aimed at designing a feasible electrically powered in-wing tiltrotor technology demonstrator. See Press Release, AgustaWestland, “Project Zero” All-Electric Tilt Rotor Technology Demonstrator International Collaboration (Mar. 21, 2013), available at <http://www.agustawestland.com/-/project-zero-international-collaboration>.

52. See Part II.A.1 for an explanation of why electric propulsion systems for rotorcraft obviate the need for blade pitch change.

53. An accessible but excellent summary of the design process for a much simpler vehicle is available from the University of Maryland team that designed the runner-up in the

The development effort would be enormous, but the result would be a machodrone optimized to perform machodrone missions, rather than being limited by design decisions made in the past to optimize a vehicle to carry people.

b. Mission Capabilities

Either type of machodrone would be designed to perform missions similar to those performed today by manned law enforcement and ENG helicopters.

Missions begin either with the aircraft already in the air on routine patrol or with the aircraft sitting on the ramp. Pre-flight inspection is done as soon as the crew's watch begins. Before the mission begins, the DROP and systems operators are at their consoles in the ground control facility. DROPs and photographers ("photogs") are stationed at the drone deployment site. Presumably, the operators would be located at an airport or heliport, requiring a control room with the equipment necessary to fly the drone, systems for the photog to work the camera, and feed video to the news station. Having two separate operators, one to fly the drone and one to manipulate the camera, is necessary to assure acceptable results.

The crew gets a call requiring deployment of the drone to provide support for ground units involved in a particular incident or to provide coverage of newsworthy occurrences. The initial call out will be ambiguous as to certain aspects of location. The drone is airborne within sixty seconds and headed toward the incident, complying with air traffic control (ATC) instructions and maneuvering to avoid other traffic in the vicinity. En route, the crew maintains voice communications with appropriate ground units, commanders, or news desks over regular very high frequency (VHF) or ultra high frequency (UHF) voice frequencies.

The drone sends real-time video imagery captured by its cameras, with quality equivalent to that captured by state-of-the-art ENG cameras. The video imagery field-of-view would include 270 degrees lateral coverage,⁵⁴ and -10 to +90 degrees vertical coverage.⁵⁵

Sikorsky human-powered aircraft competition. See BEN BARRY ET AL., DESIGN OPTIMIZATION OF GAMERA II: A HUMAN POWERED HELICOPTER (2012), available at <http://www.agrc.umd.edu/gamera/docs/pubs/gamera2-design.pdf>.

54. The peripheral cameras need not have the same resolution as the forward-looking cameras. Their purpose is to support traffic avoidance by the DROP, not to capture mission imagery.

55. When the drone reaches the incident scene, it hovers or flies a low-altitude orbit, 300–500 feet above ground level, at no more than thirty knots ground speed. In this flight configuration, the systems operator must be able to pan the camera in elevation and azimuth and zoom the lens optically to achieve one hundred-times magnification when it is zoomed out.

For law enforcement applications, the drone systems operator (DROSOP) would be able to control the high-intensity searchlight on the drone in elevation and azimuth and to link its orientation to that of the forward-looking camera.

The use of machodrones for powerline and pipeline patrol is even easier to contemplate. These operations occur in remote areas and require less ad-hoc, scene-specific maneuvering than law enforcement and ENG applications. A machodrone could be programmed to fly the line of a pipeline or powerline and send its imagery back to the DROP and a utility specialist, who could take control when he sees something that requires a closer look. It is also desirable for a remote DROP flying powerline or pipeline patrol missions to be able to hand off control to the ground crew on the scene, especially if a machodrone actually is involved in delivering components for installation.⁵⁶

Machodrones can support search and rescue missions flying like manned helicopters conducting a search. They would fly a standard search grid with no more than a fifty-foot deviation from any leg and deliver to the systems operator real-time, full-motion, high-definition video and infrared imagery equivalent to that obtained by a manned helicopter. They could record the full-motion video and infrared imagery on board the drone or at the ground station, at the option of the systems operator. They could illuminate the ground with the high-intensity searchlight at all of the specified altitudes, broadcast an oral message originating with the systems operator in real time to a person on the ground at an audio level of at least 95 dB and fly at speeds from a hover to faster speeds at the option of the DROP. They could fly for six hours at heights above the ground from two hundred feet to three thousand feet at the option of the DROP or DROSOP.

Eventually, machodrones could accomplish rescues or provide logistical support in disaster areas. They would have all of the capabilities specified for a search and rescue drone and, in addition, be capable of landing within a twenty-five foot radius of a person or object on the ground. Once they reached this position, under the

The imagery downlink to the ground station would provide quality equivalent to 1920 x 768 HD mpeg-4. Either the DROP or the systems operator would be able to toggle the forward-looking camera between infrared and full-color modes and see the results on the console displays. The system would have video recording equipment that can capture up to three hours of video in the same quality available over the downlink.

56. The idea is similar to that of a remotely controlled locomotive in a rail freight classification yard. If the crew on the ground directly controls the vehicle, they avoid delays and potential errors involved in communicating commands to the operator—the engineer of the locomotive, analogous to a DROP in a remote location.

control of the DROP, they would release a pallet or similar container with at least one hundred pounds of relief supplies such as blankets, water, food rations, and a handheld radio.

The DROP would have system function-malfunction indications equivalent to those available on manned helicopters. The drone would have the capability to fly autonomously and land successfully at the launching point if the control link is lost for more than two seconds, or if the remaining battery charge is insufficient to fly back to the launching point, plus fifteen minutes. If other specific system malfunctions occur, the drone would remain under the control of the DROP so that he can make decisions about the safest course of action.

Either of the machodrone design approaches would result in an aircraft that could perform the same basic functions as a manned helicopter in law enforcement support, news gathering, and pipeline-powerline patrol activities.

c. Merely Because It Can Be Done, However, Does Not Answer the Crucial Questions That Will Decide Whether It Will Be Done: Barriers and Benchmarks

Why is a machodrone necessary, as compared with a microdrone or a manned helicopter designed to perform the same functions? And will the cost and capabilities of a machodrone make it attractive to customers?

The first question is easier to answer than the second question. Machodrones, compared with microdrones, will be able to carry more payload at higher altitudes, beyond the line-of-sight of the DROP.⁵⁷ Relaxing these limitations of microdrones is essential to achieve mainstream mission performance. Law enforcement agencies, television stations, and utilities use manned helicopters now because they can quickly get from one place to another in an operating radius of a couple hundred miles. They can carry between two hundred to eight hundred pounds of high definition color video and infrared cameras, automatic tracking, downlink microwave antennas, and searchlights. They hover, orbit, and quickly change position as developments on the ground dictate. They can safely fly anywhere from three hundred feet above the ground to several thousand feet. Microdrones can do none of these things, although as Part II.B.1 explains, they can do useful things at the margins of current mission

57. The microdrone limitations are not the result of technology—range of the control link, payload, and ceiling can be scaled up. The limitations are the result of microdrone mission concepts being driven by what is already on the market.

requirements. Why machodrones, as compared with manned helicopters, are necessary depends on their capabilities and cost.

This leads to the second, harder question: whether machodrones can be built that will be attractive to customers who have a wide variety of manned helicopters available for purchase, lease, or contract to perform the same missions. In every instance in which a vendor might offer a machodrone, the customer can decide between it and a manned helicopter. The customer is not going to choose a machodrone unless it provides some concrete, quantifiable advantages, such as one or more of the following.

It can fly missions that would jeopardize the lives of a helicopter flight crew. This is the predominant reason why machodrones are attractive to the armed forces, intelligence agencies, and special operations units. They can fly into situations where the aircraft flight crew might be lost. Their ability to do this expands the set of missions likely to be approved. It also reduces the cost of supporting systems such as those to retrieve pilots who have been shot down, thus reducing overall system cost. Despite its importance to military and intelligence commanders, it is far less likely to be an important consideration in law enforcement support, news gathering, or pipeline and powerline patrol, except, perhaps, for close-in inspection or delivery of components for installation on powerlines.

They will have lower direct operating costs. The most significant components of direct operating costs are fuel and labor costs for the flight crew and mechanics. The skill levels—though maybe not the temperament—required for DROPs will be similar to that required of helicopter pilots. There is no reason to believe that compensation levels for DROPs will be lower. Nor is there any reason to believe that labor hours per flight hour will be any different. Likewise, mechanic labor input and skill levels are likely to be equivalent to that for helicopters; therefore, the compensation will likely be the same.

Fuel costs are likely to be similar to helicopters for machodrones powered by piston or turboshaft engines. For machodrone designs employing electric power, comparing helicopter fuel costs with the equivalent for the machodrone will require a more complicated calculation. This calculation must consider the trade-offs among engine weight, fuel weight, electricity to recharge the batteries, and so on.⁵⁸ But basic energy calculations suggest that the propulsion costs will be comparable, absent radical changes in oil prices. In sum,

58. The authors acknowledge good research contributions on battery technology from Patrick Grimaldi, Chicago-Kent College of Law, Class of 2016.

it seems unlikely that lower direct operating costs will provide a rationale for consumers to choose a machodrone.

*Utilization may be higher for machodrones.*⁵⁹ There is no reason to believe this would be the case, unless maintenance costs are lower, which is unlikely.

Acquisition costs for machodrones may be lower than for helicopters. This might be the case because (a) machodrones can be a bit smaller and still have the same payload capabilities, since there are no people aboard; (b) physical features, such as energy-absorbing seats, intended to protect the flight crew from harm, are not necessary; and (c) on-board displays and instrumentation for the flight crew are not necessary. The first two of these might actually reduce acquisition costs, but the third is illusory. Whatever is necessary to be displayed in the cockpit for the regular helicopter pilot will also have to be displayed on the ground to the DROP.

On the other hand, several factors may cause machodrones to cost *more* than manned helicopters, even before development costs are amortized over a production run. Sophisticated, reliable control systems are necessary for machodrones and unnecessary for manned helicopters. Special cameras and displays will be necessary for DROPs to obtain a replica of the visual site picture that would be naturally available if they were in the cockpit. Further, the degree of automation for flight controls will be higher for machodrones than for manned helicopters. It is easier to fly manned helicopters with stabilization systems or autopilots than to fly them without such systems, but a human pilot can easily fly safely with less sophisticated flight controls.

Finally, there is the question of recovering development costs. New aircraft are introduced in the marketplace only when a sufficient number of customers are willing to pay a price necessary to recover both the direct cost of manufacturing and the development costs over the total number of sales. Aircraft manufacturers and their investors simply will not go forward with a program unless they believe they will sell enough to recover development costs and earn a reasonable return on investment. Development costs of any machodrone program will be enormous, particularly one that is built bottom-up.⁶⁰ Thus, a

59. Utilization is a common measure of efficiency for aircraft operations. Typically, efficiency is represented by the average number of revenue hours per day divided by twenty-four hours. It can be influenced by crew availability, schedule constraints, or aircraft downtime for maintenance.

60. In the past, new civilian aircraft designs have been introduced only because the Defense Department paid for much of the development for military versions. The 747 was drawn from Boeing's entry into the C-5 heavy logistics system competition. Most early civilian helicopters were only minor variations of designs for which the armed forces had paid. That is

manufacturer would have to expect very successful sales to induce it to bring a machodrone product to market.

Some rough numbers might be helpful in understanding the issue.

Development costs for new commercial airliners are approaching \$20 billion per offering.⁶¹ Development costs for the Global Hawk were estimated as \$2.5 billion by the Government Accountability Office in 2006,⁶² compared with \$178 million for the Predator.⁶³ The difference in magnitude resulted, among other things, from “immature” technologies employed in the Global Hawk, compared to “mostly mature” technologies in the Predator.⁶⁴

The Predator is twenty-seven feet long, has a wingspan of forty-nine feet, and a maximum gross weight of 2,250 pounds. A civilian machodrone of similar size would not need the armament or targeting systems in the Predator, but it would need everything else. Even if the simpler civilian design cut the development cost by 90 percent, development would still cost about \$20 million.⁶⁵

An AS350B2 news helicopter is priced at about \$2.2 million. If that price reflects manufacturing costs only, because AS350B2 development costs have been fully recovered, it is reasonable to assume that manufacturing costs for a comparable machodrone would be similar. So, a machodrone would have to sell forty copies at a price

not likely to be the case for civilian machodrones because their mission requirements are so different from those for armed forces or intelligence applications, which emphasize combat environments and delivering fires. It should be no surprise that impressive machines exist in the national security context that have no civilian application. F-18s, F-35s, and nuclear submarines are obvious examples.

61. Erich Fischer et al., *2013 Commercial Aerospace Industry Perspective*, STRATEGY& (Dec. 13, 2012), <http://www.booz.com/global/home/what-we-think/industry-perspectives/display/2013-aerospace-industry-perspective?pg=all> (identifying price tag for large commercial wide-body aircraft at more than \$19 billion).

62. U.S. GOV'T ACCOUNTABILITY OFFICE, GAO-06-447, UNMANNED AIRCRAFT SYSTEMS: NEW DOD PROGRAMS CAN LEARN FROM PAST EFFORTS TO CRAFT BETTER AND LESS RISKY ACQUISITION STRATEGIES 9 (2006), available at <http://www.gao.gov/assets/250/249317.pdf>.

63. *Id.* at 10.

64. *Id.* at 11.

[N]ew signals intelligence and multiplatform radar systems were still in technology development, not expected to be mature and be tested in an operational environment until sometime between 2009 and 2011. . . . [T]here is risk that the aircraft, already being produced, will not have sufficient space, power, or cooling or that the sensor systems will weigh more than planned, reducing aircraft performance and ability to meet overall mission requirements—altitude, speed, and endurance.

Id. at 16.

65. Separating airworthiness certification cost from other development costs is essentially arbitrary because the certification process and design development process are iterative. A particular subsystem design is submitted to the FAA, tested, and found deficient in one way or another, so it is redesigned. The same kind of proof of design testing would be necessary even without FAA airworthiness certification requirements.

\$500 thousand higher than an AS350B2 to recover its development costs.

There are 757 AS350 helicopters presently registered in the United States.⁶⁶ That means that a machodrone manufacturer would have to displace 5 percent of Airbus Helicopters' market share to achieve a profitable program. The competitive equation is challenging and many potential manufacturers will shrink from it.

3. Hybrid Helicopter-Drone Operations

The principal limitations of microdrones relate to the logistics of getting them where they are needed and then retrieving them after they exhaust their limited range. An attractive way to deal with the first of these limitations is to use a hybrid approach: a combination of a manned helicopter and one or more microdrones. Once microdrones become commercially available, one can envision law enforcement or ENG missions in which a manned helicopter controls drones that are deployed on an ad-hoc basis to capture imagery that could not safely be captured by the manned helicopter.

In the hybrid application, a manned helicopter would be equipped with one or more microdrones to be deployed from the helicopter in flight. The DROP would be aboard the helicopter, in addition to the customary crew of the pilot and photog.

