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Small Unmanned Aerial System Certification and Traffic Management Systems

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This report reviews options for small Unmanned Aerial System (sUAS) regulation. An sUAS is defined by the Federal Aviation Administration (FAA) as an aircraft that weighs between 0.55 pounds and 55 pounds (FAA, undated). In this Perspective, an sUAS refers to either an aircraft that is remotely piloted by a human operator or to an aircraft that is autonomous. An autonomous aircraft performs operations "in which the remote pilot inputs a flight plan" that the aircraft then flies without further human direction, according to the FAA (FAA, 2016a). The potential regulations we consider include aircraft design certification requirements as well as more-novel and flexible risk-based standards. We also consider the unique challenges of air traffic control (ATC) for sUAS traffic. We describe roles that could be played by the FAA and sUAS operators and manufacturers in the future, particularly with regard to the safety and efficiency of sUAS operations.

Background

There were more than 550,000 sUAS registered in the first nine months of 2016 (Lawrence, 2016). The FAA Aerospace Forecast estimates that there will be between 2.75 million and 4.47 million aircraft flown by hobbyists and between 0.24 million and 1.62 million aircraft flown commercially by 2021 (FAA, 2017a). Goldman Sachs (undated) estimates that 7.8 million "Retail/Consumer drones" will be sold in 2020. The accompanying growth in air traffic could produce undesirable outcomes, such as an increase in the risk of bystander injury or death as a result of aircraft crashes. There have already been issues associated with sUAS operations. One news story noted that the FAA received more than 1,800 reports of "drones engaged in hazardous or unauthorized activity" over a recent 12-month period (Whitehouse and Langevin, 2017). There have been particularly high-profile incidents involving sUAS flying dangerously close to busy airports, including San Francisco

International Airport and London Gatwick Airport (Evangelista, 2017; BBC News, 2017).

Regulations, systems, and procedures can reduce the risk of sUAS operations below an acceptable threshold. A separate RAND report in this series compares and contrasts regulations regarding commercial sUAS use in various countries (Jones, forthcoming). In this report, we focus on the United States and on options for the future regulation of sUAS designs and for the future of ATC.

The FAA manages conventional aircraft in large part by requiring aircraft to have certificates of airworthiness and by actively managing air traffic in much of the country. Although the FAA has set up an Unmanned Aircraft Systems (UAS) office with a small staff to deal with these and related issues, the U.S. Government Accountability Office (GAO) worries that the "current five staff in the UAS office [could be] quickly overwhelmed by rapidly developing technology" and "would face greater problems if it [is] unclear what FAA's authority and resources would be to regulate UAS" operations (GAO, 2016). One recent media story commented that "creating a way for drones to safely integrate into the national airspace is one of the biggest linchpins holding up the future of U.S. drone regulation and drone delivery more broadly," and tied the issue of drone delivery to Trump administration plans to "privatize air traffic control" (Glaser, 2017a).

The Air Commerce Act of 1926 mandated that the federal government establish navigational aids for airmen, establish safety regulations, and enforce these regulations. This act was proposed explicitly to "promote civilian aviation" (Nolan, 2010) and its success in doing exactly that is evident today. A similar effort to promote sUAS activity is under way today. The FAA's Part 107 Regulations (FAA, 2016a) are the primary regulations for sUAS operations. These regulations do not yet include details on airworthiness certification, design standards, or the management of sUAS traffic, but observers, sUAS manufacturers and operators, and others expect that there will be updates and expansions of Part 107 in the coming years. One subject-matter expert noted that as sUAS traffic increases, "a higher threshold will be set for the reliability and capability" of such systems, but that "how this is implemented is still up in the air."[1] The FAA has convened a Drone Advisory Committee to discuss the regulation of sUAS operations. It is meeting several times per year and helping to shape sUAS regulations. Recent announcements from the White House Office of Science and Technology Policy (OSTP) and NASA also offer signs that momentum is building in this important public-policy area.

As these efforts move forward, special emphasis will be placed on setting standards for sUAS designs and possibly requiring certification of airworthiness. At the same time, manufacturers are likely to develop a relatively large number of sUAS designs fairly rapidly. Part of the appeal of sUAS technology is the low cost of owning and operating such aircraft, and thus, the industry is sensitive to the possibility of regulations raising the costs of obtaining an sUAS. Manufacturers are in a position to shoulder much of the burden of ensuring that aircraft designs are safe and of otherwise minimizing the indirect and external costs associated with sUAS operations. However, further work is needed to develop an appropriate regulatory framework, particularly when it comes to defining risk.

