American Planning Association
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PAS REPORT 597

USING DRONES IN PLANNING PRACTICE

Ric Stephens, Rob Dannenberg, Wendie Kellington, and Patrick Sherman

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ISBN: 978-1-61190-205-1

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Patrick Sherman is a pioneer in the UAS industry, with more than 10 years of experience as a drone pilot. An internationally recognized expert on UAS operations and technology, he is the author of more than 150 published articles on the subject. Recognized as a "Drone Instructor of the Year" by the Association for Unmanned Vehicle Systems International, Sherman has been quoted in the *New York Times* and the *Washington Post* for his expertise and advised state and national leaders on the development of UAS policies. Having spoken at every major U.S.-based drone conference, he is known worldwide as "Lucidity" by fans of the Roswell Flight Test Crew, his YouTube channel focused on UAS, which has more than 30,000 subscribers and six million video views.

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Drone flight in Chicago (Petra Hurtado)

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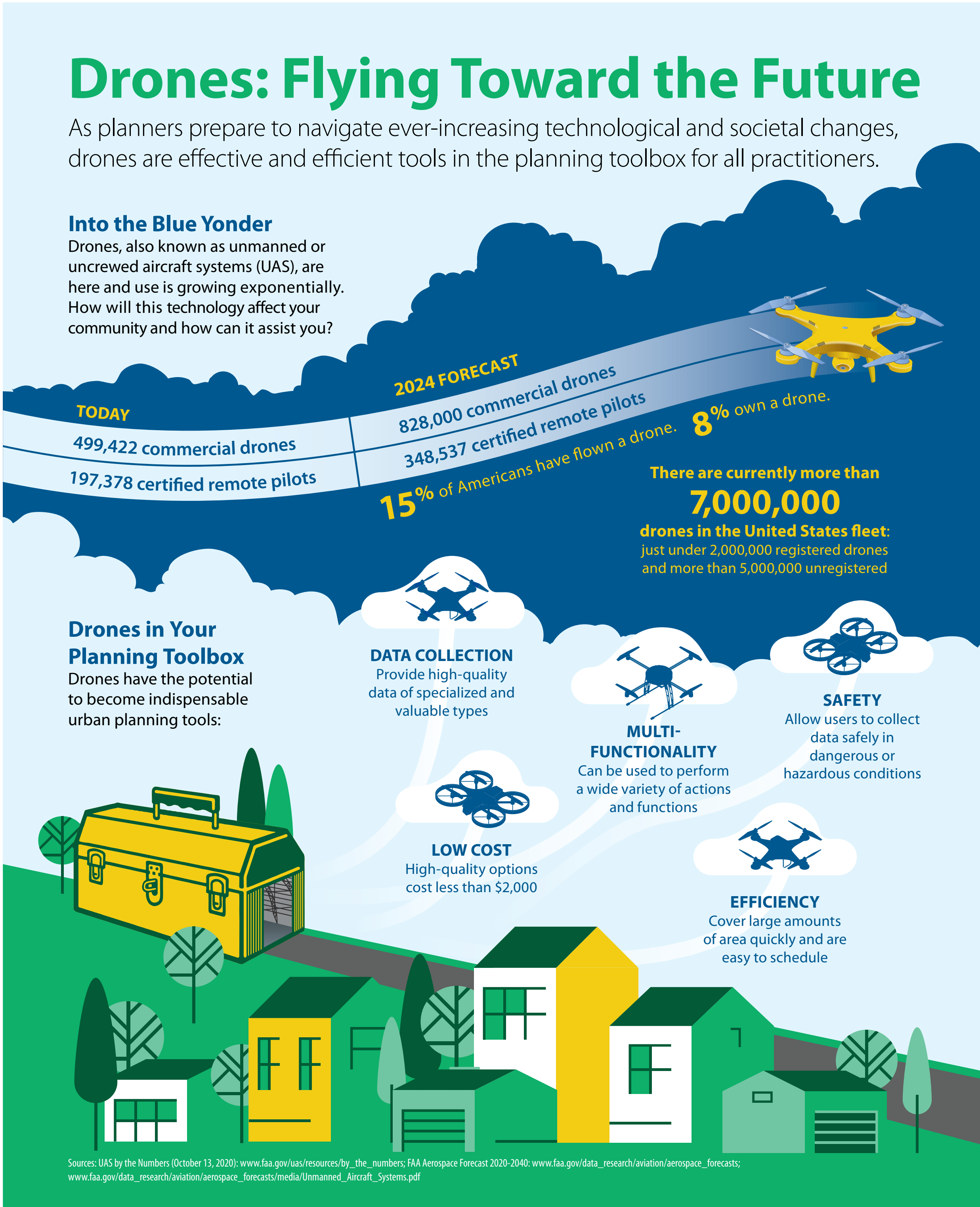
Drones: Flying Toward the Future
As planners prepare to navigate ever-increasing technological and societal changes, drones are effective and efficient tools in the planning toolbox for all practitioners.
Into the Blue Yonder
Drones, also known as unmanned or uncrewed aircraft systems (UAS), are here and use is growing exponentially. How will this technology affect your community and how can it assist you?
TODAY
499,422 commercial drones
197,378 certified remote pilots
2024 FORECAST
828,000 commercial drones
348,537 certified remote pilots
15% of Americans have flown a drone.
8% own a drone.
There are currently more than
7,000,000
drones in the United States fleet:
just under 2,000,000 registered drones and more than 5,000,000 unregistered
Drones in Your Planning Toolbox
Drones have the potential to become indispensable urban planning tools:
DATA COLLECTION
Provide high-quality data of specialized and valuable types
MULTI-FUNCTIONALITY
Can be used to perform a wide variety of actions and functions
SAFETY
Allow users to collect data safely in dangerous or hazardous conditions
LOW COST
High-quality options cost less than $2,000
EFFICIENCY
Cover large amounts of area quickly and are easy to schedule
Sources: UAS by the Numbers (October 13, 2020): www.faa.gov/uas/resources/by_the_numbers; FAA Aerospace Forecast 2020-2040: www.faa.gov/data_research/aviation/aerospace_forecasts; www.faa.gov/data_research/aviation/aerospace_forecasts/media/Unmanned_Aircraft_Systems.pdf

EXECUTIVE SUMMARY

Drones—more technically known as unmanned or uncrewed aircraft systems (UAS), or unmanned or uncrewed aerial vehicles (UAV)—are quickly becoming indispensable tools for almost every discipline from agriculture to zoology. Extraordinary opportunities exist for integrating UAS with urban planning and design.

The array of UAS functions is expanding at an exponential rate, and the multifunctionality of drones makes them versatile, adaptable, and cost-effective tools. However, drone technology is currently unfamiliar to many planners and planning agencies, and the wide array of UAVs and the various sensors and equipment that are used to outfit them for different applications may seem intimidating. Likewise, the need to learn the federal regulatory requirements for drone use and understand the basic principles of safe and responsible UAS flight may seem overwhelming. However, many practitioners have taken the plunge, and once they master the initial learning curve they have found drones to be invaluable additions to their planning and design practices.

This PAS Report seeks to demystify UAS technology and use. Its goal is to provide planners with the foundational knowledge they need to evaluate the use of drones in their planning and design work and the technical information required to integrate UAS into their professional planning practices. It offers comprehensive discussions of relevant UAS topics, including technology and equipment, operational and administrative practices, and legal and regulatory considerations. The report provides the information necessary for both the public- and private-sector planning communities to integrate drones into current practice.

DRONES: AN IMPORTANT PLANNING TOOL

A drone is an aircraft without a pilot on board that is remotely controlled by a person on the ground. Drones have the potential to become indispensable urban planning and environmental management tools for many reasons.