For example, a news helicopter could be deployed to the scene of a newsworthy event in the same way that it is presently. Once it gets to the scene, helicopter crew and station personnel would make a decision as to whether deployment of microdrones would aid in coverage. If they decide it would, the pilot would maneuver the helicopter so the drone could be launched safely without the risk of it impacting the main or tail rotor or being overpowered by the downwash.⁶⁷

The microdrone could then fly flight profiles desirable for photographic coverage while the helicopter collects its own imagery from a flight profile that is safe for it. Microdrones, for example, could hover with the tailwind or come closer to a fire or situation involving

66. Registry of AS-350s, FED. AVIATION ADMIN., http://registry.faa.gov/aircraftinquiry/AcftRef_Results.aspx?Mfrtxt=&Modeltxt=AS+350&PageNo=1 (last visited Feb. 2, 2015).

67. One way to reduce the risk would be to launch the drone from the right side of the helicopter while the helicopter is in a slight sideslip to the left. This would ensure that the rotor wash blows the microdrone away from rather than into the tail rotor. Even if a safe altitude for the helicopter exceeded the ceiling of the microdrone, the microdrone would just descend under control to its operating altitude, where its available thrust would balance gravitational forces.

gunfire, either of which would endanger the personnel in the helicopter.

Similarly, for pipeline and powerline patrol, one or more microdrones could be launched from a manned helicopter, and the microdrones would be flown closer to the hardware than the helicopter safely could do. In this scenario, a greater degree of autonomous flight⁶⁸ by the microdrone would be desirable, as it would relieve the DROP of the monotony of having to fly up along a regular and completely predictable path followed by the pipeline or powerline.

How the microdrones would be retrieved after their battery power is exhausted is a matter that requires further consideration. It is probably not cost-effective to equip the helicopter to retrieve them in flight. So, they would land somewhere. Then, in a rural setting, the helicopter might land to pick them up, or ground personnel could retrieve them later.

This mission definition takes advantage of comparative advantages of both types of vehicles: the superior imagery available from the helicopter and its flexibility of higher altitude and flexible deployment and the microdrone's abilities to operate in closer quarters in situations that would be hazardous to the helicopter.

These hybrid possibilities do not come without drawbacks, however. Safety becomes a concern with multi-purpose-role ENG platforms. For instance, drones flying near helicopters are a potential collision hazard. In addition, drones impact obstacles frequently due to DROP uncontrollability and can become a hazard to bystanders on the ground.

Moreover, a two-person ENG team will not have the ability to manage the helicopter-mounted camera as well as the drone. The first concern is the pilot's situational awareness becoming oversaturated. Furthermore, the photog has a difficult enough duty to provide the station with a good picture from the main camera. A third crew member would be required to fly the drone.

This concept, while interesting in theory, may offer few advantages over a helicopter alone and prove impracticable.

III. REGULATORY CONSTRAINTS

The FAA's regulatory approach, which has considerable buy-in—at least at the abstract level—from major industry groups and other interested parties, is to establish separate regulatory regimes for microdrones and machodrones. Microdrones will be regulated under an adaptation of the non-mandatory FAA protocols for model aircraft

68. See *supra* Part II.A.3.

flight. Machodrones will be regulated under an adaptation of the basic rules for manned aircraft, requiring certification of aircraft and personnel and detailed flight rules.

The bifurcation is sound, but reflexive imposition of the details of traditional FAA regulation for manned aircraft will be largely ignored by commercial microdrone users and will drive up the cost of machodrones to the point that few of them will be sold.

The FAA's plan for integrating drones into the NAS roughly classifies them into two size categories: microdrones (sUAS) and machodrones (all other UAS).⁶⁹ Microdrones will fly only at low heights within sight of the DROP, but will be subject to only a few equipment requirements aimed at traffic separation. Machodrones, on the other hand, will be able to fly in any unrestricted airspace, subject to aircraft certification, pilot certification, and demanding equipment requirements to ensure traffic separation.⁷⁰ In effect, microdrones are segregated, while machodrones will be integrated.

This approach makes sense. As drones become larger and more advanced, flying higher, faster, and out of line-of-sight, model aircraft rules are insufficient. Regulatory requirements must reflect a trade-off between weight and capability, on the one hand, and equipment and operating-rule flight restrictions, on the other. If a drone weighs more than, for example, twenty pounds, it should be equipped with Automatic Dependent Surveillance-Broadcast (ADS-B) Out, so that low-flying aircraft have a chance to "see" and avoid it. The DROP needs training and certification on how to operate the drone safely to avoid causing interference with other aircraft. The bigger and better performing the drone, the more regulatory oversight it and the DROP need to fly safely. The smaller and lesser performing drones need less certification and, under a certain weight class, ADS-B should not be mandatory.

69. The distinction originates with Section 333 of the FAA Modernization and Reform Act of 2012, which obligates the FAA to determine if certain drones possessing the characteristics of microdrones can be operated safely before the overall plan is implemented. See FAA Modernization and Reform Act of 2012, Pub. L. No. 112-95, § 333, 126 Stat. 11, 75.

70. The basic outline for regulation of drones is reasonably clear, based on the 2012 Act and the FAA's Comprehensive Plan and the FAA Roadmap. See FAA Modernization and Reform Act of 2012; FED. AVIATION ADMIN., *supra* note 31. The Roadmap addresses aircraft certification, operating rules, and airman qualification, generally following the recommendations of an industry advisory group. See FED. AVIATION ADMIN., *supra* note 31, § 1.4.3 (summarizing the Radio Technical Commission for Aeronautics (RTCA) principles). The RTCA has not been free from difficulties. See Bill Carey, *New RTCA Committee Seeks to Expedite UAS Standards*, AINONLINE (Apr. 5, 2013, 11:54 AM), <http://www.ainonline.com/aviation-news/2013-04-05/new-rtca-committee-seeks-expedite-uas-standards> (reporting on slow progress of 2004 committee and its replacement by new committee with mandate to expedite drone-integration standards development).

The FAA's definition of the boundary between microdrones and machodrones is critical to their safe integration into the NAS and to their utility in the marketplace. The philosophy for microdrone regulation is to keep them mostly isolated from manned aircraft and to keep them within the line-of-sight of the operator to reduce the need for him to rely on sophisticated video subsystems to maintain control, navigate, and avoid other traffic. Given these regulatory goals, a weight restriction for the microdrone category seems appropriate, as it would limit the damage resulting from collision with another aircraft or with an object or person on the ground. The very light microdrones now on the market for hobbyists, such as the Phantom 2 Vision, are not likely to represent much of a hazard, unless one of them happens to hit the tail rotor of a helicopter.

The core of the evolving regulatory environment is the identification of technologies that will allow drones and manned aircraft to coexist.

The following sections explain the FAA's current regulatory plans and identify some of its weaknesses, discuss its establishment of drone test sites, and project the timeline for comprehensive regulation.

A. Integration

The 2012 legislation⁷¹ requires the Secretary of Transportation, in consultation with interested parties, to “develop a comprehensive plan to safely accelerate the integration of civil unmanned aircraft systems into the national airspace system.”⁷² The FAA's Comprehensive Plan explicitly assumes that routine UAS operation should not require exceptions or unique authorizations.⁷³

1. Segregating Microdrones

Paradoxically, microdrones will be “integrated” essentially by being segregated into parts of the airspace not generally used by manned aircraft. Like model aircraft, they must be flown only where they can be seen by the operator and not near airports or areas of dense population. Additionally, microdrones will be subject to a maximum weight restriction.

Thus restricted, microdrones need less scrutiny of control-link integrity, imaging sensors, and display of imagery to the DROP. They also do not need traffic avoidance systems.

71. FAA Modernization and Reform Act of 2012, Pub. L. No. 112-95, 126 Stat. 11.

72. *Id.* § 332(a)(1), 126 Stat. at 73. Section 332 of the 2012 Act obligates the FAA to develop this comprehensive plan in consultation with the aviation industry. *Id.*

73. *Id.*

Working out detailed requirements for microdrones is relatively straightforward: only about a half-dozen specific decisions must be made. Accordingly, the regulatory regime for microdrones will be in place much sooner than that for machodrones.

The process began with governmental (public-use) rules. The requirements for public-use microdrones have crystallized in a form that resembles rules for non-commercial model aircraft flight.⁷⁴ The proposed requirements for commercial microdrones resemble those for public use.

The 2012 Act requires the FAA to decide if microdrones represent a separable category that can be regulated in a simpler regime than is necessary for machodrones.⁷⁵ As release of the required notice of proposed rulemaking (NPRM) slipped, the FAA came under increasing pressure to provide some kind of safe harbor for legal flight of drones, which were being purchased by the thousands and flown for commercial purposes despite the FAA ban. Initially, it allowed potential drone operators to obtain “special airworthiness certificates.” Applicants had to submit detailed maps of where the drones would be flown and multi-page details about the vehicles. The current application for special airworthiness certificates⁷⁶ provides, among other things:

- Only manufacturers can obtain airworthiness certificates for production flight testing.⁷⁷
- Flight is limited to geographic areas specified in the special airworthiness certificate.⁷⁸
- Applicants must submit “flight manuals,” checklists, and evidence of a training program for crewmembers, who must be licensed pilots or have completed an FAA-approved training program.⁷⁹
- FAA must inspect aircraft, control stations, and support equipment.⁸⁰
- The microdrone must be equipped with a transponder.⁸¹

74. *Id.* § 332(b)(1)–(3), 126 Stat. at 74.

75. *Id.* § 333(b)(1)–(2), 126 Stat. at 76 (based on size, weight, speed, operational capability, proximity to airports and populated areas, and operation within visual line-of-sight).

76. FED. AVIATION ADMIN., U.S. DEPT OF TRANSP., ORDER 8130.34C, AIRWORTHINESS CERTIFICATION OF UNMANNED AIRCRAFT SYSTEMS AND OPTIONALLY PILOTED AIRCRAFT (2013), available at [http://rgl.faa.gov/regulatory_and_guidance_library/rgOrders.nsf/0/10947cee0052205886257bbe0057bd76/\\$FILE/8130.34C.pdf](http://rgl.faa.gov/regulatory_and_guidance_library/rgOrders.nsf/0/10947cee0052205886257bbe0057bd76/$FILE/8130.34C.pdf).

77. *Id.* ch. 2, § 2(4)(a)(2), at 2-4.

78. *Id.* ch. 3, § 1(3), at 3-1, app. at A-3 to A-4.

79. *Id.* app. at A-3 to A-4, A-6 (requiring pilot-in-command with at least a private pilot certificate).

80. *Id.* ch. 3, § 1(8), at 3-3 to 3-4.

81. *Id.* app. at A-7.

- There must be two-hour advance coordination with ATC.⁸²
- Aircraft must undergo annual inspection by a certified mechanic.⁸³

Microdrones, even tiny ones like the Hubsan,⁸⁴ could not be flown for commercial purposes at all unless they have a special airworthiness certificate.

The authors submitted an application for their Movonator, but eventually abandoned it, because of the burdensomeness of following through on the process.

Then, the FAA offered an apparently more flexible process—petitioning for a Section 333 exemption. Later, it retroactively required registration of each drone and an application for a Certificate of Waiver of Authorization (COA).⁸⁵ Some eight hundred Section 333 petitions have been filed, and 137 granted, each one requiring at least a sport pilot's license.⁸⁶

The Section 333 process is providing a useful way to allow early commercial microdrone operations while the proposed general rule is being crafted.

The contents of the application for a special airworthiness certificate, and especially Appendix A of the order, are manifestly unsuited for microdrones, given their size, payload, and flight profiles. The transponder requirement, the geographic limitations, and the reference to chase planes are entirely inconsistent with the features of microdrones. Unless the FAA provides for a separate pathway for microdrone testing, it is not acting consistent with its declared intention to accelerate integration of microdrones into the NAS.

Finally, on February 15, 2015, the FAA released an NPRM, published in the Federal Register on February 23, 2015.⁸⁷ The NPRM essentially codifies the FAA's guidance for model aircraft, along the lines approved by the Congress in Section 336 of the 2012 Act, extending them to commercial flight of microdrones.⁸⁸

82. *Id.* app. at A-8.

83. *Id.* app. at A-9.

84. See *Hubsan X4 H107C Mini Drone Review*, MINI DRONES REV., <http://www.minidronesreview.com/micro-mini-hubsan-x4-mini-drone/> (last visited Feb. 2, 2015).

85. Co-author Perritt represented Section 333 petitioners and experienced this post-hoc layering of procedural burdens.

86. See *Section 333*, FED. AVIATION ADMIN., https://www.faa.gov/uas/legislative_programs/section_333/ (last modified Mar. 4, 2015).

87. Operation and Certification of Small Unmanned Aircraft Systems, 80 Fed. Reg. 9544 (Feb. 23, 2015).

88. For a detailed analysis of the NPRM, see Perritt, *Developing DROP Discipline*, *supra* note 7, and Perritt, *Law Abiding Drones*, *supra* note 7.

a. Public Use

Federal, state, and local governmental entities may not fly drones in the national airspace unless they obtain a COA from the FAA.⁸⁹ The 2012 Act requires the Secretary to expedite issuance of COAs for public UAS.⁹⁰

Section 334 of the FAA Modernization and Reform Act of 2012⁹¹ requires the FAA, within ninety days of enactment, to enter into agreements with government agencies to “simplify the process for issuing certificates of waiver or authorization” for small drones operated:

- (i) within the line of sight of the operator;
- (ii) less than 400 feet above the ground;
- (iii) during daylight conditions;
- (iv) within Class G airspace; and
- (v) outside of 5 statute miles from any airport, heliport, seaplane base, spaceport, or other location with aviation activities.⁹²

The FAA reported that it “and the Department of Justice’s National Institute of Justice have established an agreement that meets the congressional mandate. Initially, law enforcement organizations will receive a COA for training and performance evaluation. When the organization has shown proficiency in flying its UAS, it will receive an operational COA. The agreement also expands the allowable UAS weight up to 25 pounds.”⁹³

Pursuant to the congressional mandate, the FAA simplified its process for considering governmental requests for COAs.⁹⁴ It expanded the default period of authorization to twenty-four months from twelve, increased allowable weight to twenty-five pounds, and announced that it would issue COAs to law enforcement agencies for training and performance evaluation, to be followed by operational authority once the applicant establishes proficiency.⁹⁵ It established a web-based application procedure and provided for expedited

89. See *FAA Makes Progress with UAS Integration*, FED. AVIATION ADMIN., <http://www.faa.gov/news/updates/?newsId=68004> (last modified May 14, 2012).

90. *Id.*

91. FAA Modernization and Reform Act of 2012, Pub. L. No. 112-95, § 334, 126 Stat. 11, 76.

92. *Id.* § 334(c), 126 Stat. at 76–77.

93. *FAA Makes Progress with UAS Integration*, *supra* note 89.