The federal government and industry are working on systems for sUAS traffic management. Such systems should provide largely automated monitoring and management of sUAS traffic. Progress in these areas will encourage sUAS industry development while establishing a framework for managing indirect and external costs.

Regulation of sUAS Designs

Civil aviation authorities (CAAs) regulate the design and maintenance of aircraft and issue certificates of airworthiness that grant owners permission to fly aircraft. Airworthiness standards ensure the safety of the general public, in part by reducing the risk of midair collisions between aircraft and of ground impact. These standards have also been used to accomplish other goals, such as regulating the emissions and noise produced by aircraft engines.

Part 107 regulations on sUAS operations do not yet mandate airworthiness certification (FAA, 2016a). A CAA could require such aircraft to be certified or could allow only those aircraft whose designs meet certain standards to access controlled sections of airspace without mandating the use of certificates of airworthiness. These standards could be defined directly in terms of accident risk or could be based on components of an aircraft's design. A CAA could alternatively issue licenses to specific operators or manufacturers that allow for the operation of specific types of aircraft in certain sections or classes of airspace. Regulatory agencies often draw distinctions between operators who manage aircraft within their visual line of sight versus those who wish to manage aircraft traveling further afield, and between sUAS operations in populated versus unpopulated areas (Jones, forthcoming). In summary, there are many options available when it comes to certifying or otherwise regulating sUAS designs.

The FAA operates as the CAA responsible for aircraft flown in the United States. The agency has noted "existing airworthiness standards have been developed from years of operational safety experience with manned aircraft and [thus] may be too restrictive for UAS in some areas and inadequate in others" (FAA, 2013). The specific example the FAA cites is structural requirements for aircraft that ensure their survivability in all "foreseeable weather conditions" (FAA, 2013). There is also the humorous and hopefully fictional anecdote of a manufacturer having to include a seat belt in a UAS design in order to meet official certification standards. Additional testing is needed to identify appropriate structural requirements for unmanned aircraft and particularly for sUAS. The FAA is working on regulations related to the proposed rule "Operations of Small Unmanned Aircraft Over People" (White House, 2016), but it is unclear whether these regulations will include standards for sUAS design, use, or both.

Testing sUAS Designs

The FAA has selected and helped fund UAS Test Sites where sUAS operators will be able to run trials (White House, 2016). NASA researchers have proposed an additional National UAS Testing and Recording (NuSTAR) facility (Kopardekar, 2015), which would serve as a test bed for evaluating UAS technologies. This facility would allow test flights through different "atmospheric conditions" and in scenarios that involve many potential hazards, including "simulated pets" on the ground (Kopardekar, 2015). Package delivery companies and other sUAS operators may want to fly through inclement weather, but smaller unmanned aircraft in use today are not equipped to fly through such conditions. A facility like NuSTAR would help operators and federal government regulators learn about the capabilities and performance of sUAS technologies. This is important, as many of these technologies are new or evolving rapidly. There is a parallel here to the world of autonomous ground vehicles, where researchers have concluded that "accelerated testing, virtual testing and simulators, mathematical modeling, scenario testing and pilot studies" may be necessary (Kalra and Paddock, 2016).

Data-gathering and analysis are shared interests, and private firms may help fund a facility like NuSTAR. Note that such facilities have already been established to study autonomous ground vehicles: The Mcity Test Facility in Michigan is an example of a public-private partnership to test connected and autonomous vehicle technologies (University of Michigan, undated). Fifteen companies each invested more than $1 million to fund the creation of the Mcity facility. The costs to establish and manage a similar facility for sUAS testing should be quite low relative to current estimates of the size of the sUAS market in the United States. It is important to note that the testing of sUAS designs will necessarily be quite different from the testing of more-conventional aircraft. More emphasis will be placed on software testing and validation, because software will be particularly important to the safety of sUAS operations.

Data of interest will include quantitative estimates of the probabilities of specific sUAS components failing in different ways, and of the resulting risk to people and property, both on the ground and in the air. Regulators will seek detailed data on the precision of navigation systems and the reliability of communication components. Testing should allow analysts to estimate the damage that would be done to people, animals, and objects on the ground when aircraft crash into them as a function of vehicle mass and velocity. This is not an exhaustive list, but hopefully indicates some of the types of useful data that could be collected via a facility like NuSTAR.