Planners need high-quality, accurate, and timely data to analyze sites and make data-driven decisions. Drones offer the ability to collect a wider spectrum of environmental data than any other planning tool and document unique views through many types of imagery. Land use and development are three-dimensional in nature, and aerial photos taken by drones allow the average person to visualize an area much more clearly than a map or a photograph taken at ground level. Aerial videos add the fourth dimension—time—into the equation. And drone flights are relatively easy to plan and implement, allowing planners to schedule and perform data collection whenever it is needed.

A drone is a single tool that can be used to do many tasks. The same drone that creates a GIS map for a wildlife corridor might be used to evaluate the heat loss from a hospital rooftop or help in the search for and rescue of a lost child. Cameras, Lidar, and multispectral imaging sensors allow drones to collect many different types of data and serve many different functions. And they can do this very quickly: one drone pilot can document miles of roadway or acres of land in a matter of minutes that would otherwise take a full crew hours or even days, saving valuable personnel time and cost. Drones offer safe alternatives to collecting data in remote and potentially dangerous situations, such as disaster-stricken areas, tall structures, and nuclear power plants, without exposing personnel to health and safety risks.

UAS prices are continually decreasing with miniaturization and economies of scale. Today, users can purchase a high-quality drone with a high-resolution camera for around $1,500. For the public sector, this is a relatively inexpensive equipment investment for a technology with so many applications. For the private sector, drones can often pay for themselves through contract service fees within a few operations.

Designing a UAS program as an innovative effort to modernize and expand services can enhance personnel satisfaction and augment public engagement. Training and operations costs are relatively low and provide ancillary benefits, such as staff professional development opportunities and a progressive organizational image. In short, drones offer tangible and intangible benefits for public- and private-sector organizations, expanding their capabilities for a wide range of activities that would be otherwise difficult, expensive, or impossible to carry out.

WHAT'S IN A DRONE?

The hundreds of commercial drone models currently available and new models that arrive every year present a dizzying array of options for planners exploring the UAS universe for the first time.

Understanding UAS technology will help planners make appropriate and cost-effective choices when determining what is needed for the functionalities they are seeking. Chapter 2 of this PAS Report offers comprehensive guidance on drone equipment and technology, from the UAV itself and its software to the cameras, sensors, and other payloads it can carry.

THE WIDE WORLD OF DRONE APPLICATIONS

There are hundreds of drone applications spanning many fields—from agriculture and environmental science and management, to security and health and safety, to art and recreation, as well as urban planning, engineering, and architecture. Appendix C of this report offers a comprehensive list of drone capabilities, while Chapter 3 homes in on important planning-related applications.

As suggested above, one of the most important drone applications for planning is the gathering of aerial imagery. UAS aerial reconnaissance provides planners with situational awareness from an elevated viewpoint that is often more comprehensive than one at ground level. The visual and other data drones collect can be used to generate products such as georectified orthomosaics, digital surface models, 3-D models, and aerial videos illustrating time and motion. GIS mapping and modeling using the high-quality data provided by drones offers powerful applications for land-use planning.

Drone imagery, both photo and video, can also be used to create powerful visualizations for community engagement. The creation of compelling displays and materials for public meetings and hearings can help residents and stakeholders better envision the impacts and outcomes of plans and projects. Videos can be invaluable additions to project websites and online surveys, and they enhance the in-person meeting experience. Drone imagery and video can make public input methods more engaging, tactile, entertaining, accessible, and comprehensible, resulting in better community participation and improved project outcomes.

Drones can be used to carry out a range of planning-related activities and functions, including project management and construction documentation, transportation system and traffic monitoring and analysis, environmental analysis and management, disaster response and recovery, infrastructure inspection, and surveying. Drones offer jurisdictions both small and large a multipurpose tool for a reasonable price to efficiently and effectively augment staff time and resources.

GETTING STARTED WITH DRONES

Moving from interest in drone use to implementation of a drone program may seem a formidable step. Chapter 4 of this PAS Report offers practical guidance in how to carefully think through the process and determine the best way to move forward.

One way to explore UAS use is to start by hiring a consultant for a pilot project or a limited scope of services. Chapter 4 walks readers through how to contract for UAS services, from developing a scope of work and writing an RFP to evaluating proposals and selecting and working with a consultant.

Ready to take the plunge and develop an in-house program? Chapter 4 also discusses the issues planners will need to consider when setting up a UAS program: structure, budget, equipment, staffing and training, policies and procedures, public relations, and data management. And it offers a straightforward process model for putting it all together.

Finally, before integrating drones into planning practice, planners must have a solid understanding of how they can and cannot be used. Chapter 5 maps out the regulatory and legal landscape for drone use by public-sector and private-sector planners. It offers a plain-language description of the Federal Aviation Administration (FAA) rules governing drone use with insights as to their interpretation and real-world application, and it delves into how to become an FAA-certified Remote Pilot in Command. Finally, it explains the intersections of federal, state, and local regulations for UAS, and describes trespass, nuisance, and privacy considerations for safe and responsible drone operations.

DRONES FOR THE 21ST-CENTURY PLANNER

UAS technology is not new, but as this PAS Report shows, it is proving to be increasingly relevant as a planning tool. The benefits drones can provide should be clear to any planner who intends to add this technology to their toolbox.

Planners help communities navigate change and prepare for an uncertain future. For planners to continue spearheading this process, keep up with the pace of change, and stay relevant in the 21st century, agility and technological advancement are becoming ever more important. Using drones in their work enables planners to do their jobs more effectively and efficiently: they will not just be better able to respond to a changing world, they will be prepared before disruptions happen. Upskilling planners to better understand and use new technologies and tools will be crucial to raise the voice of planning in the future.

The applications for UAS are substantial and growing. Drones represent a highly useful technology that can help planners do their work more safely, efficiently, and cost-effectively. The information and guidance in this PAS Report provides planners with the knowledge they need to determine whether UAS can enhance their planning practice and, if so, to take the first steps toward UAS implementation. As planners prepare to navigate the ever-increasing technological and societal changes of the 21st century, drones should be a tool in the planning toolbox that all practitioners know when and how to use.

CHAPTER 1

AN INTRODUCTION TO DRONES

In less than a decade, drones—more technically known as unmanned or uncrewed aircraft systems (UAS)—have become indispensable tools for almost every discipline from agriculture to zoology. There are hundreds of aerial applications, and new uses are continuously being created.

There are extraordinary opportunities for integrating UAS with urban planning and design. The variety and volume of applications, positive benefit-to-cost ratio, and technological evolution all combine to make drones a vital—and perhaps inevitable—technology for planning.

WHAT IS A DRONE?

The most common definition of the term *drone* is an aircraft without a pilot on board that is remotely controlled by a person on the ground.

The original term drone dates to 1935, when U.S. Admiral William Standley viewed the Royal Navy's de Havilland remote-controlled, aerial target biplane, the *Queen Bee* (Figure 1.1). When he returned to the states, he assigned Lieutenant Commander Delmar Fahrney the task of creating a similar target practice aircraft for the U.S. Navy. As an homage to the *Queen Bee*, Fahrney named the new aircraft a "drone" (Zaloga 2008).

The term was first published by *Popular Science* in 1946: "Drones, as the radio-controlled craft are called, have many potentialities, civilian and military. Some day huge mother ships may guide fleets of long-distance, cargo-carrying airplanes across continents and oceans" (Popular Science 1946).

As the variations in type, size, and function of these aircraft have evolved, the term "drone" has proven too vague for laws and regulations. There are many names for these aircraft, as the sidebar on p. 11 demonstrates, but in 2005, the Federal Aviation Administration (FAA) adopted the term "unmanned aircraft system" (UAS). Today, the official terms used by the FAA are *unmanned aerial vehicle* (UAV) and *unmanned aircraft systems* (UAS).