94. *See id.*

95. *See id.*

procedures for one-time approvals of time-sensitive disaster relief missions.⁹⁶

The public-use COA requirements have morphed into a civil COA process.⁹⁷ Civil COAs are required in conjunction with Section 333 exemptions. Particularly problematic are the FAA's insistence on a pilot's license to fly microdrones, its insistence on a separate observer, and its insistence on manned aircraft-like flight, maintenance, and operations manuals, each page of which must be approved in advance by the FAA.⁹⁸

b. Remote-Controlled Model Aircraft

The microdrone requirements resemble those for remotely controlled model airplanes under a 1981 FAA Advisory Circular.⁹⁹ Congress has essentially embraced these restrictions. Section 336 of the 2012 Act prohibits the FAA from promulgating rules for model aircraft, which it defines as “unmanned aircraft . . . (2) flown within visual line of sight of the person operating the aircraft; and (3) flown for hobby or recreational purposes.”¹⁰⁰ The prohibition applies only if:

- (1) the aircraft is flown strictly for hobby or recreational use;
- (2) the aircraft is operated in accordance with a community-based set of safety guidelines and within the programming of a nationwide community-based organization;
- (3) the aircraft is limited to not more than 55 pounds unless otherwise certified through a design, construction, inspection, flight test, and operational safety program administered by a community-based organization;
- (4) the aircraft is operated in a manner that does not interfere with and gives way to any manned aircraft; and
- (5) when flown within 5 miles of an airport, the operator of the aircraft provides the airport operator and the airport air traffic control tower (when an air traffic facility is located at the airport) with prior notice of the operation (model aircraft operators flying from a permanent location within 5 miles of an airport should establish a mutually-agreed upon operating procedure with the airport operator and the airport air traffic control tower (when an air traffic facility is located at the airport)).¹⁰¹

These long-accepted guidelines are appropriate for commercial microdrones, but, to date, the FAA has insisted on imposing more

96. *See id.*

97. *See Section 333, supra* note 86.

98. *See* Douglas Trudeau, Realtor, FAA Regulatory Docket No. FAA-2014-0481, Grant of Exemption (Jan. 5, 2015) (imposing private-pilot, observer, and manual requirements).

99. FED. AVIATION ADMIN., U.S. DEP'T OF TRANSP., AC 91-57, MODEL AIRCRAFT OPERATING STANDARDS (1981), *available at* <http://www.modelaircraft.org/files/540-c.pdf>.

100. FAA Modernization and Reform Act of 2012, Pub. L. No. 112-95, § 336, 126 Stat. 11, 77.

101. *Id.* § 336(a), 126 Stat. at 77. The 1981 Circular adds that flight may not occur “higher than 400 feet above the surface.” FED. AVIATION. ADMIN., *supra* note 99.

stringent requirements on commercial use of what often are the same vehicles flown by hobbyists under the non-binding guidelines.

c. Height and Weight Restrictions

Heavier drones have more potential than lighter drones to create damage to bystanders and personal property. If a Cessna 172 crashes, it will not have the same effect as a Boeing 777 crashing. Similarly, heavier drones, because they have more mass, have more kinetic energy to destroy opposing aircraft. As a result, lighter drones will have less demanding certification requirements than heavier drones and will not require specific operator certification.

The following subsections identify various safety risks that can arise from drone operations, describe the type of regulatory requirement that can mitigate the particular risk, and evaluate alternative forms that such requirements can take.

i. Height Restriction

Limiting the maximum height above the ground for microdrone flights promotes safety by reducing the likelihood of encountering conflicting traffic. Lower heights also mean less kinetic energy stored in a drone falling out of the sky, but the following calculations about kinetic energy show this is not very important.

The height restriction for microdrones may not be as effective as it might seem. Seaplanes, for example, regularly fly en route only three hundred feet above the water. Thus, microdrones flying at very low altitudes would still present a dilemma. Further, there are some areas of the country, such as the area north of Boeing Field in Seattle and the Anchorage, Alaska area, where the effectiveness of the see-and-avoid rule¹⁰² is crucial at low altitudes.¹⁰³

There are maybe a half-dozen parts of the country in which see-and-avoid is equally challenging. One way to deal with this is simply to prohibit either microdrone or machodrone flights in these areas.

102. See *infra* Part III.A.2.d.

103. In the vicinity of the Kenmore (W55) and Seattle (OW0) seaplane bases, near Seattle, for example, the floor of the Seattle-Tacoma (KSEA) Class B airspace is 1,800 feet mean sea level (MSL), and the Class C airspace for Boeing Field begins just to the south. Aircraft flying instrument approaches into runway 13 fly under this airspace, talking to approach control rather than common traffic advisory frequency (CTAF). To the southeast, the Rogers Post Memorial Seaport (W36) lies under the Class D airspace for Renton (KRNT). News helicopters, traffic into Boeing Field, and seaplanes operating into Kenmore and Seattle intermingle on a regular basis, communicating on the CTAF frequency. Seeing other traffic and taking appropriate action is crucial in a space like this.

ii. Weight Restriction

Imposing a height restriction on microdrone operation is not enough; manned aircraft fly below four hundred feet, and a microdrone mishap can endanger persons or property on the ground regardless of the height at which the drone was operating. Therefore, a weight restriction would also be appropriate. If a small drone weighing less than ten pounds were to collide with an aircraft, survivability would be much greater than colliding with something any larger.

These small-scale collisions are already a major problem for manned aircraft, as bird strikes are the number two cause of accidents for helicopters.¹⁰⁴ In one case, the pilot was incapacitated when a bird penetrated the bubble. In another, a larger bird impacted the main rotor, causing it to separate, killing the occupants of the helicopter. Larger birds cause more damage and worse injuries.¹⁰⁵ Larger birds have a mass similar to microdrones now on the market. The microdrone Phantom, for example, has a mass roughly equivalent to that of a mallard duck or a seagull.¹⁰⁶

Thus, a weight limitation promotes safety by limiting the kinetic energy in the drone and therefore reducing the damage to another aircraft, ground objects, or persons on the ground if a collision or crash occurs. Engineering ballistics analysis confirms this hypothesis and shows the relationship between drone weight and expected damage.¹⁰⁷

104. BRIAN E. WASHBURN ET AL., DEP'T OF DEF., LEGACY PROJECT NO. 11-944, BIRD STRIKE HAZARDS AND MITIGATION STRATEGIES FOR MILITARY ROTARY-WING AIRCRAFT 2 (2012), available at https://www.dodlegacy.org/Legacy/project/productdocs/FINAL%20OSD%20Legacy%20Report%20Joint%20RW%20Bird%20Strike%20Hazardswithcomments%20FINAL_ff16305b-b450-4d1c-9050-4404d614c07c.pdf. Helicopters are much more likely to be damaged by bird strikes than fixed-wing aircraft. *Id.*; Gail Keirn, *Helicopters and Bird Strikes; Results from First Analysis Available Online*, U.S. DEP'T OF AGRIC. (June 6, 2013, 3:11 PM), <http://blogs.usda.gov/2013/06/06/helicopters-and-bird-strikes-results-from-first-analysis-available-online/>.

105. WASHBURN ET AL., *supra* note 104, at 17, 47. Two hundred bird strikes with US civil helicopters were reported in 2011. *Id.* at 41.

106. See Roger Nicholson & William S. Reed, *Strategies for Prevention of Bird-Strike Events*, AERO Q., Quarter 3, 2011, at 17, available at http://www.boeing.com/commercial/aeromagazine/articles/2011_q3/pdfs/AERO_2011_Q3_article4.pdf.

107. The damage done when two objects collide depends on the kinetic energy of each when the collision occurs. Kinetic energy of a moving object is half of its mass times its velocity squared. If an aircraft collides with a hailstone, damage to the aircraft is likely modest. A small hailstone, weighing one gram (0.002 pounds), has kinetic energy of 20.5 foot-poundals relative to a helicopter moving at sixty knots. The hailstone is not likely to have much horizontal velocity on its own. A 2.5 pound bird or microdrone has kinetic energy of 25,643 foot-poundals. As mass increases, the kinetic energy increases linearly.

Even modest deformation of the aircraft skin or windshield can absorb all of that energy. Aluminum absorbs more energy before it fractures under impact than plexiglas. See *Lexan vs Acrylic*, KAZULI fig. 16, <http://www.kazuli.com/UW/4A/ME534/>

In light of the potential hazards, the current limit of fifty-five pounds seems too high, considering how much damage a 9.2-pound Canadian goose can do.

With appropriate weight limits, however, the risk of microdrone collisions with manned aircraft is small:

The extreme rarity of any collisions between birds and aircraft away from airports and at low altitude, despite the population of 10 billion birds, suggests that unintentional impact between UAVs and manned aircraft away from airports and [at] low altitude will always remain extremely unlikely.¹⁰⁸

iii. Line-of-Sight Restriction

The purpose of the line-of-sight restriction is to increase controllability. So long as the DROP can see the microdrone, he can presumably avoid collisions with other aircraft and ground objects. He can keep it under control and navigate by watching it, without reliance on more sophisticated video systems installed on the drone and in his console.

This restriction also makes it far more likely that the microdrone will remain within range of an inexpensive wireless control link at all times.

iv. Commercial Use Restriction

The statute, like the model-aircraft circular, excludes commercial operations. For commercial operations, a microdrone operator must obtain a special airworthiness certificate or a Section 333 exemption.¹⁰⁹ Such certificates and exemptions require aircraft registration, limit operations to a defined geographic area, require pilot certification at the private or higher level, and require transponders, among other things.¹¹⁰ Presently, special airworthiness

lexan%20VS%20Acrylic4.htm (last modified Dec. 1, 2003). Energy absorption of either is linearly proportional to thickness, for relatively thin structures. See DAVID ROYLANCE, INTRODUCTION TO FRACTURE MECHANICS 11 (2001), available at <http://ocw.mit.edu/courses/materials-science-and-engineering/3-11-mechanics-of-materials-fall-1999/modules/frac.pdf>.

On the other hand a fifty-five pound drone with a similar velocity would have 564,190 foot-poundals of energy, and a windshield or skin designed to withstand impacts with smaller objects cannot absorb that much energy without suffering penetration.

108. EXPONENT FAILURE ANALYSIS ASSOCS., PROJECT NO. 1498989.EX0, UAS SAFETY ANALYSIS 7 (2014), available at <http://www.uasamericafund.com/assets/micro-uav-safety-analysis.pdf> (analyzing drone collision risk in terms of bird strike statistics, commissioned by UAS America Fund, LLC).

109. See FED. AVIATION ADMIN., *supra* note 76.

110. See *id.* ch. 2, § 1(1), at 2-1 (requiring registration); *id.* app. at A-3 (requiring flight be confined to defined area); *id.* app. at A-4 (requiring pilot certification); *id.* app. at A-7 (requiring transponder).

certificates allow operations only for experimentation, data collection, and market development, not for routine operations.

The distinction between commercial and non-commercial aviation operations makes sense when the operations being regulated involve the carriage of passengers. Then, the more stringent requirements for commercial operations under Parts 119, 121, and 135¹¹¹ are necessary to protect paying passengers.

Drones, of course, do not carry passengers. So, the more stringent regulation of commercial drone operations cannot be justified under this rationale.

The scope of the existing regulations for commercial operations, however, suggests that the protection of passengers is not the only justification, as it also includes commercial cargo carriage.¹¹²

Further, there are other justifications for applying higher standards to commercial operations. For one thing, economic incentives are likely to induce more operations. More aircrafts will be flown, and they will fly in more places. Thus, the increased air traffic justifies the higher standards.

Finally, research into aviation safety makes it clear that a pilot or other decision maker is more likely to fly into a risky situation when he does not want to lose the revenue for the flight or face the prospect of losing his job or a contract if he makes too many no-fly decisions. That is one of the justifications for introducing more stringent regulation of emergency medical services (EMS) operations in 2014, especially the requirement for operations control centers, which limit pilot authority to approve a flight on his own.¹¹³

Conversely, commercial operators are more likely to have insurance than hobbyists, and they are more likely to have formal risk-management procedures, both of which would make them likely to avoid reckless conduct.

111. 14 C.F.R. pts. 119, 121, 135 (2015).

112. See 14 C.F.R. § 1.1 (2015) (defining “commercial operator” as a “person who, for compensation or hire, engages in the carriage . . . of persons or property”); 14 C.F.R. § 119.1 (2015) (subjecting commercial operators to the more stringent requirements of pt. 121 (air carriers), 14 C.F.R. pt. 125 (large aircraft), or pt. 135 (commuter and on-demand operations) in addition to the more general requirements of 14 C.F.R. pt. 91).

113. See Helicopter Air Ambulance, Commercial Helicopter, and Part 91 Helicopter Operations, 79 Fed. Reg. 9932, 9935 (Feb. 21, 2014) (to be codified at 14 C.F.R. pts. 91, 120, 135) (noting that time sensitivity of EMS flights puts pressure on pilots to fly); *id.* at 9949 (discussing need for management approval of flights exceeding certain risk levels); *id.* at 9949–52 (discussing need for Operations Control Centers).

2. Integration of Machodrones

Machodrones will be regulated under an adaptation of the rules for manned aircraft including certification of aircraft types, pilots, mechanics, and other crewmembers and detailed flight rules. Differences also apparently will persist for regulation of “civil aircraft” as contrasted with “public aircraft”—those operated by units of federal, state, or local government.¹¹⁴

The biggest concern will be that collisions will result because machodrones and manned aircraft will be unable to see each other. Concerns about aircraft and pilot standards can be addressed in a relatively straightforward manner by adapting current aircraft airworthiness certification and airmen certification requirements. But adapting the rules for collision avoidance requires much more fundamental rethinking of current flight rules.

Developing flight rules necessarily invites close attention to features of machodrone flight that are unique, most obviously the absence of a pilot in the cockpit. How can his sight picture, kinesthetic perception, and control inputs be replicated from the ground?

The elaborate system for manned aircraft comprises detailed standards and testing requirements for certification of specific models of aircraft (“types”), examination and licensing of those who want to become pilots and mechanics, and detailed flight rules.¹¹⁵ In many respects, the process of adapting the existing rules will require rethinking many of them, some of which date back to the 1940s and 1950s. What risk are they meant to mitigate? Do they mitigate it in the most cost-effective manner, considering alternatives? Abundant opportunities for delay and controversy exist. The following sections look at some of the possible regulations, considering first,

114. See FED. AVIATION ADMIN., U.S. DEP'T OF TRANSP., AC 00-1.1A, PUBLIC AIRCRAFT OPERATIONS (2014), available at http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_00-1_1A.pdf (explaining requirements for public-use status and citing statutory and regulatory provisions).