Possible Risk-Based Standards

One possibility for regulating sUAS designs would be for the FAA, acting as this country's CAA, to issue certificates of airworthiness only to aircraft whose designs have been tested in a facility like NuSTAR and vetted by the FAA. Such a plan would raise fears among manufacturers and operators that the certification process would delay innovation in aircraft designs and would drive up the costs of purchasing and potentially operating an sUAS fleet. GAO concerns about the FAA's UAS office being understaffed are also relevant here (GAO, 2016). If the responsible regulatory body is underresourced, certification processes could be further delayed, and regulatory decisions could be made that do not improve public safety. On the other hand, we can take comfort in the idea that the FAA's primary priority here will be to look after the public interest. If the FAA were to certify sUAS designs, it would be important for the agency to work with manufacturers to ensure the certification process achieves its goal of improving public safety and does not unnecessarily raise manufacturer costs.

Another possibility would be for the FAA, unmanned aircraft manufacturers, or independent third parties to verify that aircraft designs meet certain standards with regard to risk when they are flown in certain environments. Such a risk-based system would more directly focus on the issues of concern (and avoid the farcical situation where a UAS design would have to include a seat belt). The European Aviation Safety Agency (EASA) produced a document in 2015 that outlined such a "risk-based approach to regulation of unmanned aircraft" (EASA, 2015). This document defines the most-relevant safety risks as risks of midair collision with manned aircraft, harm to people, and damage to property, particu-

A risk-based system for sUAS design could focus more directly on areas of concern, such as risks of midair collision, harm to people, and damage to property, particularly infrastructure.

larly infrastructure (EASA, 2015). The EASA has gone on to produce an official notice of a proposed "regulatory framework for the operation of drones" that is based on risk assessment (EASA, 2017). The FAA is said to be considering a similar approach to regulating sUAS designs (Stevenson, 2016).

The idea of a risk-based system has been put forward as an alternative to the more straightforward idea of managing sUAS designs in the same way conventional aircraft designs are managed. The conventional system is based on certifying that aircraft conform to certain design requirements based on their category. There are restrictions on aircraft dimensions and equipage. These restrictions are not expressed in terms of risk.

There is a substantial and growing body of research on the risks associated with sUAS use, but gaps remain. Lum and Waggoner (2011) present a particularly relevant mathematical model that estimates risks posed by sUAS operations based on physical properties of sUAS design. This model does not capture damage caused by building strikes and needs to be further tested and verified using empirical methods. In a risk-based system for sUAS design management, all relevant risks should be defined and estimated as a function of avionics and operating environment. The relevant risk standards would have to include the probability that an sUAS might crash into another aircraft or people or property on the ground and estimates of the damage that might result. There also could be standards related to other risks, such as the risk of the loss of communication between a remote pilot and an sUAS or the risk of an sUAS straying into controlled airspace. Additional analysis is necessary to support development of these standards and an effective risk-based system for regulating sUAS designs.

It is also important to note that while aircraft manufacturers have a natural incentive to make their sUAS designs safe, they will also be interested in reducing manufacturing costs and in ensuring that the sUAS designs they have developed are approved for use. This could lead manufacturers to overestimate the safety of their aircraft if they are allowed to "self-certify." Therefore, it is important to define risk appropriately and in a transparent manner; indeed, it might make sense to have independent third parties in charge of aircraft design testing and verification. If we move toward a risk-based system where sUAS manufacturers or independent third parties verify aircraft designs, data from UAS Test Sites and facilities like NuSTAR will be instrumental in the verification process.

There is an opportunity here for industry to shoulder much of the burden that would otherwise fall to the FAA: specifically, by making use of manufacturer expertise in aircraft design. If a risk-based system is adopted, it could produce incentives for research and development, as well as a natural laboratory for experimentation that would not exist if strict design requirements were used instead. However, the technical challenge of developing and validating models of risk is immense and should not be overlooked.

It is important to note that sUAS operations will vary. Some operators will use aircraft to monitor crops or infrastructure in remote areas, while others will want to deliver packages in urban environments. Rather than having a single set of airworthiness standards for certification or a single risk-based standard, a more-nuanced system may evolve. If an operator can meet certain requirements or guarantee a certain level of safety, based on both the type of sUAS technologies used and how the operator will use them, that operator would be allowed to access a certain section or class of airspace. For example, there could be one set of standards for flying sUAS beyond visual line of sight, another for flying sUAS over people, and yet another for flying sUAS in airspace that also serves non-sUAS air traffic. Some operations could require FAA certificates of airworthiness, while others could require only a license or verification that they meet certain standards. The FAA's UAS Integration Office appears to be considering exactly such an approach. They note a desire to "expand Part 107 to incorporate standards for flight over non-participating people" but also to "expand Part 107 to facilitate low altitude operations through Airworthiness certification" (Lawrence, 2016).