Recently, some professionals in the UAS industry have been pushing to use the word "uncrewed" instead of "unmanned," both as an issue of gender equity and to reflect the circumstances when an aerial vehicle operates autonomously while carrying a human occupant. While more inclusive and more accurate, the term "uncrewed aircraft system" has not been officially adopted for national or international regulation. As noted above, the FAA, which regulates all U.S. aircraft and the National Air Space (NAS), uses "unmanned aircraft system" in all documentation, and

Figure 1.1. Preparation for the launch of the de Havilland Queen Bee *remote-control seaplane, with Prime Minister Winston Churchill in the foreground (Imperial War Museums Archive © IWM H 10307, www.iwm.org.uk/collections/item/object/205195356)*

this term is also used by the U.S. Department of Defense, the International Civil Aviation Organization, and other aviation organizations. This report uses the term "uncrewed," the acronym "UAS," and the common term "drone" to refer to these aircraft.

A UAS has three components:

- A UAV (the remotely piloted aircraft or drone)
- A remote control system, which includes the pilot
- A communications link between the two, known as a command and control (C2) or a communication, command, and control (C3) system

The past decade has seen a proliferation of drone types and models (Figure 1.2). UAS equipment and technology is discussed further in Chapter 2.

WHY PLANNERS SHOULD USE DRONES

Drones have the potential to become indispensable urban planning tools for many reasons. They are multifunctional; they provide high-quality data of specialized and valuable types; they allow safe collection of data in dangerous or hazardous conditions; they are low-cost tools; and they are efficient.

Multifunctionality

UAS offer a wide variety of data collection applications and new interactions. They can carry a wide range of "payloads" ranging from cameras, Lidar, and thermal imaging sensors to robotic arms and packages. The same drone that creates a GIS map for a wildlife corridor might be used to evaluate the heat loss from a hospital rooftop or help in the search for and rescue of a lost child. This makes a drone an effective

Figure 1.2. A visual sampling of the wide range of drone models available (Stephens 2015).

and efficient investment—it is a single tool that can be used to do many tasks.

As UAS technology advances, new applications will become more interactive and integrated with other functions. For example, 3-D models may become integrated into GIS mapping for specific structures or geographic features.

Data Collection

Planning is a data-driven profession that relies on accurate and timely geospatial information. The cameras and other sensors drones can carry enable them to provide unique views and types of imagery, along with a wider spectrum of environmental data than any other planning tool.

Most planning documentation is two-dimensional, such as zoning maps and site plans. These do not capture the true three-dimensional nature of land use and development, which is critical in areas with varied topography and urban development. Just as a picture is worth a thousand words, aerial photos taken by drones allow the average person to visualize an area much more clearly than a map or a photograph taken at ground level (Figure 1.3, p. 12).

Drones can fly programmed missions that take hundreds or thousands of photos to create a photomosaic, which can then be used in mapping and GIS applications to generate value-added products such as 3-D models, georectified orthomosaics, aerial video illustrating time and motion, digital surface models, and more. The images that UAS can capture and generate are discussed in more detail in Chapter 3.

In addition to providing aerial perspective, drones can acquire additional types of data such as multispectral and infrared. The human eye sees a small fraction of the full electromagnetic spectrum. Multispectral imaging cameras can be mounted on drones to measure various invisible wavelengths and used for various applications such as vegetation and geological analyses. Forward-looking infrared cameras provide thermal imaging with a wide range of applications, such as commercial building inspection, landscaping health assessment, nocturnal urban wildlife monitoring, thermal pollution point-source monitoring, and many others.

Safety

UAS operations can be conducted in remote and dangerous environmental situations without exposing planners to health and safety risks. Environmental assessment and infrastructure monitoring can be conducted by drones without risk to planners. Examples include post-disaster sites such as flooded areas, tall structures such as bridges, and potentially hazardous areas such as nuclear power plants.

AUTONOMOUS AIRCRAFT TERMS

Autonomous aircraft/aerial vehicle (AA/AAV): generic terms for aircraft without an onboard pilot and with some level of independent flight operations

Drone: most popular term worldwide

Micro/mini aerial vehicle (MAV): very small drone

Platform: term often used when discussing equipment or payload

Remote-controlled (RC) aircraft: term most associated with hobbyists

Remotely piloted aircraft/aircraft system/aerial vehicle (RPA/RPAS/RPAV): international terms

Small unmanned aircraft (SUA): abbreviated FAA term

Small unmanned aircraft system (sUAS): FAA term for UAS weighing less than 55 pounds

Uncrewed aircraft system/Uncrewed aerial vehicle: nongendered alternative terms

Unmanned aerial vehicle (UAV): FAA term for aircraft only

Unmanned aircraft (UA): abbreviated term

Unmanned aircraft system (UAS): FAA term for aircraft, remote control, and communications link

Unmanned flying machine: antiquated term occasionally used in legislation

Figure 1.3. Aerial photos offer context and perspective missing from maps and ground-level images (Maser Consulting)

In many jurisdictions, planners assist first responders in emergency management.

Many communities are incorporating drones into their disaster preparedness, response, and recovery planning. Drones have been documented in saving nearly 300 lives through search and rescue, evacuation, medical delivery services, and other ways (Willoughby 2019). The ability of UAS to ensure personal safety and assist in community emergency services are significant reasons to consider using drones for planning purposes.

Costs

Like many information technology devices, the cost of drones continually decreases with miniaturization and economies of scale. As with personal computers, some drones devalue as much as 50 percent in a single year as they are replaced by more sophisticated models. These older drones are not obsolete; to the contrary, they are a great value in performing standard UAS tasks not requiring new features, which may not have any utility for planning applications.

Today, users can purchase a high-quality UAV with state-of-the-art avionics (aviation electronics), programming, and a high-resolution camera for around $1,500. As noted above, the multifunctional aspect of drones makes them a cost-effective tool for planners as they can expedite and enhance services in both the public and private sectors. For the public sector, this is a relatively inexpensive equipment investment for a technology with so many applications. For the private sector, drones can often pay for themselves through contract service fees within a few operations. Training and operations costs are also relatively low and provide ancillary benefits, such as staff professional development opportunities and a progressive organizational image.

Efficiency

Drones allow users to collect a wide range of different data types from large areas very quickly. A drone can fly over and document miles of roadway or acres of land area in a matter of minutes that would otherwise take hours or even days, saving valuable personnel time and concomitant costs.

Having in-house drone capabilities allows planners to schedule and perform data collection as it is needed, based on the availability of the agency's or company's drone pilot. For traditional aerial imaging, aircraft are chartered far in advance and must be scheduled with flight crews and facilities. The costs can be high for a single operation, so these are often done on an annual or biannual basis. In contrast, UAS operations are highly flexible and—weather permitting—can be scheduled on-demand at a fraction of the cost and as frequently as required or desired. In summary, UAS expand the capabilities of public- and private-sector organizations for a wide range of activities that would be otherwise difficult, expensive, or impossible to carry out.

As suggested above, the most immediate use for drones is acquiring inexpensive, precision, and timely aerial reconnaissance data for spatial planning and design. This data can then be used for construction or development monitoring, emergency management, energy efficiency evaluation, environmental assessment, GIS, mapping, master planning, site analysis, urban design, and many other functions. The sidebar on pp. 15–16 offers an example of how drones are being used to support more resilient and sustainable planning outcomes for communities.

Beyond these essential services, drones can provide additional services that may become useful to planning organizations—there are hundreds of commercial applications and more are being developed. Appendix C offers a list of commercial uses for drones in architecture, engineering, and urban planning, as well as in additional fields such as agriculture, business, environmental science, health and safety, meteorology, security, and recreation. This expanding range of applications makes UAS an ideal tool for interdepartmental agencies and multidisciplinary firms.