115. The FAA Roadmap provides, “UAS operators comply with existing, adapted, and/or new operating rules or procedures as a prerequisite for NAS integration. . . . UAS meet performance and equipage requirements for the environment in which they are operating and adhere to the relevant procedures.” FED. AVIATION ADMIN., *supra* note 31, § 4.1. The RTCA Special Committee recommends, “UAS commercial operations will need to apply the operational control concept as appropriate for the type of operation, but with different functions applicable to UAS operations.” *Id.* § 1.4.3. The FAA Roadmap further provides “[n]o new classes or types of airspace are designated or created specifically for UAS operations.” *Id.* § 4.1. The RTCA Special Committee further recommends, “UAS will have access to the NAS, provided they have appropriate equipage and the ability to meet the requirements for flying in various classes of airspace[.] Routine UAS operations will not require the creation of new special use airspace, or modification of existing special use airspace.” *Id.* § 1.4.3.

requirements for certification of aircraft and pilots or DROPs and second, the role of operating rules, including new rules requiring “NextGen” technologies, the centrality of the see-and-avoid principle, and fail-safe mechanisms for drones.

a. Certification of Aircraft and DROPs

The 2012 Act requires the FAA to adopt rules to define standards for operation and certification of civil UAS.¹¹⁶ Because the operating rules for microdrones and machodrones are almost certain to be quite different, the aircraft and airmen certification requirements should be different as well. The FAA’s NPRM recognized this by defining a new category of airman—sUAS operator—and prescribing knowledge test requirements focused on drone flight, rather than airplane or helicopter piloting.¹¹⁷

i. Aircraft

Aircraft certification is intended to reduce the risk that machodrone vehicles might be poorly designed or poorly manufactured, causing them to have unsafe flight characteristics or frequent failures of critical subsystems.

The traditional way the FAA has dealt with this risk is to require airworthiness certification for each type of aircraft. No person may operate an aircraft in the NAS unless the aircraft has a type certificate and a certificate of airworthiness.¹¹⁸ The Roadmap provides, “Civil UAS operating in the NAS obtain an appropriate airworthiness certificate while public users retain their responsibility to determine airworthiness.”¹¹⁹

The FAA’s aircraft certification process begins with application for a type certificate.¹²⁰ An applicant is entitled to a type certificate if the applicant submits designs, flight-test reports, and computations necessary to “show that the product to be certificated meets the applicable airworthiness, aircraft noise, fuel venting, and exhaust emission requirements of this subchapter and any special conditions

116. See FAA Modernization and Reform Act of 2012, Pub. L. No. 112-95, § 332(a)(2), 126 Stat. 11, 73.

117. Operation and Certification of Small Unmanned Aircraft Systems, 80 Fed. Reg. 9544, 9589 (Feb. 23, 2015).

118. See FED. AVIATION ADMIN., *supra* note 76, ch. 1, § 2, at 2-3.

119. FED. AVIATION ADMIN., *supra* note 31, § 4.1. The RTCA Special Committee recommends, “Except for some special cases, such [microdrones] with very limited operational range, all UAS will require design and airworthiness certification to fly civil operations in the NAS.” *Id.* § 1.4.3.

120. See 14 C.F.R. § 21.15 (2015).

prescribed by the FAA” and that “no feature or characteristic makes it unsafe for the category in which certification is requested.”¹²¹

For example, Part 27 prescribes the airworthiness standards for normal category rotorcraft.¹²² It addresses flight requirements,¹²³ strength requirements,¹²⁴ design and construction,¹²⁵ powerplant,¹²⁶ equipment,¹²⁷ and operating limitations and information.¹²⁸ In the flight category, the aircraft must demonstrate takeoff at maximum gross weight, with the most critical center of gravity, without exceptional piloting skill, in a manner that allows a safe landing if the engine fails.¹²⁹ Static longitudinal and directional stability must be demonstrated.¹³⁰ The structure must be designed to protect the occupants in an emergency landing involving upward loading of 4 Gs, forward loading of 16 Gs, and sideward loads of 8 Gs.¹³¹ A height-velocity (HV) diagram must be constructed for rotorcraft.¹³²

In each case, the burden is on the applicant to show that the candidate aircraft meets the requirements and that the aircraft can perform safely within a defined flight envelope. The flight envelope is defined as a part of the certificate, and information about it must be disclosed in the form of instructions, requirements, and limitations for pilots and mechanics. Typically, a completely new design gets a type certificate specific to that model, and then subsequent modifications to the model get new airworthiness certificates with reference to the type certificate. Typically, the submissions to the FAA comprise detailed design specifications, theoretical calculations, and flight test results.

For example, a height-velocity diagram familiar to all helicopter pilots results from flight tests in which the test pilot demonstrates his ability to set up an autorotation from various heights above the ground and ground speeds. His success in a series of maneuvers defines the outer envelope of the crosshatched, or “avoid,” area of the diagram.

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121. 14 C.F.R. § 21.21 (2015).
122. See 14 C.F.R. pt. 27 (2015).
123. 14 C.F.R. pt. 27(B) (2015).
124. 14 C.F.R. pt. 27(C) (2015).
125. 14 C.F.R. pt. 27(D) (2015).
126. 14 C.F.R. pt. 27(E) (2015).
127. 14 C.F.R. pt. 27(F) (2015).
128. 14 C.F.R. pt. 27(G) (2015).
129. See 14 C.F.R. § 27.51 (2015).
130. See 14 C.F.R. §§ 27.171–177 (2015).
131. See 14 C.F.R. § 27.561(b)(3) (2015).
132. See 14 C.F.R. § 27.87 (2015).

Certification of navigation and control systems are a demanding part of the aircraft certification process.¹³³

Familiar designs are easier to get accepted than completely novel ones. For example, the Learjet 85 has suffered delays in airworthiness certification because of difficulty proving acceptable characteristics of its composite-materials manufacturing process for the fuselage.¹³⁴

Airworthiness certificates are available as a matter of course for new aircraft manufactured under a type certificate if “the FAA finds after inspection that the aircraft conforms to the type design and is in condition for safe operation.”¹³⁵ The requirements for certification are quite detailed.¹³⁶

In the NPRM, the FAA recognized that traditional airworthiness certification for microdrones is unworkable:

However, it is not practically feasible for many small UAS manufacturers to go through the certification process required of manned aircraft. This is because small UAS technology is rapidly evolving at this time, and consequently, if a small UAS manufacturer goes through a 3-to-5-year process to obtain a type certificate, which enables the issuance of a standard airworthiness certificate, the small UAS would be technologically outdated by the time it completed the certification process.¹³⁷

For machodrones on the other hand, their larger weight and the idea that their operations would be integrated with manned aircraft means that they should meet essentially the same certification requirements as manned aircraft, with the exception of those requirements that address the cockpit interface between pilot and aircraft. Those requirements should be replaced by suitable requirements for interface between drone and DROP display.

The most straightforward way to address certification of drones and DROPs is to establish a new category of aircraft known as “UAS” in addition to the existing categories such as airplane, rotorcraft, and lighter than air. Then, microdrones and machodrones would be defined as classes within the category.

133. See generally Graham Warwick, *Herk Works*, AVIATION WK. & SPACE TECH., Feb. 17, 2014, at 35 (reporting that certification of civilian version of Lockheed-Martin’s C-130J depends on system-by-system certification and that engines and structure of aircraft already certificated).

134. See Matt Thurber, *Learjet 85 Schedule in Doubt*, AVIATION INT’L NEWS, Mar. 2014, at 6.

135. 14 C.F.R. § 21.183(b) (2015).

136. See, e.g., 14 C.F.R. § 27.2 (2015) (seatbelt and shoulder harness requirements); 14 C.F.R. § 27.33 (2015) (main rotor speed and pitch limits); 14 C.F.R. § 27.45 (2015) (specifying relative humidity and temperatures for calculation of performance figures); 14 C.F.R. § 27.75 (2015) (imposing requirement for landings without excessive vertical acceleration or tendency to bounce); 14 C.F.R. § 27.145 (2015) (prescribing speeds for which static stability must be demonstrated); 14 C.F.R. § 27.303 (2015) (prescribing factor of safety for structural design).

137. Operation and Certification of Small Unmanned Aircraft Systems, 80 Fed. Reg. 9544, 9549 (Feb. 23, 2015) (discussing infeasibility of airworthiness certification).

ii. DROPs

Certification of pilots, mechanics, and other crewmembers is intended to reduce the risk of insufficiently trained and disciplined operators who can cause even well-designed aircraft to endanger the public. Accordingly, the 2012 Act requires the FAA to adopt rules to establish standards for the licensing of UAS operators and pilots.¹³⁸

In doing so, the FAA aims at requiring UAS DROPs to satisfy manned-aircraft pilot standards to the extent feasible:

UAS training standards will mirror manned aircraft training standards to the maximum extent possible, including appropriate security and vetting requirements, and will account for all roles involved in UAS operation. This may include the pilot, required crew members such as visual observers or launch and recovery specialists, instructors, inspectors, maintenance personnel, and air traffic controllers.¹³⁹

Human factor issues in manned aviation are well known, but there needs to be further analysis regarding integration of UAS into the NAS. In the near term, data will be collected to permit analysis of how pilots fly UAS, how controllers provide service involving a mix of manned aircraft and UAS, and how pilots and controllers interact with each other, with the goal of developing pilot, ATC, and automation roles and responsibilities concepts.

Airmen certification should be structured similar to aircraft certification. A new category, “drone operator,” should be established, paralleling the airplane, rotorcraft, and lighter than air category in the existing Part 61. Particular levels would be established within these categories, such as microdrone and machodrone, roughly paralleling single-engine and multi-engine ratings. An alternative would be simply to maintain the existing levels—recreational, private, commercial, and ATP—but the complexity of the drone and its control systems should matter more in the certification of airmen than the purpose for which it is flown.

The airmen certification requirements for microdrone DROPs should emphasize the rules and procedures that are pertinent to microdrone operations: keeping the drone in sight, limiting its height, and alternating DROP reference between the video display and visual reference to the drone.

As for aircraft certification, the requirements for machodrone DROP certification should resemble those for pilots of manned aircraft: with greater emphasis on procedures when the control link is

138. See FAA Modernization and Reform Act of 2012, Pub. L. 112-95, § 332(a)(2), 126 Stat. 11, 73.

139. FED. AVIATION ADMIN., *supra* note 31, § 3.6.

lost and on use of the DROP's video display to spot other aircraft and maintain situational awareness.

This does not mean, however, that requiring a conventional pilot's license—of any level—for microdrone operation is appropriate. Microdrone pilots do not need to deal with flight risks, such as stalls and threats to structural integrity from turbulence, that manned-aircraft pilots are trained for and tested on. They do need to be skilled on matters, such as management of autonomous features and control-link characteristics that are irrelevant to manned aircraft flight.

It may be appropriate to require completion of a written “knowledge” test but not the flight “practical” test. This is the approach taken by the FAA in the NPRM.¹⁴⁰

b. Collision Avoidance and NextGen

Machodrone integration will be easier because of the basic requirements of the FAA's “NextGen” initiative. The Next Generation Air Transportation System (NextGen) is a comprehensive plan for updating the National Airspace System to reflect new technologies. The 2012 Act requires that drone integration be part of the NextGen plan.¹⁴¹

NextGen is defined in large measure by the essentiality of moving “from ground-based surveillance and navigation to more dynamic and accurate airborne-based systems and procedures”¹⁴² A central part of the NextGen environment is Automatic Dependent Surveillance (ADS).¹⁴³ Automatic Dependent Surveillance-Broadcast

140. See Operation and Certification of Small Unmanned Aircraft Systems, 80 Fed. Reg. at 9550, 9567–70 (explaining decision to require knowledge test tailored to drone operations but not practical test or aeronautical experience).

141. See § 332(a)(2)(I), 126 Stat. at 73.

142. Automatic Dependent Surveillance-Broadcast (ADS-B) Out Performance Requirements To Support Air Traffic Control (ATC) Service, 75 Fed. Reg. 30160, 30161 (May 28, 2010) (to be codified at 14 C.F.R. pt. 91); see also Proposed Provision of Navigation Services for the Next Generation Air Transportation System (NextGen) Transition to Performance-Based Navigation (PBN); Disposition of Comments, 77 Fed. Reg. 50420 (Aug. 21, 2012) (analyzing comments on FAA proposal to replace airways, routes, and procedures using VOR with RNAV and RNP systems).

143. See MITRE, NEXTGEN INDEPENDENT ASSESSMENT AND RECOMMENDATIONS 1–11 (2014), available at http://www.faa.gov/nextgen/media/MITRE_NextGen_Independent_Assessment_and_Recommendations.pdf. Ultimately, drone integration will also benefit from NextGen's goal of greater reliance on digital communications for air traffic control. As a part of NextGen, voice communications gradually will be replaced by digital communications through the Controller Pilot Data Link Communications (CPDLC) system. *Id.* at iv n.1. Certain elements of CPDLC messages can be directly loaded to Flight Management Systems (FMS). *Id.* at 2–11. FMS are enhanced autopilots. As these digital systems are deployed, no particular technological challenge will be presented by integrating drones and providing for CPDLC messages to be

(ADS-B) comprises two different services: ADS-B Out and ADS-B In. ADS-B Out periodically broadcasts information about the aircraft on which it is installed, including current position, altitude, and velocity, derived from GPS. This information is intended to be received by ATC ground stations and other aircraft. ADS-B In receives and displays information received from other aircraft's ADS-B Out broadcasts, Automatic Dependent Surveillance-Re-broadcast (ADS-R), and Traffic Information Service-Broadcast (TIS-B).¹⁴⁴

In a final rule promulgated in 2010,¹⁴⁵ the FAA required all aircraft operating in Class A, B, or C airspace, above 10,000 feet in Class E airspace, and within thirty miles of certain high-density airports to be equipped with ADS-B Out.¹⁴⁶ The required equipment must be operated in transmit mode at all times¹⁴⁷ and must transmit, once per second:¹⁴⁸

- Three-dimensional position, including latitude and longitude,
- Velocity,
- Barometric pressure altitude,
- Length and width of the aircraft,
- Call-sign or registration number,
- ATC-assigned squawk code,
- IDENT when requested by ATC, and
- Capability to indicate radio failure, emergency, or unlawful interference.¹⁴⁹

The Rule also sets maximum error tolerances of 0.05 nautical miles for position and ten meters per second for velocity.¹⁵⁰

exchanged with DROPs and drone autopilots. Full-scale deployment of CPDLC is not expected, however, until 2020. *Id.*

144. TIS-B collects information from primary and secondary ATC surveillance radars and broadcasts it for ADS-B In receivers. ADS-R collects traffic information from ADS-B Out broadcasts and rebroadcasts it for receipt by ADS-B In receivers. Automatic Dependent Surveillance-Broadcast (ADS-B) Out Performance Requirements To Support Air Traffic Control (ATC) Service, 75 Fed. Reg. at 30161–62 (describing ADS and its components).

145. *Id.* at 30160.

146. 14 C.F.R. § 91.225(a)–(b), (d) (2015). Specifically, the regulation requires specific operators to be equipped with Extended Squitter (ES) ADS-B and TIS-B operating on the frequency of 1090 Megahertz (MHz), and Universal Access Transceiver (UAT) ADS-B equipment operating on the frequency of 978 MHz by January 1, 2020. *Id.*

147. 14 C.F.R. § 91.225(f).

148. The ADS-B Out broadcast occurs automatically, without the need for any query from a ground station or other aircraft. It also occurs without the knowledge of whether other aircraft or ground stations are receiving it. RTCA, DO-242A, MINIMUM AVIATION SYSTEM PERFORMANCE STANDARDS FOR AUTOMATIC DEPENDENT SURVEILLANCE BROADCAST (ADS-B) § 1.2.1 (2002) *available at* http://adsb.tc.faa.gov/WG6_Meetings/Meeting%2016/WG6-WP16-04-Working%20Draft_242B_Body_V1.pdf (describing ADS-B, its capabilities, and the infrastructures in which it can provide the basis for controlling air traffic).