Analysts expect sUAS to be equipped with sense-and-avoid systems that allow them to reliably and automatically avoid obstacles, including other aircraft. The White House and NASA are funding research to set up "standards for Detect and Avoid and Command and Control" technologies (White House, 2016). The presence, absence, and attributes of sense-and-avoid systems will determine the risks of unmanned aircraft crashing into one another or other objects. As sense-and-avoid systems are developed, it will be important to test them, particularly if the nation adopts a risk-based system for airworthiness certification.

Use of sUAS is currently prohibited in certain areas, including near busy airports. Certificates of airworthiness could be withheld from sUAS that do not include systems ensuring that the aircraft do not fly through specific areas. Such systems could be standardized through regulation, as FAA Technical Standard Order TSO-C166b set standards for automatic dependent surveillance–broadcast (ADS–B) equipment. There is not a universally accepted set of standards for "geofencing" technologies today, although DJI consumer sUAS are already advertised as being equipped with such technology (Leswing, 2015). Geofencing technology requirements will be unique to sUAS and setting standards will be a new technical challenge for the FAA and for industry partners, regardless of regulatory framework.

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It is essential that an sUAS operating in an urban environment has equipment allowing an ATC and management system to easily monitor the aircraft's operations. If the FAA manages certificates of airworthiness, standards could be set for such equipment. If the industry agrees to meet risk-based standards, researchers should determine how to translate such equipment into risk reduction in a defensible and transparent manner. It is in the interest of manufacturers to ensure that their aircraft can be tracked and managed by ATC systems that operators will see as useful tools to reduce risk.

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Issues Related to ADS–B

Many assume that ADS–B technologies will be used to track sUAS operations and that ADS–B Out equipment should be required in sUAS designs. Such equipment generally includes a GPS receiver and a Mode S transponder with extended squitter, using a 1090 MHz data link, or a Universal Airborne Transceiver, transmitting data at 978 MHz. Aircraft that are ADS–B Out equipped broadcast high-accuracy, high-integrity position, velocity, and identification information. The current cost of an ADS–B system, including a GPS receiver and transponder, is roughly $2,000 (uAvionix, undated). This is a significant amount relative to the acquisition cost for an sUAS, which varies from $4,000 to $50,000, depending on aircraft type (Vascik and Jung, 2016). As traffic on the relevant data channels grows, there are concerns that channel quality will degrade. One publication noted the potential for "serious message loss caused by growing traffic on the 1090 MHz channel" (Strohmeier et al., 2014). The potential for ATC or aircraft communications not to be received, and thus not acted on, is particularly problematic given that sUAS are remotely piloted. If messages describing an aircraft's position and velocity are lost, it becomes more difficult to manage the aircraft's trajectory and to ensure that the aircraft avoids hazards, including other aircraft.

At a recent event, industry representatives advocated for the use of alternative communication technologies, except in "off-nominal" situations where coordination with larger aircraft or traditional ATC systems would be necessary.[2] The representatives did not seem particularly concerned by issues of spectrum management, noting that modern cellular towers could enable persistent, reliable, and secure communications, particularly in urban areas.[3] We have all experienced the occasional dropped call or visited an area with poor cellular service, which raises questions about the ability to use cellular towers to monitor and manage sUAS activity throughout the United States.

Industry representatives and others are concerned about the security of ADS–B and other data links. Research has shown that it is remarkably easy to use software-defined radios to perform flooding, spoofing, and other cyberattacks on systems that rely on ADS–B messages (Strohmeier et al., 2014). An attacker could use an ADS–B or other data link to issue commands, enabling them to control and even purposefully crash an aircraft. These concerns will be mitigated, to some degree, by establishing an sUAS traffic management system that is capable of automatically flagging off-nominal traffic patterns. For example, an sUAS traffic management system can notify operators when aircraft are forecast to fly through areas where their use has not been authorized. Such notification may allow operators or public officials to disrupt an attack.

sUAS Traffic Monitoring and Management

Air Navigation Service Providers (ANSPs) provide ATC and management services to pilots and air carriers. The FAA is both the CAA and the ANSP in the United States, a somewhat unusual arrangement.