There are also intangible benefits to developing a UAS program. Designing a UAS program as an innovative effort to modernize and expand services can enhance personnel satisfaction and public opinion, and drones provide an innovative and highly visible opportunity to engage with the public.

UAS CONSIDERATIONS

Before launching (or expanding) a drone program—or writing their first RFPs for UAS services—public agencies and private firms should carefully consider how these services will be integrated into their organizations' missions and structures. This analysis should provide the foundation for a UAS vision that will further study and guide program administration, funding, crew training, equipment selection, flight operations, data management, products, and services. The program should be scalable and adaptive—from a single staff member taking occasional aerial photos to a complete department or multiple departments involved in a wide spectrum of UAS activities. Chapter 4 provides key information necessary for creating a UAS program for an agency, company, or individual planner.

The need for planning professionals to master UAS is imperative—autonomous aviation technology is advancing at an accelerated speed and is already far ahead of governmental regulation, public understanding, and acceptance. This technological cultural lag can—and does—create problems and conflicts. This report will consider these key challenges, including questions of safety, privacy, private property, and public nuisance. At the same time, UAS offer exceptional platforms to measure and monitor development, analyze and manage the urban environment, and expand and improve planning services.

The accelerated pace of autonomous aviation also means elements of this report will become outdated as technology and regulations evolve. Regardless of imminent changes, there is an immediate need to create a starting point for planners to develop programs to include UAS in their box of tools.

Creating good public relations—more than technological or economic considerations—is often the most critical element of a successful UAS program. Organizations will need to create UAS programs that balance the value of drone applications with safeguarding community values related to privacy, property rights, and nuisance.

ABOUT THIS REPORT

The array of UAS functions is expanding at an exponential rate, and the multifunctionality of drones makes them versatile, adaptable, and cost-effective tools for planners. But drone technology is currently unfamiliar to many planners and planning agencies, and becoming familiar with the wide array of UAVs and the various sensors and equipment that are used to outfit them for different applications may seem like an intimidating prospect. Likewise, learning the federal regulatory requirements for drone use and understanding the basic principles of safe and responsible UAS flight may appear overwhelming. However, many practitioners have taken the plunge, and once they master the initial learning curve, they have found drones to be invaluable additions to their planning and design practices.

This PAS Report seeks to demystify UAS technology and use. Its goal is to provide planners with the foundational knowledge they need to evaluate the use of drones in their planning and design work and the technical information required to integrate UAS into their professional planning practices. It offers comprehensive discussions of relevant UAS topics, including technology and equipment, applications, operational and administrative practices, and legal and regulatory considerations. The report provides the information necessary for both the public- and private-sector planning communities to integrate UAS into current practice. Sidebars in the report share practitioner experiences with drones and planning, and resources are suggested for planners to keep current in UAS and regulatory development.

Chapter 2, UAS Equipment and Technology, introduces the aerodynamics and avionics required for autonomous aviation as a background to operating UAS. It describes commercial UAV equipment and software to familiarize planners with UAS options available for their needs.

Chapter 3, UAS Applications for Planning, describes specific UAS applications for planning ranging from aerial site analysis and 3-D mapping to environmental assessment and disaster response. Planners, architects, landscape architects, and other environmental design professionals are using drones for a myriad of uses, and examples are shared to provide models for other agencies and firms.

Chapter 4, Implementing UAS Operations, discusses important considerations for UAS use by both public- and private-sector planners, beginning with the primary question: in-house program or contract service? The chapter discusses considerations for hiring a UAS consultant, including writing an RFP for UAS services and evaluating proposals, and walks through the basic elements of establishing an in-house UAS program. This chapter also offers some practical operational considerations for planners for using UAS technology in safe and responsible ways.

Chapter 5, UAS Legal and Regulatory Considerations, provides an overview of the current federal administration and legal considerations for UAS. An overview of federal requirements for remote pilot certification and UAS operations is provided. Although the federal government retains sole responsibility for regulating the NAS, state and local governments have established—and continue to adopt—a wide range of laws and regulations governing drones. Regulation of the NAS focuses on safety, but public concerns encompass a wide spectrum of operational and ethical considerations including privacy, private property, and nuisance.

Chapter 6, The Future of Planning and UAS, wraps up the report with a look at the ongoing evolution of drone equipment, technology, regulations, and applications that continue to improve its value to planning practice and help planners better prepare to face a changing and uncertain future.

The appendices offer a list of common UAS abbreviations, a UAS glossary, a list of commercial UAS applications, a UAS model safety policy, and a UAS model operations manual to provide additional guidance to planners in developing and administering a UAS program.

LEVERAGING UAS TECHNOLOGY FOR MORE EQUITABLE AND RESILIENT COMMUNITIES

Emily McCoy, Design Workshop, Inc.

Flooding, lack of high-quality open space, poor water quality, damage to personal property, and poor health are typically disproportionate burdens for communities in low-lying areas and areas adjacent to industrial land uses. To overcome these hydrological challenges and issues of environmental injustice, investment in green infrastructure, open space, and community-building projects are increasingly critical to achieve a high quality of life without displacing long-term residents. However, these communities often do not have access to the same levels of resources or social and financial capital as more affluent communities to quickly and effectively remediate these challenges.

For planners or designers with an eagerness to partner with communities and bridge resources to transform these liabilities into assets, uncrewed aircraft systems or UAS, also known as drones, are an important low-cost technology to consider adding to their toolkits. They can effectively help communities share their stories and perspectives with a larger audience to connect with those entities that can bolster efforts to improve hydrological conditions and connect the community to financial capital. Furthermore, UAS technology can help engage a community, especially during COVID-19, by immersing them in their neighborhood from above through video, photography, and mapping, and can take them into places that are difficult to access or view during situations such as the aftermath of large storm events.

Although drones require a moderate level of investment up front, the payback over time can be relatively quick. Most importantly, UAS can help clients, organizations, officials, and communities "see" their neighborhoods and project sites in a new light.

Not only do UAS have the capacity to offer new perspectives through photography and videography, planners can use their cameras and sensors to create base maps of existing conditions for much less than a full survey of a property typically costs. For one recent project site in southeast Raleigh, North Carolina, with wetlands, hotspots of invasive species, illegal dumping areas, and unknown drainage channels, we used a UAS to quickly map 30 acres (Figure 1.4). We used the data to create a base map with publicly available GIS data, resulting in fundraising documents that led to additional financial resources.

For this project, a standard survey would have cost around $20,000 and taken about four to six weeks to execute, whereas the UAS, associated licenses and software, and time and labor cost $2,500 and the mapping process took 15 minutes. Although a standard survey will eventually be necessary for the construction drawings, a UAS-created base map made possible an informed plan with high-quality imagery and analysis that compelled decision makers to fund and thus execute the project.