149. 14 C.F.R. § 91.227(d) (2015) (setting minimum message elements).

150. 14 C.F.R. § 91.227(c).

ADS-B is already having a significantly favorable impact on specialized domestic operations, such as helicopter support for oil and gas operations in the Gulf of Mexico.¹⁵¹

The 2010 Rule did not require ADS-B in capability, but it will likely be required eventually—at least for those aircraft that must have collision-avoidance systems.

ADS-B is the key technology for integrating machodrones into the NAS, but it is only a traffic conflict detection system; collision avoidance depends either on pilot action or on collision-avoidance software layered on top of traffic conflict detection software. Airborne Traffic Collision Avoidance Systems (TCAS), based on transponder signals from the conflicting aircraft, initially were developed before widespread availability of GPS.¹⁵² Transponders, however, do not provide information on direction of flight. Thus, their utility in limiting collisions is limited.

Now, GPS provides all the relevant data, including position, altitude, and direction and speed of flight. Two basic approaches of using this GPS system to avoid collisions have evolved. One gives urgent voice synthesizer commands to the flight crew. When the data is available, typical TCAS systems can issue synthesized voice commands such as:

“Traffic! Traffic! Climb, Climb—Now”

or

“Traffic! Traffic! Descend, Descend—Now”

And so on.

The second basic approach is to command the aircraft to perform evasive maneuvers without pilot intervention. For the second approach to be available, the aircraft must be equipped with an autopilot. Pilots generally disfavor the automatic approach because they do not want their aircraft to be programmed to make some abrupt maneuver that they have no way of expecting.

With either approach, determining the protocols for collision avoidance is more challenging than programming the protocols into software. Suppose two aircraft are approaching head on. One of them dives to avoid the other, but the other dives as well and so they still collide. Lateral evasion is easier, as are head-on conflicts when there

151. See *NextGen Is Platform for Helicopter Flights*, FED. AVIATION ADMIN., <http://www.faa.gov/nextgen/snapshots/stories/?slide=21> (last modified Feb. 11, 2015) (reporting on impact of ADS-B on 5,000–9,000 daily helicopter operations in Gulf of Mexico, enabling PHI to increase instrument flight rules (IFR) flights from 1,500 hours annually to almost 20,000).

152. See James K. Kuchar & Ann C. Drumm, *The Traffic Alert and Collision Avoidance System*, 16 LINCOLN LABORATORY J. 277, 278–79 (2007), available at http://www.ll.mit.edu/publications/journal/pdf/vol16_no2/16_2_04Kuchar.pdf (summarizing history and development of TCAS).

is some altitude separation or overtaking situations. For all of those, the Federal Aviation Regulations (FARs) and the rules of the road prescribe what each aircraft must do.

Adapting this technology to machodrones is straightforward. The challenges of getting the collision-avoidance protocols right remain, but either the voice synthesized approach or the automatic evasive action approach is conceptually feasible. The urgent voice-synthesized command can be given to the DROP, and he could fly the drone appropriately, just as an onboard pilot would. Likewise, assuming the drone is equipped with autopilot, automatic evasive maneuvers can be triggered.

Collision-avoidance systems for drones will surely piggyback off the ongoing development of traffic detection and collision-avoidance systems for manned aircraft as part of the NextGen effort. The Roadmap provides: "All UAS [must be] equipped with ADS-B (Out) and transponder with altitude-encoding capability. This requirement is independent of the FAA's rule-making for ADS-B (Out)."¹⁵³ Traffic detection equipment promotes safety, especially if it is coupled with collision avoidance capability. It directly manages the risk of midair collisions, but it has nothing to do with avoiding threats to people or property on the ground, except by reducing the likelihood of collisions with other aircraft and thus crashes of one or more of the aircraft.

Several challenges exist, however, in implementing requirements for drones that will permit them to be integrated into the NAS before 2020. First, identifying and installing the necessary equipment in drones is not a major problem, although it will increase weight and cost. The traffic detection and avoidance hardware and software will be the same as is being developed for manned aircraft. The physical design will have to be different, however. Manned aircraft solutions place a premium on good graphical video displays in the cockpit. For drones, good graphical displays will have to be available to the DROP, not in the drone itself. So, the interface among the transceiver, processor, and display components will be different: hardwired and physically proximate in manned aircraft, wireless and remote in drones. That has implications for the necessary bandwidth in the communications link. It is one thing for the drone to send frequent updates on its own position and velocity vector down to the DROP; it is another thing for it also to send large amounts of position and velocity vector information about other aircraft.

Second, there needs to be clear divisions of responsibility between the DROP's exercise of human judgment and the automatic evasive maneuvers programmed into the drone's flight control system.

153. FED. AVIATION ADMIN., *supra* note 31, § 4.1.

Even for manned general aviation aircraft, collision avoidance algorithms are still in their relative infancy as part of NextGen.

Exercise of human judgment for collision avoidance is feasible, but its effectiveness depends on the capabilities of what the DROP sees¹⁵⁴ and how quickly the drone can respond to his commands.¹⁵⁵

c. ATC Communications

The Roadmap preserves ATC authority to control access to airspace and ensure traffic separation, but without direct links to drones.¹⁵⁶ DROPs must “compl[y] with all ATC instructions and use standard phraseology”¹⁵⁷ Drones must comply with ATC clearances and instructions, including instructions that require visual reference,¹⁵⁸ but the FAA identifies the following realities that must be considered:

- The UAS pilot must depend on a data link for control of the aircraft. This affects the aircraft’s response to revised ATC clearances, other ATC instructions, or unplanned contingencies (e.g., maneuvering aircraft);
- UAS cannot comply with certain air traffic control clearances, and alternate means may need to be considered (e.g., use of visual clearances); . . .
- And some UAS launch and recovery methods differ from manned aircraft and require manual placement and removal from runways, a lead vehicle for taxi operations, or dedicated launch and recovery systems.¹⁵⁹

A drone with a ground operator can deal with voice communications, most likely by equipping the drone with the appropriate transceiver and antenna for ATC and air-to-air communications and then inserting those communications on the down link to the ground operator. Likewise, the ground operator’s radio transmissions back to ATC or to other aircraft would be uplinked to the drone and transmitted by it.

For example, a drone approaching an airport might get a tower instruction that says: “Extend your downwind leg until cleared to start base. You’re number two, to follow the Piper Arrow on long final. Advise when you have him in sight.” The DROP would examine his video display showing live video captured by cameras on the drone and respond by voice radio: “We’ll extend downwind. We have the

154. The DROP’s visual capability is considered in Part II.A.2.a.

155. Replicating a pilot’s visual field of view is considered in Part II.A.2.b.

156. FED. AVIATION ADMIN., *supra* note 31, §§ 1.4.2–2.2.1. The RTCA Special Committee recommended, “UAS will comply with ATC instructions, clearances, and procedures when receiving air traffic services.” *Id.* § 1.4.3.

157. *Id.* § 4.1.

158. *Id.* § 2.2.2.

159. *Id.* § 2.2.3.

traffic in sight.” Except for the two-stage radio link, and the fact that the DROP is on the ground, the transaction is the same as it would be for a manned aircraft in the same position.

Similarly, for Instrument Flight Rules (IFR)¹⁶⁰ operations, the question is not whether the drone autonomously can fly an IFR flight plan; it probably can, assuming it has a state-of-the-art autopilot. The question is how amended clearances would be transmitted—digitally to the drone or verbally to the operator.

d. See-and-Avoid

The core principle for reducing the risk of mid-air collisions between aircraft is “see-and-avoid.” That is, pilots must keep a lookout for other aircraft and comply with various right-of-way rules to avoid them. Visual Flight Rules (VFR) use see-and-avoid, supplemented by ATC instructions at busier airports and differing weather criteria for different types of airspace, depending on traffic density.¹⁶¹ When weather conditions do not permit visual observation of other aircraft, a distinct regulatory regime shifts responsibility for traffic separation to air traffic controllers. This system is known as IFR¹⁶² and applies, as previously stated, when the weather is bad or when a qualified pilot prefers to yield some of his autonomy to ATC. Each of these presents different challenges for integrating drones into the flow of manned aircraft traffic. Nevertheless, the 2012 Act requires the FAA to adopt rules to require that all civil UAS include a “sense and avoid capability.”¹⁶³

See-and-avoid is the appropriate principle for microdrone operations, implemented in a line-of-sight requirement. Imposing IFR rules on drones is unworkable.

Under VFR,¹⁶⁴ pilots may fly wherever they want and at whatever speeds and headings they want. Certain geographically specific restrictions are imposed, however. A handful of prohibited areas exist, such as those over certain national facilities in Washington and over certain national defense facilities. Operation in prohibited areas requires advance permission from a controlling authority.

160. See *infra* Part III.A.2.d.

161. See 14 C.F.R. § 91.155 (2015).

162. 14 C.F.R. § 91.157 (2015).

163. FAA Modernization and Reform Act of 2012, Pub. L. 112-95, § 332(a)(2), 126 Stat. 11, 73; see also FED. AVIATION ADMIN., *supra* note 31, § 2.2.3 (identifying challenges).

164. A pilot may elect to fly VFR whenever sky conditions provide more than three statute miles of visibility and ceilings of one thousand feet above ground level or better.

In contrast, IFR flight is permitted only pursuant to an IFR clearance,¹⁶⁵ which specifies the precise route of flight, altitudes, and, in some cases, speeds. Typically, a pilot files an IFR flight plan through the Internet, on the telephone, or, at a rapidly diminishing number of Flight Service Stations, by filling out a printed form and submitting it in person. Then, when he is ready to take off, he calls ATC on a frequency known as Clearance Delivery and receives his clearance, which may be the same as that filed or different.

It is not unusual for a pilot to receive one or more amendments to his IFR clearance en route to accommodate potentially conflicting traffic and changing weather conditions.

The challenge for integrating drones into either VFR or IFR traffic is not so much how to design and deploy systems that enable onboard computers to detect and to decide how to avoid traffic, but rather to understand:

- What the human operator can perceive through his video link,
- Whether he can detect conflicting traffic visually or with the aid of on-board collision-avoidance systems alerting him through the video link, and
- How quickly the data link will allow him to take evasive action.

IFRs will be easier to adapt for machodrones than visual flight rules, since see-and-avoid is not so central to IFR as it is to VFR. After all, sitting in the cockpit, scanning gauges, and providing appropriate control inputs is not all that different from sitting on the ground doing the same thing. Of course, the nature of the control link differs in that it extends much further and relies on wireless radio instead of wired signals or mechanical linkages.

The *capability* of drones to fly IFR flight plans does not mean, however, that IFR flight plans should be *required*. The Roadmap provides: “All UAS must file and fly an IFR flight plan.”¹⁶⁶ This is manifestly infeasible if full drone capabilities are to be available. Filing and adhering to an IFR flight plan is completely incompatible with useful law enforcement or ENG missions. Instead of being point-to-point flights of relatively long distances, well-suited for IFR clearances, law enforcement and ENG machodrones must follow unpredictable routes and be able to change position quickly. Requiring them to obtain an amended IFR clearance every time they want to move around would make mission performance impossible.

165. Pilots who have instrument ratings may fly IFR in IFR-equipped aircraft even when conditions are VFR. In Class A airspace, the airspace above 18,000 feet, only IFR is permitted.

166. FED. AVIATION ADMIN., *supra* note 31, § 4.1.

e. Special Drone Arrival and Departure Procedures

The National Airspace System can handle drone traffic with proper procedures. Special rules of the air exist, much like rules of the road, to keep the flow of traffic moving efficiently, and, more importantly, special procedures limit risk in congested airspace. Special procedures for helicopters are good models for drone regulations.

Aircraft arrival and departure procedures minimize radio congestion in and around busy airports. Airborne routes, such as instrument approaches, map a route for aircraft to fly into airports providing altitudes, headings, and speeds. These instrument approaches provide terrain and obstacle clearance.

Drone arrival routes would be structured similar to that of an instrument approach or departure procedure. Utilizing a “plate,” a DROP would simply taxi the drone to a pre-approved departure point on the airfield. When ready for departure, the DROP would call ATC providing a tail number and name of the departure plate. ATC would then clear the aircraft for the departure. From then on, very limited radio communication, if any, would be needed. Traffic-obstacle separation would not be an issue because of the pre-determined route.

Depicted arrival-departure procedures would be published by the same methods under which current charts are published.¹⁶⁷

The basic concept resembles that presently in the FARs for helicopter flight into, out of, and in the vicinity of airports with significant fixed wing traffic.¹⁶⁸ Typically, at a tower-operated airport, helicopters receive clearances to operate directly from ramps and taxiways, while fixed-wing aircraft use the runways. These helicopter rules are not mandatory and usually are defined on an ad hoc basis in radio communications between an air traffic controller and helicopter pilot.

Also, in major cities, the FAA publishes helicopter charts that show nonbinding “preferred routes” over expressways or other

167. See FED. AVIATION ADMIN., U.S. DEPT OF TRANSP., AERONAUTICAL INFORMATION MANUAL: OFFICIAL GUIDE TO BASIC FLIGHT INFORMATION AND ATC PROCEDURES ¶ 5-2-8 (2014), available at http://www.faa.gov/air_traffic/publications/media/AIM_Basic_4-03-14.pdf (Instrument Departure Procedures (DP)); *id.* ¶ 5-4-1 (Standard Terminal Arrival (STAR) Procedure).

168. For example, 14 C.F.R. § 91.126(b) prescribes traffic patterns for fixed-wing aircraft operating at airports without control towers, while simply saying that helicopters must be operated so as to “avoid the flow of fixed-wing aircraft.” 14 C.F.R. § 91.126(b)(2) (2015).

prominent ground features, which ease the burden on air-traffic controllers and pilots when helicopters fly these routes.¹⁶⁹

These special rules for helicopters embrace the idea that aircraft with significantly different flight characteristics can be separated without much burden on either type of aircraft. They represent a model for doing the same thing with drones.

f. Fail-Safe Protocols

Fail-safe features built in to drone computers can handle many emergencies. For about eighty years, a central philosophy of traffic separation in the NAS has been based on knowing what to expect from other aircraft. This is a philosophy inherited from rules of the road for maritime navigation. It is as important that the vessel with the right-of-way assert its right-of-way¹⁷⁰ as it is for the vessel obligated to give way to alter course. In its application to aviation, an aircraft being overtaken has the right-of-way, and the overtaking aircraft must alter course to the right. The overtaken aircraft, having the right-of-way, must maintain its course.