The Current ATC System

The current ATC system is based on human controllers at airport towers and other facilities monitoring the positions of a handful of aircraft each. Pilots and dispatchers at airline operations centers file flight plans and flight plan modifications with ANSPs, informing these organizations of planned aircraft trajectories. Controllers may request that pilots follow certain routes and that they change course as issues arise, in particular ensuring that aircraft never get closer than a few nautical miles to one another or to obstacles. Controllers communicate regularly with pilots and with one another—for instance, to manage the safe handoff of responsibility from one controller to another as an aircraft travels from one geographic area to another. Controllers maintain situational awareness, some at a tactical and some at a strategic level, over air transportation system resources and relevant information, such as weather forecast data. As an example, consider an airport tower controller. This person clears airport ground support vehicles and aircraft onto a runway, ensuring that the ground vehicles and aircraft adhere to policies, procedures, and clearance instructions. The controller will route aircraft on specific airport taxiways, ensure the aircraft are de-iced when weather conditions require this, and line them up in a certain sequence to make the most efficient use of the departure runway. The controller ensures that wake cortex temporal separation standards among arriving and departing flights are met. All of this is managed primarily using voice communication.

There are various tools that have been developed or are under development to assist controllers, to automate certain tasks that controllers would otherwise do, or to improve safety and efficiency. For example, modern aircraft are equipped with proximity sensors and systems for preventing imminent midair collisions that operate independently of ATC, such as the Traffic Collision Avoidance System (TCAS). TCAS was originally designed to

> (1) *advise* pilots visually on a horizontal situation display if there is traffic in the nearby vicinity (a range extending beyond that defining an operational error for controllers); (2) *alert* them both visually and aurally if a possible collision is imminent (assuming both aircraft remain on the same course); and ultimately, if necessary, (3) *issue* a redundant (visual and auditory) *resolution advisory*, instructing the pilot on a vertical maneuver to avoid the possible collision (National Research Council, 1998).

Certain modern versions of TCAS will automatically execute certain advisories, but, in general, pilots remain responsible for ensuring the safety of the aircraft that they are flying. It is also worth noting that TCAS serves as a kind of fail-safe or safety check of last resort and was never intended to replace ATC or be the sole tool used to eliminate the risk of midair collisions. It would be impossible to use TCAS or any other tool that has been developed to date to fully and completely coordinate, manage, and monitor traffic on a busy airport runway.

TCAS operates on a relatively short time scale, seeking to prevent imminent disaster. In contrast, consider the part of ATC known as *air traffic flow management*. Air traffic flow management is based on a much more-strategic view and a relatively long planning horizon of roughly two to 24 hours. Traffic managers, including staff at the national air traffic flow management control center, may request that air carriers avoid flying through certain areas when and where weather conditions are poor or adjust flight schedules to avoid forecast supply-demand imbalances.

It is worth pointing out that airspace in the United States is divided into different classes with different forms of ATC services on offer. Class G airspace is particularly relevant in the context of sUAS activity and includes airspace less than 1,200 feet above ground level not in the vicinity of an airport with a control tower (FAA, 2016c). Class G airspace is *uncontrolled airspace*, meaning that the FAA "has no authority or responsibility to control air traffic" (FAA, 2016c).

Both pilots and operators, or the organizations that fly aircraft managed by an ANSP, implement the directives of air traffic controllers. Operators have some flexibility, particularly when it comes to the relatively strategic world of air traffic flow management. There are many ways to adjust flight schedules to eliminate forecast supply-demand imbalances, and under the current collaborative decision making paradigm, large commercial air carriers help to draft traffic flow management policies with the FAA.

Air traffic controllers do not currently manage sUAS traffic in the way that they manage air carrier traffic. This is largely because sUAS traffic mainly operates in Class G airspace. Operators can only fly in other classes of airspace with prior approval from the FAA. The restrictions are actually tighter than this would indicate: Commercial operators must keep their aircraft in their visual line of sight at all times, fly their aircraft under 400 feet above ground level, fly their aircraft at speeds less than 100 miles per hour, fly during the day, not fly above people, and yield to manned aircraft unless they have a waiver from the FAA (FAA, 2017b). Air traffic controllers have, on occasion, had to reroute other air traffic around an sUAS operating in an inappropriate area.