In addition to base mapping of existing conditions, drones were also used in this project to record approximate flood elevations over time after various storm events. Collecting UAS imagery is much quicker than walking or driving a watershed or drainage area and can be less expensive and more engaging to the public than water-level sensors and their associated data loggers. Additionally, UAS processing software makes these analyses quick and easy with tools that can perform rapid comparisons of elevations of features over time. With the use of software for planning autonomous

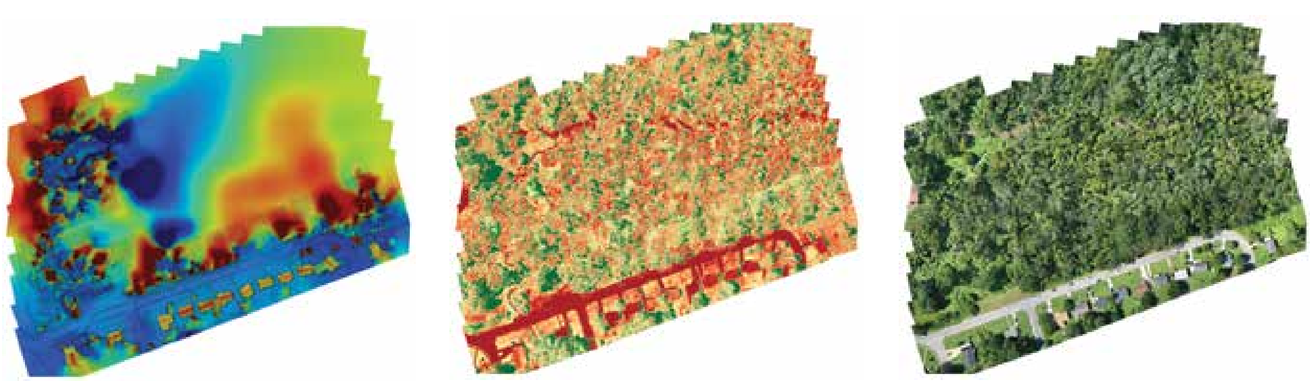

Figure 1.4. Elevation (left), Normalized Difference Vegetation Index (NDVI; center), and orthomosaic (right) views of a project site (Design Workshop)

flights, the same photograph or data collection activity can be repeated in the same location time after time.

A summary of the potential of UAS base-mapping capabilities and uses for planning and design of green infrastructure and park projects are listed below, but this is by no means representative of all the possibilities:

- Providing general topography information
- Creating 3-D models and elevations of vegetation, water, bridges, topography, buildings, etc.
- Tracking flood events, erosion and sedimentation, and water flow over time
- Analyzing vegetation health, such as identifying dead or dying trees that may be due to disease, pests, or changes in hydrology
- Balancing cut and fill grading
- Identifying different species of vegetation, particularly trees, using multispectral imagery
- Mapping the urban heat island using thermal imagery
- Tracing traffic patterns and general vehicular speeds
- Monitoring wildlife and wildlife movements
- Delineating overhead utility lines and other utilities
- Identifying damaged infrastructure in difficult-to-access areas, such as clogged inlets or other areas where waterflow is blocked
- Tracking shoreline changes over time and establishing rates of change
- Assessing existing and proposed viewsheds
- Mapping neighborhood resources such as sidewalks and crosswalks

A lack of access to capital funding, professionals with technical backgrounds, and technological tools to gather data about existing conditions can be steep barriers to overcoming issues of equity in planning and design in communities that are prone to flooding, poor water quality, and other poor environmental conditions. For planners who seek to work with communities to build much-needed high-quality and high-performing open space to provide ecological and social services, UAS technology can be an inexpensive tool that reveals the often hidden realities of a place and shares different perspectives to help catalyze change.

CHAPTER 2

UAS TECHNOLOGY AND EQUIPMENT

The evolution and technological advancements of drones, along with similar improvements in the quality and accessibility of sensors, has created an important paradigm shift in how local aerial data can be collected, analyzed, and implemented to streamline workflow.

Drone technology blends a variety of different disciplines. Aeronautics, robotics, autonomy, and even electromagnetic radiation all play important roles in the operation of any uncrewed aircraft system (UAS). To be a safe and efficient drone operator, it is important to have a basic understanding of these principles and how they determine certain flight characteristics and data collection procedures. Understanding UAS technology will also help planners make appropriate and cost-effective choices when determining what is needed for the functionalities they are seeking. While no one drone can do it all, there is a drone for virtually everything.

This chapter provides a comprehensive overview of UAS equipment and technology, from the drone itself to associated cameras, sensors, and software. It also describes some integrated features that support safe and responsible UAS use.

UAS TECHNOLOGY

Drone technology comprises uncrewed aerial vehicle (UAV) design, equipment, and software. These are integrated for specific applications and determine flight operations.

The key aerodynamic principle for UAS is the airfoil (Figure 2.1). An airfoil is a shape that provides lift when air passes across it. It is the aerodynamic element in bird wings, ship sails, aircraft wings, and propellers. For a helicopter, the rotor with its airfoil-shaped blades is the lift-producing device.

The proliferation of drones has been made possible by the refinement and miniaturization of avionics (aviation electronics), including sensors and controls for speed, level flight, positioning, and many other functions (Figure 2.2, p. 20). UAVs originally mirrored general aviation with fixed-wing and rotorcraft designs. In the last decade, these distinctions have become increasingly blurred by technological innovation, mass production, and hybridization, with drones adopting a wide array of designs not seen in general aviation. This innovation has led to significant growth of the commercial drone market sector. The consumer drone market size alone (which includes toy/hobbyist, "prosumer," and nonmilitary commercial uses) has increased from $355.9 million in 2015 to $22.5 billion in 2020. It is projected to grow to $42.8 billion by 2025 (Schroth 2020).

UAV Types

There are two primary UAV types: fixed wing and rotorcraft.

Fixed-wing UAVs achieve lift through a combination of propellers and wings. The advantage of fixed-wing drones is their speed and ability to cover large areas, making them ideal for mapping and surveying, environmental studies, and similar applications. There are two types of fixed-wing drones

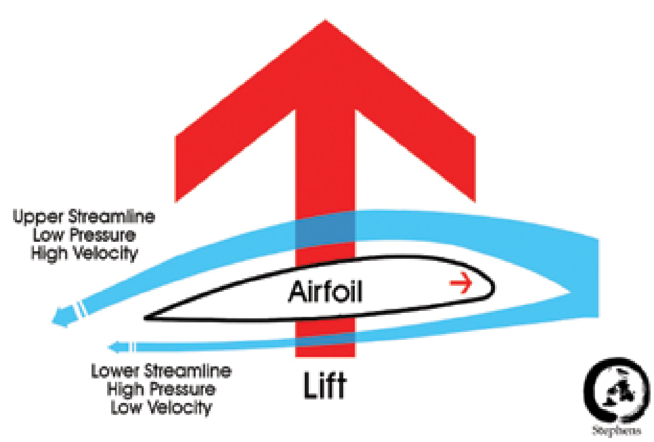

Figure 2.1. The aerodynamic principles of airfoil and lift (Ric Stephens)