It must also maintain its course when in-flight emergencies or less urgent incidents occur. An IFR flight losing radio communications is obligated to fly the last clearance.¹⁷¹ An aircraft experiencing an emergency necessitating deviation from an ATC clearance may deviate as necessary,¹⁷² but must inform ATC by radio as soon as it can do so safely.¹⁷³

One of the challenges for integrating drones into the NAS is to prescribe rules for drones experiencing emergencies that let everyone else—other aircraft and controllers—know what to expect. The first step in outlining such an approach is to identify what might happen that would constitute an emergency. The following incidents clearly belong to any list:

- Propulsion plant failure,
- Loss of control link,
- Loss of control while the control link is maintained,
- Impairments to visibility,

169. See, e.g., FED. AVIATION ADMIN., U.S. DEPT OF TRANSP., CHICAGO HELICOPTER ROUTE CHART (2010), available at http://www.faa.gov/air_traffic/flight_info/aeronav/digital_products/vfr/ (depicting “Des Plaines” standard route through O’Hare Class B airspace).

170. See *Rules of the Road*, BOAT U.S. FOUNDATION, http://www.boatus.com/foundation/guide/navigation_3.html (last visited Feb. 2, 2015) (noting stand-on vessel—the one with the right of way—must maintain current course and speed until burdened vessel has passed).

171. 14 C.F.R. § 91.185(c) (2015).

172. 14 C.F.R. § 91.3(b) (2015).

173. FED. AVIATION ADMIN., *supra* note 164, ¶ 1-1-1.

- Loss of navigational data link, and
- Loss of voice communications through the drone.

The responses should be different depending on whether the DROP is still able to control the drone. If he is unable to control the drone because of a loss of the control link or for other reasons, three options are possible:

- The drone lands immediately,
- The drone returns to its starting point, or
- The drone follows the last flight plan that was agreed to with ATC.

Whether returning to base or continuing to fly the flight plan is feasible depends on remaining endurance. The DROP should know remaining endurance before he lost contact.

Landing immediately or returning to the starting point represents a deviation from what is expected by nearby users of the airspace. That means that some mechanism is necessary to alert the others to the drone's intentions, or at least to alert them to the fact that the drone is in distress. A standard way of doing that for manned aircraft is for the pilot to transmit a radio call, either "Mayday, Mayday, Mayday" for a serious emergency or "Pan, Pan, Pan," for a less urgent incident. In addition, if the aircraft is transponder-equipped, the pilot must squawk 7700 for an emergency or 7600 for a radio communications failure.¹⁷⁴ Any drone capable of flying outside the line-of-sight of the DROP will be transponder-equipped, and its on-board flight control systems can be programmed to set a special transponder code when one of the listed incidents occurs.

A lost communications link is one obvious trigger for an emergency procedure. This passage, from the order for special airworthiness certificates, indicates the FAA's approach to lost-link procedures:

In the event of lost link, the UA must provide a means of automatic recovery that ensures airborne operations are predictable and that the UA remains within the flight test area. The chase aircraft or observer, all other UAS control stations, and the appropriate ATC facility must be immediately notified of the lost link condition and the expected UA response. Comply with the following provisions:

- (1) If lost link occurs within a restricted or warning area, or the lost link procedure takes the UA into a restricted or warning area, the aircraft will not exit the restricted or warning area until the link is re-established.
- (2) The UA lost link mission will not transit or orbit over populated areas.
- (3) Lost link programmed procedures will avoid unexpected turn-around and/or altitude changes and will provide sufficient time to communicate and coordinate with ATC.

174. *Id.* ¶ 6-2-2.

(4) Lost link orbit points will not coincide with the centerline of published airways.¹⁷⁵

B. Six FAA Test Regions

The 2012 Act requires the FAA to establish pilot projects at six test ranges¹⁷⁶ to conduct research and development in operational settings to support its eventual requirements for aircraft and airmen certification as well as flight rules. The test range program is to continue until 2017, with a report to be sent to Congress within ninety days after its termination.¹⁷⁷

On December 30, 2013, the FAA selected six test sites for drone research and development.¹⁷⁸ Each has a particular area of focus:

- University of Alaska—standards for unmanned aircraft categories, state monitoring and navigation, and UAS operations.
- State of Nevada—UAS standards and operations, operator standards and certification requirements, and evolution of air traffic control procedures.
- New York’s Griffiss International Airport—test evaluation, verification, and validation processes under FAA safety oversight, and sense and avoid capabilities.
- North Dakota Department of Commerce—airworthiness essential data, validation of high reliability link technology, and human factors research.
- Texas A&M University—Corpus Christi—system safety requirements and protocols and procedures for airworthiness testing.
- Virginia Polytechnic Institute and State University (Virginia Tech)—failure mode testing and identification of operational and technical risks areas.¹⁷⁹

The test site approach is logical and should result in much useful data and analysis, helping to crystallize regulatory approaches. It will be an impediment, however, if the FAA defers most other proposals for drone testing until 2017.

175. FED. AVIATION ADMIN., *supra* note 76, app. at A-9.

176. See FAA Modernization and Reform Act of 2012, Pub. L. 112-95, § 332(c)(1), 126 Stat. 11, 74.

177. FED. AVIATION ADMIN., *supra* note 31, § C.7.

178. See Press Release, Fed. Aviation Admin., FAA Selects Unmanned Aircraft Systems Research and Test Sites, (Dec. 30, 2013), available at http://www.faa.gov/news/press_releases/news_story.cfm?newsid=15576.

179. *Id.*

Moreover, if the FAA requires the six test site operators to obtain certificates of airworthiness for microdrone testing, and if it is inflexible in adapting the published requirements,¹⁸⁰ the test site program may not provide much useful information about microdrones.¹⁸¹ Not many microdrone proponents will elect to meet unrealistic and unduly burdensome requirements to participate in the test sites.

C. Regulatory Timeline Realities

As of early 2014, the FAA had released its congressionally mandated Comprehensive Plan for integrating drones into the NAS;¹⁸² its first annual “UAS Roadmap,” which summarizes regulatory steps to integrate drone operations into the national airspace;¹⁸³ a final privacy policy for the six UAS test sites;¹⁸⁴ and conducted an online public-engagement session on privacy issues arising from drone use.

But serious drone-related activity by manufacturers, operators, and end-users will not occur until the regulatory framework for drones exists. While the 2012 Reform Act imposes various deadlines for the FAA’s integration of drones into the NAS, it is not uncommon for agencies to miss statutory deadlines for rulemaking.¹⁸⁵

The FAA’s Comprehensive Plan sets the following deadlines:

- Routine public small UAS (microdrone) Visual Line-of-Sight (VLOS) operations in the NAS without COAs by 2015. These operations would be permitted only outside of Class B/C airspace and not over populated areas.

180. See *U.S. Unmanned Aircraft Systems: Integration, Oversight, and Competitiveness: Hearing Before the Subcomm. on Aviation of the H. Comm. on Transp. and Infrastructure*, 113th Cong. 2 (2004) (statement of Rep. Frank LoBiondo, Chairman, Subcomm. on Aviation of the H. Comm. on Transp. and Infrastructure), available at <http://www.gpo.gov/fdsys/pkg/CHRG-113hrg91735/pdf/CHRG-113hrg91735.pdf> (pointing out FAA rigidity in approving test site operations).

181. See *supra* Part III.A.2.a.i for a discussion of the unsuitability of current special airworthiness requirements for microdrones.

182. See FED. AVIATION ADMIN., U.S. DEP’T OF TRANSP., UNMANNED AIRCRAFT SYSTEMS (UAS) COMPREHENSIVE PLAN: A REPORT ON THE NATION’S UAS PATH FORWARD (2013), available at http://www.faa.gov/about/office_org/headquarters_offices/agi/reports/media/UAS_Comprehensive_Plan.pdf. The Committee comprised representatives from the Department of Transportation, the FAA, the Department of Defense, the Department of Homeland Security, the Department of Commerce, NASA, and the Executive Office of the President.

183. FED. AVIATION ADMIN., *supra* note 31, § 1.

184. *Id.* § 1.4.

185. For example, the 2012 Act set a deadline of mid-2012 for air ambulance rules, but the final rules were not promulgated until February 21, 2014. See *Helicopter Air Ambulance, Commercial Helicopter, and Part 91 Helicopter Operations*, 79 Fed. Reg. 9932 (Feb. 21, 2014) (to be codified at 14 C.F.R. pts. 91, 120, 135) (referring to Congressional deadline).

- Routine civil microdrone VLOS operations in the NAS without special airworthiness certificates by 2015. Such operations would not be allowed in Class B/C airspace or over populated areas.
- Routine public drone operations in the NAS by 2015, initially using mitigation to comply with 14 C.F.R. Part 91 requirements and eventually under revised operating requirements addressing unique drone attributes.
- Routine civil UAS Operations in the NAS by 2020, initially using mitigation to comply with 14 C.F.R. Part 91 requirements and eventually meeting revised operating requirements addressing unique drone attributes.¹⁸⁶

The FAA Roadmap sets a goal of 2014 for release of a NPRM.¹⁸⁷ The FAA did not meet this deadline, instead releasing the NPRM on February 15, 2015.¹⁸⁸ From that point forward, it is reasonable to use the timing of the FAA's most recent final rule making significant changes in the FARs as a baseline from which to project timing for the drone-integration rule. The FAA issued its NPRM for air ambulance operations on October 12, 2010, with a comment deadline about ninety days later on January 10, 2011.¹⁸⁹ It then took three years and one month to consider the comments and to promulgate the final rule.

Extrapolating from this experience to the drone-integration rulemaking,¹⁹⁰ one could expect the following:

186. FED. AVIATION ADMIN., *supra* note 182, at 9–10.

187. *Id.* at 15. An NPRM is the first formal step in the promulgation of regulations by an administrative agency. *See* 5 U.S.C. § 553 (2012) (providing for notice-and-comment rulemaking).

188. The NPRM was published in the Federal Register a little over a week later. Operation and Certification of Small Unmanned Aircraft Systems, 80 Fed. Reg. 9544 (Feb. 23, 2015).

189. *See* Helicopter Air Ambulance, Commercial Helicopter, and Part 91 Helicopter Operations, 79 Fed. Reg. at 9936.

190. While the drone-integration rules are more sweeping than the Air Ambulance Rules, they affect new entrants more directly than existing participants in the NAS, and thus the prospect of intense opposition to protect vested interests is less likely than for the Air Ambulance Rules, which stiffened requirements imposed on existing operators. Both rulemaking activities were and are supported by well-structured industry advisory committees. The drone-integration committee already has reached consensus on the basic features of drone integration. *See* FAA Modernization and Reform Act of 2012, Pub. L. 112-95, § 332(a)(2), 126 Stat. 11, 73 (describing Regulatory Impact Analysis (RIAs) and summarizing its guidelines). Likewise, an Aviation Rules Committee was convened for the Air Ambulance Rules and made consensus recommendations to the FAA in 2005. *See* Helicopter Air Ambulance, Commercial Helicopter, and Part 91 Helicopter Operations, 79 Fed. Reg. at 9935.

NPRM published in the Federal Register	February 23, 2015 ¹⁹¹
Comment period closes in sixty days	April 24, 2015
Evaluation of comments takes six months to three years ¹⁹²	
Final Rule	November 1, 2015 to April 30, 2018

Drone proponents are not going to remain passive while the rulemaking proceeds. They will continue their development and testing work, many in conjunction with test-site operators. Some operators and end-users will participate in these activities and refine their economic and operational analyses as more data become available. Others will ignore the ban and continue to fly commercial missions. As draft regulations become more specific, however, agreement on broad principles is likely to erode and sharper disagreements will likely emerge.

In any event, commercial and public-use drone operations will not be legal under reasonable requirements, unless the FAA conforms its Section 333 exemption criteria to the content of the NPRM, until late 2015 and perhaps not until early 2018.

IV. REALITIES

How soon drones become a regular feature of air commerce depends on a complex interplay of technology development, regulatory constraints, entrepreneurship, demand and supply interaction, and politics.

The supply chain is already full of microdrones and filling it with machodrones is uncertain because of the development cost. The labor market for DROPs depends on whether those aspiring to be pilots will be interested in becoming DROPs and the wage levels they will command. Contending political interests, especially those relating to individual privacy, will shape legal constraints.

191. The Roadmap calls for release of a microdrone NPRM in early 2014 and release of a more general NPRM for drone integration in 2014. FED. AVIATION ADMIN., *supra* note 31, § C.6.

192. It is possible that the FAA would issue a final rule on some issues and ask for further comments on other issues. This would be consistent with the agency's commitment to an incremental approach. *See* Operation and Certification of Small Unmanned Aircraft Systems, 80 Fed. Reg. at 9551–52 (discussing incremental approach). If that occurs, it could reduce the evaluation period toward the six-month low end for some aspects of the rule and extend it beyond the high end for other aspects. It also is possible that judicial review over some aspects of the rule would delay its implementation further.

A. Supply Chain

The market is in its infancy. A handful of suppliers are selling rotary-wing microdrones to law enforcement agencies and advertising them for ENG as well as pipeline and powerline patrol. The civilian category currently comprises mostly microdrones. It is likely to stay that way until certification requirements for larger civilian drones crystallize in the 2018–2019 time period.

Even before the FAA finalizes the safe harbor for microdrones and well before requirements for machodrones crystallize, however, the pipeline is beginning to fill. Flint Hills Systems, for example, offers a family of drones, from microdrones at the low-end to two machodrones. It is actively promoting them for powerline patrol, law enforcement, and ENG. The designs are conventional, since they involve one main rotor and tail rotor in all four configurations.¹⁹³

The level of activity is greater for fixed-wing machodrones weighing about fifty-five pounds. In October 2013, the FAA granted a special airworthiness certificate to Applied Research Associates, Inc. for its Nighthawk IV fixed-wing microdrone operating at its Randolph, Vermont location for the purposes of research and development, customer demonstrations, and crew training.¹⁹⁴ The company is advertising the availability of the Nighthawk IV for public safety agencies that can use data generated by the manufacturer to expedite issuance of a COA.¹⁹⁵ Earlier in 2013, the FAA issued restricted category type certificates for the Scan Eagle X200 and Aero Vironment's PUMA, permitting them to conduct aerial reconnaissance pertinent to wildfire surveillance, oil spill monitoring, and tracking ice flows and migrating whales in Arctic oil exploration areas.¹⁹⁶

It is likely that major manufacturers such as Boeing, Lockheed Martin, and Grumman will adapt their military versions for civilian application, but the nature of these adaptations is still murky.

For the near term, the greatest level of product design and sales activity will be limited to the microdrone segment. Then, as regulatory aircraft certification, airmen certification, and flight rules for operations mature, manufacturers will be able to crystallize their plans for machodrones.

193. See FLINT HILLS SOLUTIONS, LLC, <http://fhslc.com/> (last visited Feb. 2, 2015).

194. See Press Release, Applied Research Assocs., Inc., Federal Aviation Administration Grants Special Airworthiness Certificate for Nighthawk IV Micro Unmanned Air System (Oct. 16, 2013), available at <http://www.prweb.com/releases/2013/10/prweb11228997.htm>.