Challenges Posed by sUAS Traffic

Note that the current regulations restrict or prohibit many potential uses of sUAS technologies. Commercial package delivery via sUAS is impractical when sUAS cannot fly above people and must be controlled by a pilot maintaining visual line-of-sight control. Farming applications are also limited by the line-of-sight requirement and by restrictions on the dimensions of allowed aircraft. Inspections of cellular towers and other infrastructure are challenging when sUAS cannot fly more than 400 feet above ground level and, again, due to visual line-of-sight requirements. Industry is pushing the FAA to relax the restrictions around sUAS use. West (2015) calls the current FAA standards "too restrictive" and "business-unfriendly," claiming that "many U.S. companies, stymied by the FAA, have moved their drone operations overseas." One study estimated that allowing beyond visual line-of-sight operations would, in the short term, enable growth in "business sectors, including pipeline and railroad inspection, construction, and maritime applications" and would grow the market for sUAS services by over 30 percent (Vascik and Jung, 2016). Allowing flights over populated areas would increase the market for communications tower inspections via sUAS by over 600 percent to over $30,000,000 per year in 2020 (Vascik and Jung, 2016). The authors do not provide quantitative data on the size of the package delivery market or other markets that are only feasible once sUAS activity is allowed beyond Class G airspace. It is clear, however, that there are important commercial and other reasons to allow sUAS use in controlled airspace.

The FAA reports that its Air Traffic Organization had an enacted fiscal year (FY) 2016 budget of $7.51 billion, and a requested FY 2017 budget of $7.54 billion (FAA, 2016b). In addition, the FAA had an enacted FY 2016 budget of $1.83 billion and a requested FY 2017 budget of $1.63 billion for ATC facilities and equipment (FAA, 2016b). Thus, the cost of the current ATC system was roughly $9.34 billion in FY 2016. This excludes numerous other line items from the FAA budget that relate to ATC, including research and development programs supporting the NextGen ATC system modernization effort. (It is worth mentioning that President Donald Trump has proposed to transfer ownership of the nation's ATC system to a nongovernment organization, in part to control the costs of the system [Reuters, 2017].) The FAA reports that there were roughly 8.73 million commercial flights in the United States in 2015 (FAA, 2017c). This means that the cost of the ATC system works out to about $1,000 per commercial flight. As a point of comparison, Vascik and Jung (2016) report that the current average hourly operating costs of an sUAS vary from $75 per hour for a small, multipurpose, multirotor aircraft to $500 per hour for a larger, fixed-wing aircraft weighing between 25 pounds and 55 pounds.

The cost of the current ATC system was roughly $9.34 billion in FY 2016, or about $1,000 per commercial flight. As a point of comparison, the current average hourly operating costs of an sUAS vary from $75 to $500 per hour.

ATC is not provided solely for the benefit of commercial flight; the system also supports general aviation and rotorcraft traffic and provides other benefits. For example, the ATC system was essential in protecting national security in the aftermath of the 9/11 attacks, grounding civilian air traffic and assisting military jets that patrolled the skies. However, it is clear that if the current ATC system or a system modeled on the ATC system were used to manage sUAS traffic, the cost to the ANSP would likely be quite high. Requiring sUAS operators to pay for such a system would dramatically raise the cost of sUAS operations.

Furthermore, the current system relies on human operators that can only monitor a limited amount of air traffic at any given time. The FAA has established Monitor Alert Parameter (MAP) values to determine when and where the number of aircraft in sections of airspace are high enough to become problematic for air traffic controllers (FAA, 2010). MAP values are, essentially, thresholds of aircraft density in airspace sectors managed by individual FAA controllers, and are typically set to values between 5 and 15. Current demand from air carriers and others already threatens to outstrip capacity in certain areas at certain times of day. As mentioned earlier in this Perspective, the FAA is forecasting that there will be between 2.75 million and 4.47 million sUAS flown in the United States by 2021 (FAA, 2017a). If these sUAS were to fly in controlled airspace and be managed the same way conventional aircraft are managed, the sheer density of traffic would prove problematic.

Much of the current sUAS traffic operates in uncontrolled airspace, in areas where other types of air traffic do not operate, and in unpopulated areas. Although this traffic is not currently managed in any formal way, operators are interested in reducing risk by using systems to track and control this traffic. They are also hopeful that the development of sUAS traffic management systems can persuade regulators to open up additional airspace to sUAS traffic.

UAS Traffic Management Systems

The relevant systems under development are called UAS Traffic Management (UTM) systems. In 2017, the French aerospace services firm Thales announced the launch of its ECOsystem UTM platform (Thales, 2017). The platform promises "automated flight authorizations as well as real-time alerting and intervention in emergency situations" (Thales, 2017). The Italian aerospace firm Leonardo has announced its own air traffic management system for unmanned aircraft flying less than 150 meters above ground level (Rees, 2017). American firm Harris is working on a similar system (Price, 2017), and NASA is working with industry partners on its own similar systems. NASA ran one experiment where 22 drones flying simultaneously in one area were successfully tracked by an automated traffic management system (UAS Vision, 2016). More recently, NASA tested its systems at the FAA Test Sites, allowing pilots to operate aircraft flying beyond the pilot's visual line of sight (Warwick, 2017). The Single European Sky air traffic management research initiative has developed a blueprint for what it calls *U-space*, which consists of "new services and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones" (SESAR Joint Undertaking, 2017). The blueprint, like the larger initiative, is focused on air traffic management. Both the NASA UTM and European U-space efforts are targeting 2019 for the delivery and roll-out of new technologies.