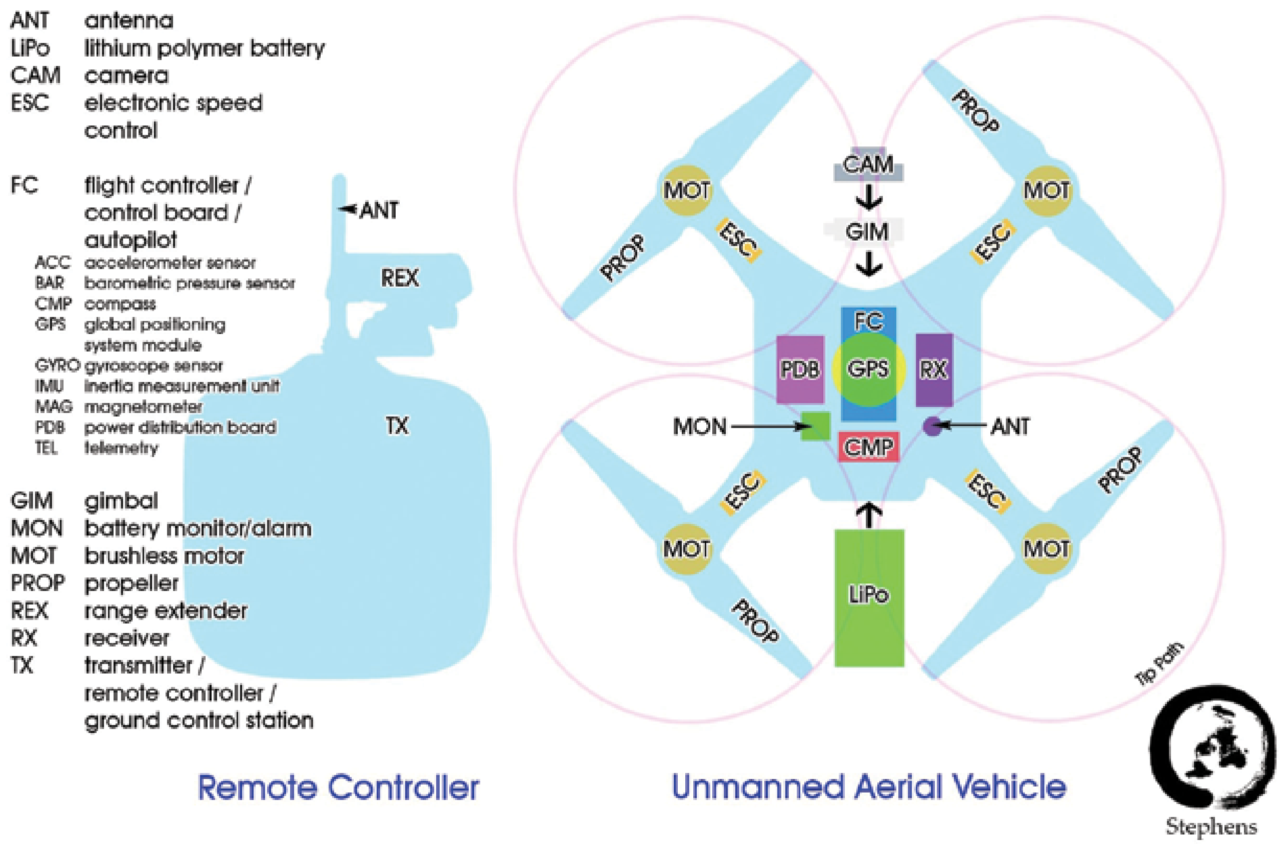

Figure 2.2. Drone avionics (Ric Stephens)

(Figure 2.3, p. 21): the airplane type, which resembles common airplanes, and the flying-wing type, which does not have a fuselage (body) and empennage (tail).

Rotorcraft are also broken into two primary types: single rotors and multirotors. Of the two types, multirotors are by far the most common, owing to their reliability and mechanical simplicity. Capable of taking off and landing vertically, rotorcraft can hover and move in any direction, making them ideal for mapping small areas or maintaining focus on a specific subject. Due to their ease of operation, maneuverability, and control, multirotor drones occupy the majority of the global hobbyist and prosumer markets.

Single-rotor platforms, which resemble the design of a conventional helicopter, offer several advantages. First, they are able to land after losing main rotor power using autorotation. Although this requires significant skill on the pilot's part, it could save an expensive payload in the event of a system failure. Second, owing to the size of their main rotor, they are more efficient than multirotor aircraft. However, these advantages are largely offset by the significant additional maintenance required by single-rotor platforms and the potentially lethal hazard created by a single large spinning rotor. It is for these reasons that multirotors remain far and away the most common type of rotorcraft UAV.

Multirotors are classified by the number and configuration of their rotors (Figure 2.4, p. 21). A typical multirotor with four rotors is a quadcopter, one with six rotors is a hexacopter, and one with eight rotors is an octocopter. "Coaxial" rotors are a pair of rotors mounted on top of each other. UAVs are named after the configuration and number of rotors; for example, a multirotor with four pairs of rotors oriented in an "X" pattern is an X8. Rotors may also be oriented in a "+" or "H" pattern. While there is no physical limit to the number of rotors, for practical applications, few drones have more than eight.

Some drones have characteristics of both types. Vertical take-off and landing (VTOL) designs can take off and land

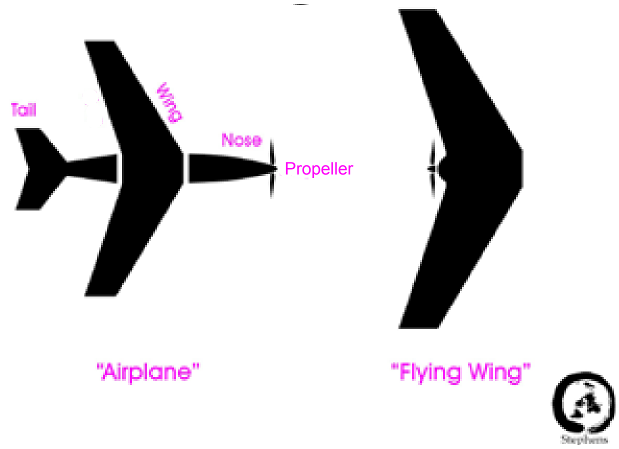

Figure 2.3. Fixed-wing drones (Ric Stephens)

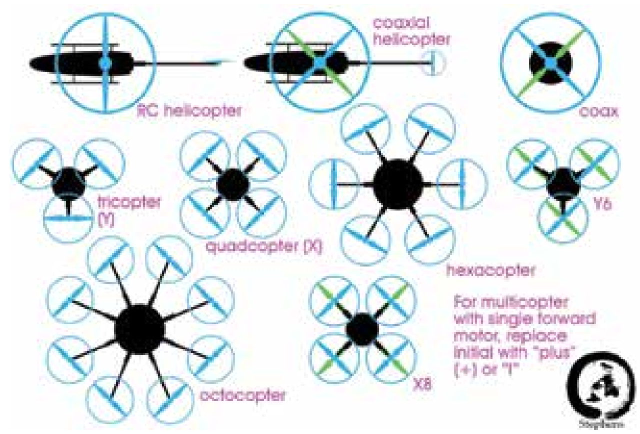

Figure 2.4. Rotorcraft drone typology (Ric Stephens)

vertically like a rotorcraft, maximizing operational flexibility. Once they are airborne, they transition to fixed-wing flight to take advantage of the increased efficiency this flight mode provides. However, because VTOL platforms represent a compromise between fixed-wing and rotorcraft designs, they are never quite as capable as either type.

Size

There are no universally recognized size descriptions for drones, and conventions vary across manufacturers.

The FAA uses the term *small unmanned aircraft system* (sUAS) for drones less than 55 pounds. This description covers virtually all commercial drones used by local government and the private sector.

Quadcopters are measured diagonally from motor to motor, and there is some consensus on sizes based on these frame dimensions. Nano drones are less than 100mm (less than four inches). Micro drones are 100–175mm (four to seven inches). Mini drones are 175–280mm (seven to 11 inches). Professional UAVs are typically larger than 500mm (20 inches), but there is a new generation of mini-quads with commercial-grade avionics and cameras that are filling the 11- to 20-inch range.

Fixed-wing aircraft tend to have wingspans greater than 1200mm (four feet) to accommodate heavier payloads. Commercial remote-controlled helicopters are relatively rare for professional operations other than some models designed for precision agriculture, which have rotor diameters greater than 2000mm (six feet, seven inches). Average drone sizes compiled from over 500 models are shown in Figure 2.5 (p. 22).

In addition, the U.S. military has also developed its own classification scheme for UAS based on weight. A Group 1 UAS is defined as weighing less than 20 pounds and operating below 1,000 feet of altitude and at speeds less than 100 knots (or 115 miles per hour). Group 2 UAS weigh between 21 and 55 pounds and fly below 3,500 feet at speeds below 250 knots. Groups 3, 4, and 5 UAS are heavier than are allowed to operate under 14 CFR Part 107, the federal regulations for small UAS use, with some exceeding 1,300 pounds and operating at altitudes in excess of 18,000 feet.

Power Source

The drones most likely to be employed on planning projects are powered by lithium-polymer (LiPo) batteries. LiPos are the most energy-dense battery type available within the constraints of current technology. The combination of minimal size and weight with high capacity and the ability to discharge stored energy quickly is what makes them practical.