195. See *id.*

196. See *US Approves Drones for Civilian Use*, RT (July 27, 2013), <http://rt.com/usa/us-drones-civilian-use-685/>.

B. Labor Market

Significant deployment of civilian drones also depends on the availability of DROPs and other qualified personnel. Presently, the view is that DROPs need essentially the same training as pilots for manned aircraft. In response, Embry-Riddle Aeronautical University has added UAS training and degrees to its long-standing aviation education programs.¹⁹⁷ The curricula of the handful of other universities—Kansas State,¹⁹⁸ Northern Michigan,¹⁹⁹ and the University of North Dakota²⁰⁰ are offering UAS degrees²⁰¹—that have established degree programs for DROPs are similar to Embry-Riddle's; they are modifications of traditional pilot-oriented degree programs with the addition of three or four courses specifically concerning unmanned aircraft systems. The pipeline will be augmented, of course, by DROPs being discharged from the armed forces.

The equilibrium between supply and demand in the labor market for the relevant skills is hard to estimate until more progress is made on regulatory initiatives and until manufacturers ramp up their production. Prices and capabilities in the product market will, of course, influence demand in the law enforcement, ENG, and utility-industry segments. They have to decide how active their drone operations will be before they know their hiring plans.

The aviation community has already entered a period of pilot shortages as the Vietnam-era generation of pilots accelerates its retirement and fewer young people are beginning pilot training. This means that drone operators and the institutions that train DROPs will have to compete with manned flying opportunities for the same

197. See *Bachelor of Science in Unmanned Aircraft Systems Science*, EMBRY-RIDDLE AERONAUTICAL U., <http://daytonabeach.erau.edu/degrees/bachelor/unmanned-aircraft-systems-science/index.html> (last visited Feb. 2, 2015) (describing pilot and non-pilot tracks and degrees); *B.S. in Unmanned Aircraft Systems Science*, EMBRY-RIDDLE AERONAUTICAL U., <http://catalog.erau.edu/daytona-beach/aviation/bachelors/unmanned-aircraft-systems/> (last visited Feb. 5, 2015) (listing specific course requirements).

198. See KAN. STATE UNIV., UNMANNED AIRCRAFT SYSTEMS (2014), available at <http://www.salina.k-state.edu/aviation/uas/Salina%20uas.pdf> (detailing bachelor of science requirements in Unmanned Aircraft Systems major).

199. See *Unmanned Aerial Systems*, NORTHWESTERN MICH. C., <https://www.nmc.edu/programs/academic-programs/aviation/uas-courses.html> (last visited Feb. 5, 2015) (describing courses offered).

200. See *Unmanned Aircraft Systems Operation*, U. N.D., <http://aviation.und.edu/ProspectiveStudents/Undergraduate/uasops.aspx> (last visited Feb. 5, 2015) (describing requirements for a Bachelor of Science degree in Aeronautics with a Major in Unmanned Aircraft Systems Operations).

201. See Matthew L. Wald, *Just Don't Call It a Drone*, N.Y. TIMES, Feb. 1, 2013, http://www.nytimes.com/2013/02/03/education/edlife/universities-offer-degrees-in-unmanned-aircraft-systems.html?_r=0.

pool of potential commercial pilots. They may experience difficulty in the competition because DROP careers seem less romantic than pilot careers. There is a possibility that the lure of flying drones will attract a new group of people that are not interested in becoming pilots of manned aircraft, but this is entirely speculative, and even if such attraction exists, demanding training requirements may discourage the potential new entrants.²⁰²

The labor market for DROPs will also be influenced by the attitudes of helicopter pilots toward drones. Pilots have an outsized, but not determinative, influence on public policy relating to aviation. However, they have enormous influence on young people considering careers in aviation. And given that many in the pilot community are viscerally opposed to drones, for reasons ranging from fear of lost employment opportunities to sheer enjoyment of flying manned aircraft, their skepticism could impede labor market entry for new pilots. “Who wants to sit on the ground and fiddle with a videogame console while the aircraft flies around without you?”²⁰³

But the fear that their jobs are at risk is neither in their self interest nor backed up by reality. Indeed, for the first few years of operational drone use, no pilot’s job will be at risk, as it will be years, or even decades, before any customer starts canceling helicopter contracts or selling helicopters because its needs can be covered by drones.

At any rate, attitudes toward new technologies are generational. And a new generation is ready to enter the pilot workforce. They have grown up with drones being a part of any conversation about aviation and aviation careers. The generation ahead of them feels blindsided by the threat of drones just as they get a leg up on getting paid to be in the cockpit. The reaction of the two groups is likely to be quite different. Older generations of pilots—those in their forties and fifties—have retirement within their planning horizons. Their attitude is likely to be, “Just stave off the drones until I am ready to retire.”

C. Political Factors

The deployment pace of drones will depend as much on politics and privacy concerns as on technology and FAA regulation.

202. It may turn out that microdrones operating within line-of-sight and at limited altitudes likely will be operated by regular police officers, reporters, or utility inspection personnel with modest on-the-job training. This would ease the barriers to recruitment in the microdrone segment.

203. The quoted language is a synthesis of what the authors have heard again and again from their pilot associates when they talk about drones.

1. Privacy Concerns

The privacy community is up in arms about the potential for drones to expand intrusion into private affairs by law enforcement, foreign intelligence, and journalistic organizations. The FAA's online telephonic session on privacy issues relating to the test sites illustrated some of the concerns.

Those focusing on privacy identified the perceived threats:

[Used] as evidence in a criminal court of law[,] . . . videotaping the facial expressions of people on the ground from hundreds of feet in the air will usher in a new age of surveillance in our society. No person, whether he is at a political rally, exiting a house of worship or simply walking around downtown will be safe from the prying eyes of these devices.²⁰⁴

The Electronic Frontier Foundation (EFF) summarized the privacy threats:

UAS are capable of highly advanced and near-constant surveillance through live-feed video cameras, thermal imaging, communications intercept capabilities, and backend software tools such as license plate recognition, GPS tracking, and facial recognition. They can amass large amounts of data on private citizens, which can then be linked to data collected by the government and private companies in other contexts.²⁰⁵

The Center for Democracy and Technology (CDT) summarizes it this way:

Surveillance-capable UASs are quite different than manned aircraft and other types of surveillance activities for a number of reasons. First, platforms for UAS-based surveillance are increasingly inexpensive, with small systems costing a few hundred dollars, compared to many thousands of dollars per hour of operation for manned surveillance aircraft such as airplanes and helicopters. Because of their small size and lack of an on-board human pilot, UASs are capable of going many places manned aircraft cannot (such as between narrow buildings) and capable of operation in environments that humans cannot (such as during high-g tactical maneuvers, high altitudes and long times aloft). UASs, like manned surveillance aircraft, are capable of unique vantage points from which ground-based individuals may not expect surveillance systems to observe. Finally, the nexus of these considerations result in aerial surveillance platforms that may be very difficult—if not impossible—to visually identify, such that many types of UAS surveillance are possible with no notice to ground-based individuals.²⁰⁶

204. FED. AVIATION ADMIN., U.S. DEP'T OF TRANSP., FAA UAS ONLINE LISTENING SESSION 4 (2013), *available at* <http://www.faa.gov/uas/media/uastranscription.pdf> (statement by Michael Covari).

205. Letter from Jennifer Lynch, Staff Att'y, Elec. Frontier Found., to Robert Davis, Cadwalader, Wickersham & Taft LLP, and Mead Treadwell, Lieutenant Governor, Aerospace States Ass'n (May 31, 2013), *available at* https://www.eff.org/files/eff_asa_model_drone_legislation_letter.pdf.

206. JUSTIN BROOKMAN ET AL., CTR. FOR DEMOCRACY & TECH., COMMENTS TO THE FEDERAL AVIATION ADMINISTRATION ON UNMANNED AIRCRAFT SYSTEM TEST SITE PROGRAM 1–2 (2013), *available at* https://www.cdt.org/files/file/CDTComments_FAA-UAS.pdf.

In addition to intrusions on individual privacy, another concern is that widespread use of drones will make it easy to monitor crowds and other public gatherings that have First Amendment implications.

In response to these concerns, support is growing for a requirement that drone operators file and adhere to data collection and management plans. Such plans would include:

- The purpose for which the UAS will be used and the circumstances under which its use will be authorized and by whom,
- The specific kinds of information the UAS will be capable of collecting, including whether that information is personally identifiable or not,
- The length of time for which the information will be retained (in a manner that preserves identifying data),
- Methods used to minimize or aggregate data and delete old data,
- Parties with which information will be shared,
- The possible impact on individuals' privacy,
- The specific steps the operator will take to mitigate the impact on individuals' privacy, including protections against unauthorized disclosure,
- The individual responsible for safe and appropriate use of the UAS, and
- An individual point of contact for citizen complaints.²⁰⁷

Many critics would require search warrants.²⁰⁸ This may not provide much protection, however, because search warrants are required only of governmental entities; the “open fields” doctrine says that warrants are not required to conduct surveillance of activities going on in public areas.

Moreover, widespread support exists for making data collection and distribution transparent. Some would even require that any downlink be unencrypted and represented in standard data structures so that anyone could see what is being collected.

Others propose making metadata about drone collection available on the web, perhaps for each flight—route of flight, time and date, targets of collections efforts, and amount of data being collected.

207. *Id.* at 3.

208. The Fourth Amendment to the United States Constitution protects against governmental invasions of privacy; no such legal provision protects against private invasion. Accordingly, the legal framework for privacy protection with respect to law enforcement use of drones is more robust than it is otherwise.

The basic concept of the Fourth Amendment is that the government may not intrude into areas clothed with a “reasonable expectation of privacy” without a search warrant, absent other circumstances that make the intrusion “reasonable.” *See Katz v. United States*, 389 U.S. 347, 360 (1967) (Harlan, J., concurring). Search warrants may be obtained only upon showing a probable cause to believe that evidence pertinent to a criminal investigation will be obtained by the search and only then subject to conditions that minimize the intrusion.

The Electronic Privacy Information Center recommends a searchable database for drones and drone operators.²⁰⁹ A more modest proposal, not aimed at data collection itself, but rather at drone flights, would simply require drones to have ADS-B Out capability, which would permit anyone to track them.

Significantly, CDT would exempt microdrones:

Certainly, the traditional exemptions for model aircraft operation and the current unregulated airspace below 400 feet should still allow relatively simple UAS operations without such equipment requirements; however, if the UAS has sufficient power and recording capability, it should also be able to generate an ADS-B Out signal.²¹⁰

Privacy fears will continue to dominate the political calculus. But in many respects, the privacy concerns are unfocused, reflecting a lingering conspiracy theory about “black helicopters” as the wedge of a crushing state intruding into individual activities.²¹¹ On the other hand, some of them are more focused and rely on factual analysis. The starting point is to understand what drones are likely to do that manned aircraft are unlikely to do in the hands of the same types of operators.

To begin, there *are* differences. It is widely perceived that drones will be much cheaper than manned aircraft and, therefore, that there will be many more of them. As Part III explains, however, these hopes are likely to be dashed on the shoals of regulatory reality. But that remains to be seen. If there are indeed many more drones, the possibilities of using them to invade personal privacy increases linearly, in proportion to their numbers, eventually flattening.

Of greater importance is the near certainty that drones will be flown much lower than manned aircraft. Helicopter pilots typically stay at a height above ground level that permits a safe landing in the event of an engine failure. However, flying higher also decreases the likelihood of colliding with obstructions such as radio antennas, water towers, electrical wires, and wind turbines. This particular safety concern is diminished with drones because an accident does not threaten the lives of the aircrew. It may, of course, threaten the lives of people on the ground. The prevailing view is that lower is better for drone flight to reduce potential conflicts with manned aircraft, most of which are flying higher. At least until low-flying drone accidents

209. MARK ROTENBERG ET AL., ELEC. PRIVACY INFO. CTR., COMMENTS OF THE ELECTRONIC PRIVACY INFORMATION CENTER TO THE FEDERAL AVIATION ADMINISTRATION OF THE DEPARTMENT OF TRANSPORTATION UNMANNED AIRCRAFT SYSTEM TEST SITE PROGRAM 10 (2013), available at <http://epic.org/privacy/drones/EPIC-Drones-Comments-2013.pdf>.

210. JUSTIN BROOKMAN ET AL., *supra* note 206, at 7.

211. See MICHAEL BARKUN, *New World Order Conspiracies II: A World of Black Helicopters*, in *A CULTURE OF CONSPIRACY: APOCALYPTIC VISIONS IN CONTEMPORARY AMERICA* 65, 65–78 (2003).

occur and the public demands minimum altitudes, flying low will be preferable.

The corresponding privacy concern is that, by flying lower, drones will be able to intrude more closely on private lives. The typical cartoon highlighting this concern depicts a small drone hovering and looking through a bedroom window.

To some extent, the concern with height above ground is misplaced. Good on-board camera equipment is capable of zooming so that intimate detail of ground objects is clearly visible from heights of one thousand feet above ground level or so. Hence, a minimum altitude restriction would have to be quite high to prevent this, but, as discussed previously, flying higher comes with its own set of problems. On the other hand, to actually focus in on someone's bedroom window, sight angles matter. ENG and law enforcement helicopters usually find a 45-degree offset ideal to capture ground detail. At that angle, one cannot see much through a bedroom window—except the floor.

In contrast, a drone hovering at ten feet, twenty feet from the side of a single-family detached dwelling, can see almost anything going on inside a room through an unobscured window if the drone is positioned at roughly the same height as an exterior window.

An important aspect of how the law protects privacy is the likelihood of detecting violations. Peeping toms are often caught because they make noise, can be seen without too much difficulty, and can run only so fast when they try to get away. Similarly, drones, even small electrically powered ones, make a fair amount of noise, so auditory detection is equally probable. On the other hand, they can fly away very fast, and the likelihood of catching them is low unless the victim is quick enough to capture detail and unless the regulatory system tracks their movements. But it will be relatively easy to track the movements of larger drones—those equipped with ADS-B Out systems.²¹² Hence, there is a good chance that individuals using larger drones for these inappropriate purposes will be caught and reprimanded. On the other hand, microdrones are unlikely to be required to have such systems; therefore, the mechanism for tracking them will not be very robust.

Independently, privacy advocates are concerned about the use of data collected by drones. Not only may law enforcement and intelligence agencies have an inventory of data about a citizen, the same data may be in the hands of an employer, an insurer, or a blackmailer.

There will be continuing battles between privacy groups and ordinary citizens concerned about privacy and proponents of wider

212. See *supra* Part III.A.2.b.

drone use. While the proposals for data collection plans and open access to ADS-B Out data are reasonable on their face, potential operators will oppose the data collection plans because they will impose additional paperwork burdens and restrict operations. Many of them also will oppose transparency in ADS-B Out data on law enforcement security or proprietary grounds. If anyone can know the exact flight path of law enforcement drones, they can frustrate the law enforcement mission. Moreover, if competitors know the details of ENG drone flights, they can gain a competitive advantage. Indeed, such data meet most of the elements for trade secret status.²¹³ Whether the secrecy element can be met depends on how transparent the data transmissions are.

2. The Political Calculus

It is too early to predict with any confidence the values and variables in the political calculus for widespread drone use. Nevertheless, the FAA-sponsored “public listening session” over the test sites and the first thousand or so comments on the NPRM provide a reasonable snapshot of the political equation as of early 2015.²¹⁴

Proponents and opponents of widespread drone use were about evenly split, with a slight tilt toward proponents.