These UTM systems are primarily concerned with deconflicting sUAS trajectories. The systems may also issue alerts to ensure that sUAS traffic avoids obstacles, including non-sUAS aircraft. The larger projects—such as the NASA UTM effort—have the more-ambitious goal of offering extensive traffic management services, such as "airspace design, corridors, dynamic geofencing, severe weather and wind avoidance, congestion management, terrain avoidance, route planning and re-routing, separation management,

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sequencing and spacing, and contingency management" (NASA, 2017). These goals are clearly based on services offered by conventional ATC agencies.

In the same way that a system like TCAS does not eliminate the need for conventional air traffic management, sense-and-avoid systems in the sUAS world will not eliminate the need for UTM systems. A sense-and-avoid system would not be capable of allocating and policing access to a congested section of airspace in a way that maximizes safety, efficiency, and equity. It will be challenging to develop a system with these capabilities. Current UTM efforts represent important but early steps in the right direction. In particular, current systems do not manage sUAS and manned aircraft together. These systems, at least at present, should not be used to manage sUAS operations in controlled airspace or in populated areas. These systems should also not be used to manage passenger aircraft.

The nascent UTM systems need to be tested and further refined. Such systems could be set up to issue alerts to operators and the relevant ANSP when aircraft fly through areas to which they have not been authorized, when wind or weather threatens operations, when the system cannot verify the airworthiness of an aircraft observed in operation, when an sUAS flies too close to other air traffic, and when aircraft density exceeds soft or hard capacity thresholds. Traffic managers could then communicate with law enforcement authorities and others to resolve problems as they arise. Rapid response to off-nominal situations can prevent catastrophe. One day, it may even be possible to use such systems to manage sUAS traffic that operates in controlled airspace, that transitions across various kinds of airspace, or that operates when and where other types of aircraft are present. In such a scenario, it will be important for UTM systems to communicate with the existing ATC system.

Existing sense-and-avoid systems would not be capable of allocating and policing access to a congested section of airspace in a way that maximizes safety, efficiency, and equity. It will be challenging to develop systems with these capabilities.

NASA researchers hope that sUAS traffic management system development may have the added bonus of producing insights and tools that can be applied to traditional ATC systems to improve safety and efficiency. Kopardekar et al. (2016), after defining a concept of operations for UTM, claim that a similar system for managing conventional air traffic could "improve the efficiency of the airspace operation."

The FAA is currently in the middle of its NextGen effort to modernize the ATC system. This program is complex and has proven challenging to manage. For example, in a recent report on the current NextGen effort, the GAO noted that the costs of several program elements "increased from their initial estimates by a total of $4.2 billion" and that the "FAA cannot provide reasonable assurance to Congress and other stakeholders that NextGen and other ATC programs will avoid additional cost increases or schedule delays" (GAO, 2012). Some of the difficulties encountered during efforts to modernize the conventional ATC system stem from entrenched stakeholder positions and investments made based

As the skies become more crowded, action is needed from the federal government and sUAS manufacturers and operators to ensure the public's safety. Such action could also spur development in the sUAS space, in much the same way that federal government action promoted civil aviation in its infancy.

on current policies and procedures. The opportunity to start from scratch and to focus on the development of new ATC systems that scale well for sUAS traffic management could indeed prove valuable. As Kopardekar et al. (2016) note, the present situation offers "a unique opportunity to examine how the roles and responsibilities and supporting functionalities can be distributed among UAS operators and their automation systems." Such an examination could produce insights relevant to conventional ATC systems that would otherwise elude us.

It is particularly encouraging to see that stakeholders in the sUAS domain are cooperating with one another and with government agencies in efforts to establish sUAS traffic management policies and procedures. Industry trade groups and nonprofit organizations have been established and are putting out relevant white papers. A nascent nonprofit, known as the Global UTM Association, looks to encourage and assist with UTM system development (Global UTM Association, undated). Members of this association include representatives from sUAS manufacturers, operators, and government agencies around the world. In the United States, the Commercial Drone Alliance is "a leading industry association that advocates for U.S. drone policy" (Glaser, 2017b). The AUVSI industry group also tracks developments in sUAS certification and traffic management policy.