Unfortunately, these favorable characteristics come at a considerable cost: LiPos pose a very real threat of starting fires that emit toxic smoke if they are damaged or handled or used improperly. A plan to deploy UAS must include battery safety precautions around use, charging, and storage. LiPos should never be left unattended while charging and should be stored and transported in a fireproof container.

At this point, there are two main alternatives to LiPo batteries. Aircraft powered by gasoline engines are available, but have a number of serious drawbacks: they are extremely loud, require significant maintenance at regular intervals, and the torque generated by the engine must be transformed

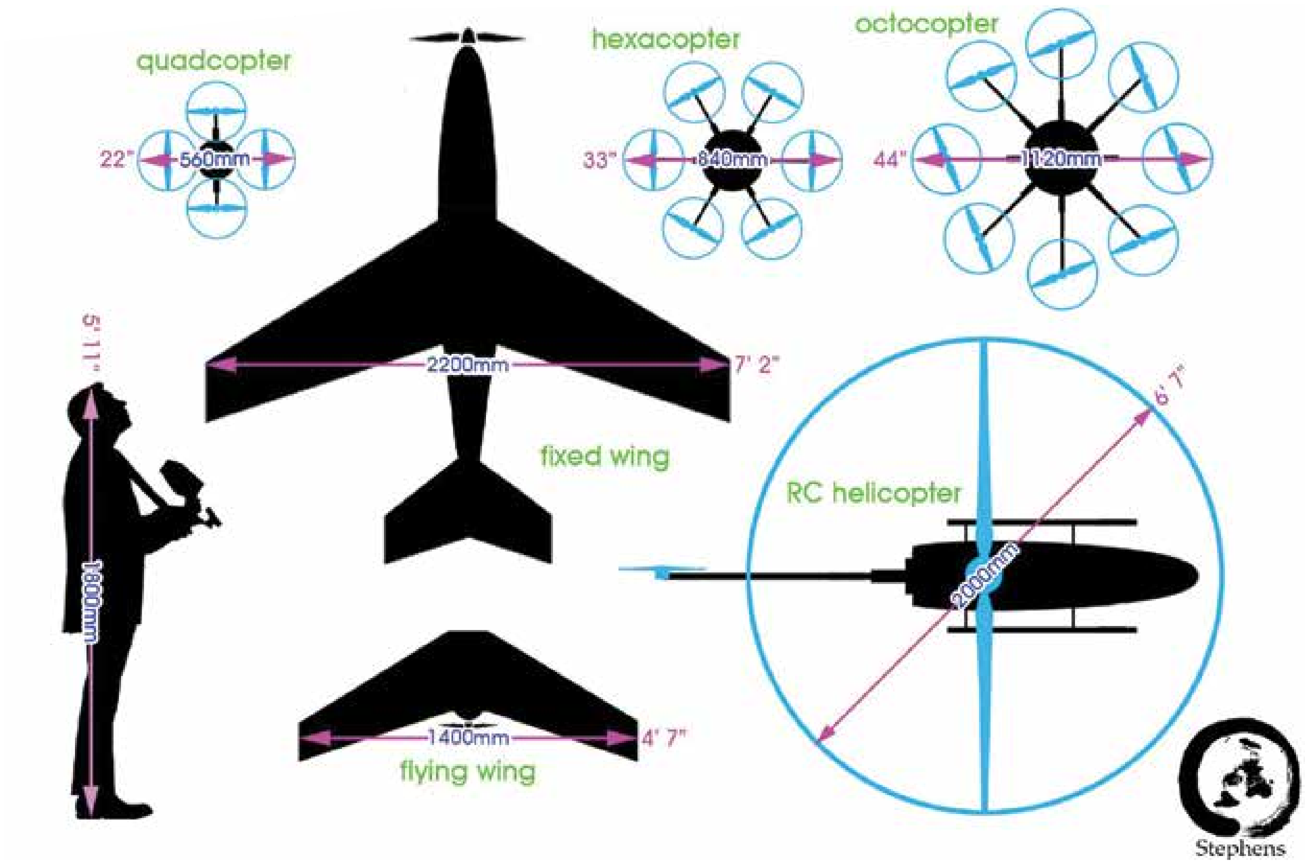

Figure 2.5. Typical drone sizes (Ric Stephens)

into electric current before it can power the aircraft's systems, which adds weight and technical complexity.

Another alternative is a hydrogen fuel cell. By combining oxygen from the atmosphere with hydrogen stored on board in a high-pressure cylinder, the fuel cell generates electrical current. Fuel cells are clean, quiet, and require little maintenance. However, they are very expensive and require regular access to high-pressure hydrogen gas.

Owing to the size of these power systems, both fuel cells and gasoline-powered engines are only practical with larger aircraft. However, they both offer much longer endurance than battery-powered models. In March 2020, a Chinese company reported testing a prototype UAS powered by a hydrogen fuel cell that flew for 331 minutes (Edel 2020). By comparison, the battery life on a typical UAS is about 20 minutes.

The addition of high-performance solar cells can substantially increase the flight time of electrically powered fixed-wing UAS. The wings provide a large surface area to mount the solar cells and fixed-wing flight is considerably less energy-intensive than rotary-wing flight. However, the expense of using solar cells generally limits this technology to applications where the need for extended flight time is acute, such as in military operations.

Grade

Toy-grade drones have a basic level of technology with limited real-world application. They usually come fully assembled with limited range and are controlled by smartphones. They generally cost less than $200, with basic entry-level toy-grade models as low as $50.

Hobby-grade drones offer medium-level technology with autonomous functions. They may come fully assembled or as kits to be put together by the consumer. They usually cost less than $1,500.

Prosumer drones are the most widely used grade for more professional collection procedures. They generally have the same features of hobby-grade drones, but come with more professional cameras, larger sensors, better lenses, and additional autonomous planning capabilities. These UAS generally cost in the $1,000–$2,000 range.

Professional or commercial-grade drones have sophisticated avionics, programmability, and equipment. These UAS can cost tens of thousands of dollars depending on size and equipment. Though typical costs are in the $6,000–$15,000 range, they can run to as much as $80,000, with additional costs for sensors—such as magnetometers, radiation sensors, Lidar sensors, and professional-grade digital single-lens reflex cameras—that can range from $2,000 to $200,000.

A fourth category, institutional drones, includes those used for government agencies. These are for specific government applications such as disaster response, border security, and military. They will not be discussed in this PAS Report.

Though a company offering professional drones services for hire will most likely need to invest in professional or commercial-grade drones to carry out more sophisticated applications needed for such a business, a planning firm or agency wishing to implement a basic in-house UAS program can purchase a high-quality prosumer-grade drone capable of most principle urban planning applications for less than $2,000.

Figure 2.6. UAS remote control for a hexacopter (Ric Stephens)

Controls

Although UAVs themselves, along with their equipment and software, vary greatly, the basic flight operations of drones are relatively standardized.

The standard remote control includes a screen to display the camera's view (Figure 2.6). This screen and any associated heads-up display (i.e., glasses or goggles worn the by pilot that display the drone camera's view) may be integrated within the remote or connected as a separate component, typically by means of a tablet or smartphone with an associated application. Also typically displayed is telemetry and other real-time metrics such as altitude, number of GPS satellites, camera settings, flight modes, and other data.

Two joysticks control how the aircraft maneuvers. For multirotors, these typically control rotate (yaw) and power (altitude) on the left, and flight direction (roll and pitch) on the right. For fixed-wing drones, the left joystick is for turning (rudder) and power (throttle), and the right stick is for direction (aileron and elevator).

Additional switches, sliders, and other controls are often attached for specific features and applications such as operating cameras or other equipment.