All of the major privacy advocacy groups participated and demonstrated a high level of sophistication about the issues. They all made similar proposals with regard to privacy protection. Many of the concerns focused, however, not on privacy, but on safety—the prospect of drones falling out of the sky—as much as drones at the bedroom window.

At this point I am less concerned with the privacy issue. I am more concerned with safety with mid air collisions between a UAV and a manned aircraft and pieces of aircraft debris falling from the sky.²¹⁵

The thought of running into a 400 pound UAV that's 400 feet around my airport is very very scary and I don't want that to happen in my air space.²¹⁶

How would you feel if a 45 foot wingspan drone came crashing to the ground in one of your elementary schools? There have been other accidents such as a 400 pound shadow drone crashing into a C130 Hercules transport plane.²¹⁷

213. See HENRY H. PERRITT, JR., *TRADE SECRETS: A PRACTITIONER'S GUIDE* § 1.2.1 (2d ed. 2014) (summarizing elements of trade secret misappropriation: (1) information conferring competitive advantage because not generally known, (2) reasonable efforts to maintain secrecy, and (3) wrongful means to obtain).

214. See FED. AVIATION ADMIN., *supra* note 204, at 2 (statement by Jim Williams, Manager, UAS Integration Office, Fed. Aviation Admin.).

215. *Id.* at 7 (statement by Alice Sheflaw).

216. *Id.* at 10 (statement by David Lemmon).

As is typical with such opportunities for general public participation, several of the individual participants had overblown concerns or fixations on bizarre solutions to general social problems. One participant, who called in twice, favored wider use of drones as instruments of the constitutional right to self-defense, which, he claimed, would diminish gun violence and generally improve society.

Nevertheless, most of the proposals for privacy protections were rational in the sense that they would diminish the opportunities for intrusion or at least make targets aware of it. They demonstrate a realization that the greatest threat comes from law enforcement collection and that considerable benefits result from other uses, such as for news gathering.

Here is how the EFF summarized the status of state legislation in mid-2013:

Some proposals floated so far, such as California's AB 1327, lay out a decent framework for limiting the use of drones by law enforcement. Few states, however, have adequately handled the use of drones by private individuals. Texas' recently passed (but so far unsigned) HB 912 manages to mess up both sides of the table by allowing cops to use drones without a warrant while also hampering the press' ability to use drones in newsgathering. The ACLU has a comprehensive breakdown of the legislation, along with analysis of the good and the bad and what has passed into law so far.²¹⁸

EFF argues that the following principles should govern state legislation:

1. Law enforcement must be required to obtain warrants before using drones in investigations to protect the Fourth Amendment rights of citizens from overbroad or undue data collection.
2. Commercial drone operators must be held to established privacy standards and must disclose the details of their operations.
3. Legislation that regulates private and media use of drones must strike an appropriate balance between privacy and First Amendment protected activities, such as news gathering.

The EFF continued, “[We] believe[] that the public has a right to know where drones are being used, what kind of information the surveillance technology records, how long the data will be stored, who has access to the data and whether the information can be used outside of the original, stated purposes.”²¹⁹

217. *Id.* at 7–8 (statement by Shirley Mikinott).

218. Dave Maass, *All Drone Legislation Must Meet These Three Requirements*, ELECTRONIC FRONTIER FOUND. (June 3, 2013), <https://www.eff.org/deeplinks/2013/06/all-drone-legislation-must-meet-these-three-requirements>.

219. *Id.*

It is tempting to conclude that exciting new technologies cannot be held back, but they can. Political opposition based on noise and other environmental effects killed the supersonic transport. James Chiles' book, *The God Machine*,²²⁰ meticulously details how the prospects for helicopters and gyrocopters to be a pervasive part of everyday life have repeatedly been derailed by political opposition to noise, safety risks, and economic disparity.²²¹

But a coalition of supporters is equally possible. Significant to evaluating the political equation, however, is the fact that Congress has been pushing the FAA to accelerate drone integration rather than pulling it back.²²² The inclusion of the push in the 2012 Reform and Revitalization Act suggests constituencies influential with the Aviation Committee are the most active. A review of testimony on the subject would be helpful. Drone manufacturers—both those who have supplied drones to the armed services and those who are supplying new entrants—federal, state, and local law enforcement agencies, potential operators, including those now in the ENG, pipeline and powerline patrol, and oil-and-gas exploration are pushing to accelerate drone use. Suppliers of wireless control systems and DROP video displays see opportunities as well. Others, now at the margins, are commercial entities like Google that obviously could benefit from drone use for applications like Google Maps.

But local groups and national privacy advocates are pushing back. The most prominent privacy groups, however, are not implacably opposed to drone deployment; they have a more nuanced position. Significantly, CDT appears to favor ENG drone use.²²³ It reserves its strongest concerns for abuse by law enforcement and intelligence agencies.

V. FORECAST

As soon as, and even before, the FAA further relaxes its Section 333 exemption, COA,²²⁴ and special airworthiness certificate²²⁵ requirements for microdrones,²²⁶ the deployment of these small systems will proliferate. They will transform the way law

220. JAMES R. CHILES, *THE GOD MACHINE* (2007).

221. *See id. passim*.

222. *See, e.g.*, Helicopter Air Ambulance, Commercial Helicopter, and Part 91 Helicopter Operations, 79 Fed. Reg. 9932 (Feb. 21, 2014) (to be codified at 14 C.F.R. pts. 91, 120, 135).

223. *See* JUSTIN BROOKMAN ET AL., *supra* note 206.

224. COAs are available only to federal, state, and local governments.

225. Drones may be operated as civil aircraft only pursuant to special airworthiness certificates.

226. sUAS is the formal designation for what this article calls *microdrones*.

enforcement and news gathering organizations use aviation support. It will make aviation support more affordable for police departments, and journalists may flood the news gathering marketplace with amateur-recorded imagery, much as cell-phone-acquired imagery has already transformed it. It will stimulate demand for relatively low levels of training for a large cadre of qualified DROPs.²²⁷

The timing and extent of use of microdrones will depend on the willingness of law enforcement agencies, television stations, and utilities to try them out. Their prices and capabilities are well-established. How far they will spread will depend, of course, on early experience with them and the responses of police officers, reporters, and utility inspection crews who try them out.

On the other hand, the development of machodrones will occur more slowly. They have essentially the same capabilities as manned helicopters, but stabilization of the regulatory regime will take another ten years. It is far from clear at this point that the weight and power-consumption requirements of equipment necessary to ensure safe integration into the NAS will offer any particular advantage in price or operating cost over manned helicopters. Anticipated labor cost savings will be largely nullified by requirements that DROPs have the same basic qualifications and certifications as pilots and systems operators for manned helicopters. Ultimately, the revised FARs²²⁸ applicable to certification of drones and their operations may result in prices and operating costs that are less favorable than those for manned helicopters.

The timing and extent of use for machodrones will depend mainly on cost and capabilities, influenced greatly by political reaction. They will be used more widely for pipeline and powerline patrol than for law enforcement and news gathering. This concentration in pipeline and powerline patrol will occur for several reasons: pipeline and powerline patrol can be carried out in remote areas, reducing political opposition; avoiding risks to flight crews is a bigger issue in powerline or pipeline patrol and repair; and the finely tuned, ad-hoc adjustments that human pilots on-board make is less needed in these applications than for law enforcement and news gathering.

Of course, none of this will happen tomorrow. As this Article is published, drone use in the civilian sector is illegal, except under

227. In contrast to the DROP, the person who flies the drone from a remote ground station, the DROSOP (DROne Systems Operator) is the person who manages the drone's sensors and other non-flight equipment, such as cameras, searchlights, and video downlinks. Further, a DROTOG (DROne phoTOG) is a DROSOP used in ENG, and a DROTSO (DROne TSO) is a DROSOP used in law enforcement support.

228. FAA regulations applicable to aviation operations usually are referred to as FARs.

tightly restricted model-airplane rules that preclude commercial purposes and under case-by-case Section 333 exemptions, all of which require pilots' licenses and limit operational areas..²²⁹

The regulatory environment will evolve in three basic stages. The first is the present one, in which the FAA has sketched with reasonable specificity its basic intentions with respect to integration into the NAS and is collecting and evaluating data from the six test sites. During this stage, however, drone use by either law enforcement or news gathering organizations is illegal unless the users have Section 333 exemptions, for ENG or pipeline and powerline drones, or COAs, for law enforcement drone operations.

In the second stage—as early as the end of 2015 or as late as early 2018—general drone operator certification and operating rules will be on the books. That does not mean, however, that hundreds of drone operations will suddenly spring up. Instead, this will be a period of intense experimentation and market shakeout. Drone manufacturers will jockey to provide product capabilities reflecting the suggestions in the NPRM, DROP candidates will begin preparing for the proposed knowledge test, and end-users will embark on various test programs either with their own certified drones or by contracting with operators. Pricing and operating costs will become clearer.

During this period, existing helicopter operators will decide whether they want to incorporate drones into their fleet or whether they will view them as an existential threat to their businesses.

Most would-be machodrone manufacturers will discover they do not have the capital, expertise, or patience to get their products certified. Furthermore, they will realize they cannot invest what is necessary to sell them in quantities and at prices that will cover their costs and generate a return on investment.

Some end-user experiments will be successful, and these end-users will make substantial orders. Others will conclude, after their experimentation and tests, that large-scale drone use does not offer benefits proportionate to costs. If the past is any guide, most existing helicopter operators will view drones only as a threat; they will expect their market share to diminish as drones move into some of their territory. Others will make strategic decisions to offer mixed fleets, including drones, to their customers.

229. See *Busting Myths About the FAA and Unmanned Aircraft*, FED. AVIATION ADMIN., <http://www.faa.gov/news/updates/?newsId=76240> (last modified Mar. 7, 2014) (noting that only two special airworthiness certificates have been granted, both limited to Alaska, and lowering a 2011 FAA estimate of 30,000 operational drones by 2030 to the area of greatest expected growth, projecting 7,500 microdrones by 2018).

The procedures for obtaining airworthiness certification will undoubtedly be divided by aircraft category—one simplified set for microdrones and another more demanding set for machodrones.

A number of manufacturers and service providers are gearing up to exploit the market for both microdrones and machodrones. Already, civilian microdrones are flying under Section 333 exemptions and COAs for a limited amount of law enforcement support. As the FAA moves to a regulatory framework for microdrone flight, instead of requiring COAs or special airworthiness certificates in every case, the use of microdrones on an exploratory basis will explode. Not all of these uses will turn out to be viable. As with the development of any new market, initial enthusiasm will be moderated by experience, as supply and demand gradually settle down to what is sustainable.

But it will be surprising if a number of microdrone uses like those sketched in this Article do not prove to be viable. Therefore, we predict that by the end of 2018 or so, microdrones will regularly be flying missions for segments at the margin of pipeline, powerline, and railroad patrol, law enforcement support, and ENG. Well before 2020, it is likely that a growing percentage of patrol officers will carry microdrones in the trunks of their squad cars and fly them to support localized tactical missions.²³⁰ Similarly, television stations will be unable to resist the temptation to use videos acquired from microdrones by ordinary citizens—just as the widespread broadcast of iPhone-captured video is a current mainstay of journalism. For example, on February 13, 2004, WBBM, the local CBS affiliate in Chicago, featured a story about ice floes piling up on the southern shore of Lake Michigan, accompanying the report with video taken from a microdrone operated by the Indiana Department of Natural Resources.²³¹ Channel 7 in Chicago even solicits viewer videos.²³²

Experimentation, especially with microdrones, will be decentralized. A particular police department or television station—or more likely an individual police officer or reporter—will obtain possession of a drone and try it out. If success results, word will spread and institutional interest will grow.²³³ If a negative incident occurs, the early, informal adopter will likely get fired.

230. Aerobatic Solutions markets a microdrone, the Huntsman, very similar in weight and appearance to the Phantom, for law enforcement application. See Aerobatic Solutions, *The Huntsman Kit*, YOUTUBE (Jan. 29, 2014), <https://www.youtube.com/watch?v=8TSvt5gE8tM>.

231. The authors heard the story on the radio and watched the video clip on the web. It since has become unavailable, perhaps only to make room for more current news items.

232. See *U See It*, ABC 7 EYEWITNESS NEWS, <http://useeit.abc7chicago.com> (last visited Jan. 30, 2015).

233. See Alan Frazier, *Draganfly X4-ES First Look*, AIR BEAT MAG., Nov.–Dec. 2013, at 49 (describing successful experiments by Canadian and North Dakota agencies using a \$25

Existing helicopter operators may participate in early drone evaluation, or they may decline to participate, limiting themselves to manned helicopter operations. If they decline, their customers are likely to undertake drone testing and, in some cases, drone deployment without involving the helicopter operators.

Early experimentation and evaluation will go much more smoothly if it takes place in remote areas where almost no one lives, works, or plays. Public outcry is going to be much less in the country than in the city.

Gradually, machodrones will find their way into law enforcement and ENG fleets, but opponents will find it much easier to delay widespread use of machodrones than to block the proliferation of microdrones. Their operations will be scrutinized and inevitable accidents will provoke an outcry insisting on further restrictions. But then, at some point, a drone will find a lost child and the political balance will tilt in the favorable direction.²³⁴

It is hard to block new technologies; however it is even more difficult when an objective review of the technologies shows that they can deal—for the most part—with concerns about traffic separation and keeping machodrones in the air and away from people on the ground. The trick is figuring out what “for the most part” means.

Anyone who flies both airplanes and helicopters, as the authors do, knows that helicopters are considerably harder to fly than airplanes. Helicopters require constant control inputs to keep them level; airplanes do not. In calm air, a pilot can take his hands entirely off the yoke and throttle, and the airplane just purrs straight ahead. By contrast, a helicopter pilot almost never takes his hand off the cyclic stick. If he does, the aircraft reminds him in a second or two that he better put it back. Likewise, it is relatively easy to set off pilot-induced oscillations in a helicopter and quite difficult in an airplane. Helicopter autopilots have become available much later than airplane autopilots, and full-functioned autopilots capable of flying departures and landing approaches are only just being introduced.

Based on this experience, it is counterintuitive to believe that rotary wing drones will have performance characteristics and safety features that put them at the leading edge of drone integration. Even if an engineer believes it, a pilot will not. All an opposition group

thousand, 5.7-pound microdrone with a one kilometer range and twenty minutes of endurance capable of flying Sony RS-100, Sony NEX5R Low Light, or FLIR Tau 640 thermal imager).

234. See, e.g., Mike Masnick, *FBI Has Used Drones on Americans to Save a Child . . . And the Rest Is Secret*, TECHDIRT (July 26, 2013), <https://www.techdirt.com/articles/20130726/12513523962/fbi-has-used-drones-americans-to-save-child-rest-is-secret.shtml>.

needs is one or two helicopter pilots to testify that drones are inherently unsafe, and they can block almost anything.

Confidence on either side of the debate is misplaced. Who is talking today about ordinary people flying their own helicopters from their driveways?