It is an accident of good timing that current research into sUAS traffic management might lead to technologies that could be useful in ongoing efforts to improve systems that manage manned air traffic.

Conclusion

As the skies become more crowded, action is needed from the federal government and sUAS manufacturers and operators to ensure the public's safety. Such action can also spur development in the sUAS space, in much the same way that federal government action promoted civil aviation in its infancy.

A key way to manage both risk and indirect costs attributable to sUAS operations will be to set standards for unmanned aircraft designs. The federal government and the aviation community do not yet have the experience or data needed to set airworthiness standards for sUAS. The data of interest will include quantitative estimates of the probabilities of specific sUAS components failing, and of the resulting risk to people and property on the ground and in the air. The use of special FAA sUAS Test Sites could be valuable when it comes to gaining experience regarding sUAS designs. The establishment of a new sUAS design testing facility, where individual aircraft, components, and software systems could be tested in different simulated environments would also be helpful.

Given the diversity of uses for sUAS technologies, we recommend a tiered system when it comes to certification; the sUAS designs that meet the highest standards would be granted the most access, e.g., would be able to fly above urban areas. The standards could be defined in terms of risk rather than in terms of specific equipment requirements. Risk-based standards appear promising, in part because of their flexibility, and research is already under way that could be used to identify a defensible and transparent methodology for estimating risk. If more-conventional airworthiness standards for sUAS are mandated, these standards should incorporate novel elements, such as requirements that aircraft have geofencing technologies that prohibit their use in dynamically defined areas as identified by federal or local government agencies. Many analysts are expecting sUAS to use ADS–B technologies, but substantive issues related to frequency allocation and security remain.

The current system for control of conventional aircraft is expensive and depends on human system monitoring and tactical-level control. Using a similar system to manage sUAS traffic may not be feasible. Instead, systems for managing sUAS traffic should be more flexible, more automated, and focus more on the observation and strategic management of traffic flows than the system currently used to manage conventional aircraft. This is particularly true in unpopulated areas, low-altitude airspace, and in areas where conflict with other forms of air traffic is unlikely. Updating systems for managing sUAS traffic is especially relevant given the potential widespread use of autonomous sUAS, which fly themselves between an origin and destination provided by a remote pilot. The development of the relevant traffic management systems is already under way, although current systems are only suitable for use in low-altitude uncontrolled and segregated airspace. The development of more-advanced systems can produce insights and tools that will also be helpful in the effort to modernize the conventional ATC system.

Notes

[1] Personal communication with professor Juan Alonso, February 2017.

[2] Industry expert panel on "Innovation, New Entrants, and ATM," ATM R&D Seminar, June 30, 2017.

[3] Industry expert panel on "Innovation, New Entrants, and ATM," ATM R&D Seminar, June 30, 2017.

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About This Perspective

Delivery drones may become widespread over the next five to ten years, particularly for what is known as the "last-mile" logistics of small, light items. Companies like Amazon, Google, the United Parcel Service, DHL, and Alibaba have been running high-profile experiments testing drone delivery systems. The development of such systems reached a milestone when the first commercial drone delivery approved by the Federal Aviation Administration took place on July 17, 2015. In the future, drones could augment, or in some situations even replace, truck fleets and could have important implications for energy consumption, public safety, personal privacy, air pollution, city noise, air traffic management, and goods and service consumption patterns in urban areas.

To support awareness of the relevant issues, the RAND Corporation launched an exploratory study that brings together RAND's expertise in unmanned aerial vehicle operations, transportation research, systems analysis, and behavioral analysis and applies it to this emerging and underexplored research area.

The study includes several complementary research efforts focused on different facets of the delivery drone systems and their likely impacts. In this report, I summarize the policy landscape and describe the options available for the regulation of drone designs and for the future of air traffic management. This research should be of interest to entrepreneurs and hobbyists considering the future use of drone fleets for commercial and reactional purposes, policymakers, and those interested in airspace and aviation systems management. This Perspective will be useful to all those interested in public policy regarding aviation and drones. The other RAND publications in this series include the following:

- *What's the Buzz on Delivery Drones?* (Welser and Xu, 2016)
- *What's the Buzz? The City-Scale Impacts of Drone Delivery* (Lohn, 2017)
- *The Energy Implications of Drones for Package Delivery* (Gulden, 2017)
- *Design Perspectives on Delivery Drones* (Xu, 2017)
- *International Commercial Drone Regulation and Drone Delivery Services* (Jones, forthcoming).

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