UAS EQUIPMENT

The UAV is often referred to as a "platform" for the equipment that it carries for its specific applications. This equipment or "payload" is most often a camera, but other types of equipment include delivery systems and robotic arms. Planners should consider what UAV characteristics are essential and what types of equipment are necessary to fulfill the drone's flight objective, or "mission."

Cameras

The most common equipment for drones is a camera for photography or videography. For prosumer-grade drones, these are typically 16–20mp for still photos and up to 4K or ultra-high definition (UHD) resolution for video (resolution can typically be adjusted to limit data size). These systems commonly have features similar to conventional modern point-and-shoot cameras, including adjustable shutter speeds and ISO ranges, digital filters, and burst shooting, and they support multiple file formats.

While minimal data storage capabilities are often built into the integral system, the data (image or video files) is most often stored on a removable MicroSD card. A minimum UHS-I or Class 10 MicroSD card is recommended

UAS FLIGHT MODES

Most high-end consumer drones come packed with automated flight modes to make the product more user friendly. While the terminology may differ from brand to brand, these drones incorporate many, if not all, of the following "intelligent" features:

Acro, Aerobatic, Agility, Manual: This advanced flight mode does not self-level the drone, allowing for more pilot control.

Active Track: This smart mode targets a stationary object or follows a moving object. This feature is ideal for when there is a specific site or object of interest.

Altitude Hold, A-Mode, ATI: This advanced mode allows the drone to drift in the wind while holding a set altitude. This mode has applications in aerial videography and cinematography in which the imagery corresponds with the winds.

Auto Land, One Touch Down: This flight mode has the drone land at a safe descent rate. It is one of many failsafe systems required for commercial drones.

Course Lock: This mode has the drone follow a set path regardless of orientation. It may be useful in viewing or filming a road or feature from an angle while flying.

Drift: In this advanced mode, the drone (typically a fixed-wing UAS) takes on characteristics of a full-size airplane.

First Person View: By wearing a hood or goggles, the pilot in command can fly the drone from the perspective of the on-board camera. This is currently not allowed for commercial applications without an FAA waiver, but within a few years, this will likely become a more standard flight mode.

Follow Me: This flight mode has the drone follow the pilot in command.

Geofencing, Safe Circle: This mode sets boundaries around airports or other sensitive facilities that the drone will not enter. Some of these boundaries are fixed (e.g., airports) and others may be set by the operator, such as distance from remote control or maximum altitude.

Gesture: In this mode, the drone responds to commands given by hand and arm gestures.

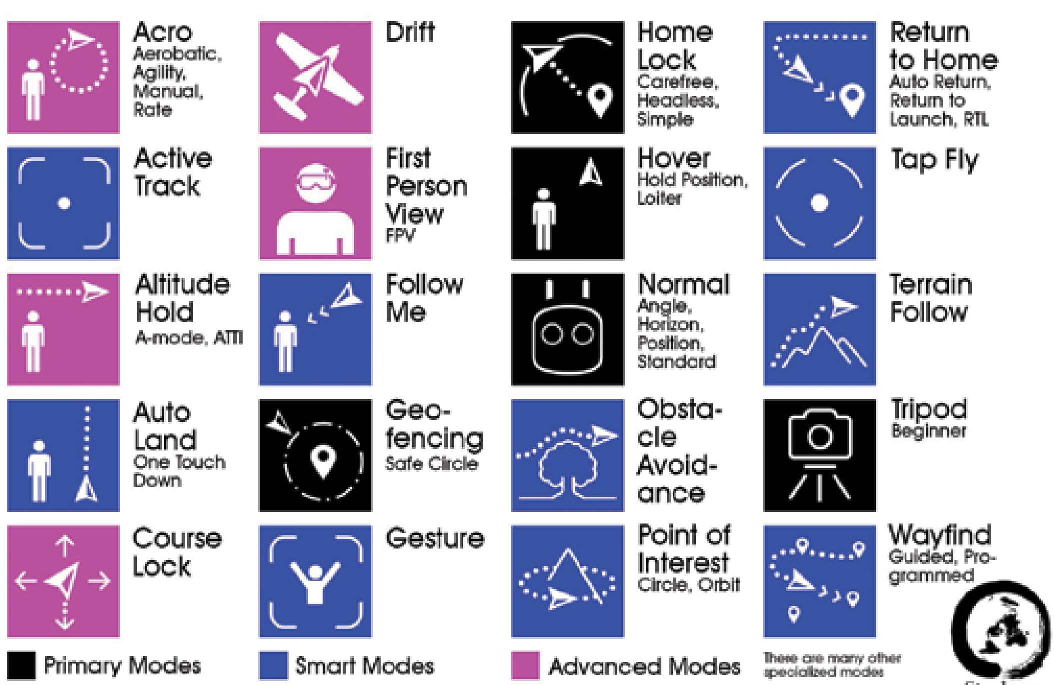

Figure 2.7. UAS flight modes (Ric Stephens)

Home Lock, Carefree, Headless, Simple: This is the basic flight mode in which the orientation of the drone does not affect flight direction, in contrast with the Normal mode. This is the ideal mode for beginning pilots as they do not need to orient their maneuvers from the perspective of the UAV.

Hover, Hold Position, Loiter: This mode allows multirotors to remain stationary in flight. For current UAVs, the stationary position will not deviate more than one foot in light to moderate winds.

Mapping/Lawnmower Grid: Drones can be programmed with set areas, ground sampling distance, and overlap to automatically set a flight plan to collect the data needed to generate an orthomosaic or point cloud for 3-D renderings.

Normal, Angle, Horizon, Position, Standard: This is the typical flight mode for drones in which the front of the aircraft corresponds with the direction of flight. This is the preferred flight mode for most UAS operations requiring pilot control.

Obstacle Avoidance: This mode enables the drone to fly around, over, or under obstructions in its flight path. This is a failsafe mode that is continually being developed using sonar, optics, and—in the near future—electronic communications with other aircraft.

Point of Interest, Circle, Orbit: This mode has the drone fly a path around a point or object of interest. This feature is ideal for reconnaissance of a particular site.

Return to Home, Auto Return, Return to Launch (RTL): This is a convenience and failsafe feature that has the drone return to where it was launched. A similar mode has the drone return to the vicinity of the ground station even if it has moved.

Tap Fly: This mode allows the pilot to determine the flight path by setting points on the flight control screen.

Terrain Follow: Similar to obstacle avoidance, this mode allows the drone to navigate over terrain at a set altitude.

Tripod, Beginner: Drones can be programmed for amateur pilots through regulating the speed and maneuverability of the drone. Using a "governor" that reduces responsiveness of the controls forces new pilots to fly slower and safer.

Waypoint/Guided/Programmed Navigation: Drones can be programmed to follow a specific flight path with GPS coordinates or online mapping.

for most prosumer-grade drones, as those with lower read speeds may result in data errors.

The camera is attached to the drone on a gimbal, which is a device that maintains the camera's position in flight, allowing for stable photography or smooth videography despite aircraft vibration or variations in wind speed. Optical cameras can be enhanced with computers for improved object recognition and other analyses.

Neutral density (ND) filters, which reduce the amount of light that enters a camera's lens, can be helpful on bright days to prevent image overexposure while still capturing detail. ND filters can be used for automated missions to keep the consistency of the exposure in each picture and can help with motion blur if taking video footage.

Sensors

The second most common piece of drone equipment is a thermal infrared camera able to capture heat imagery. These cameras are commonly referred to as forward-looking infrared (FLIR) cameras, though this term also refers specifically to cameras made by FLIR Systems, one of the largest designers and manufacturers of thermal infrared imaging cameras. Thermal infrared cameras may be combined with optical cameras in a drone's payload.

Multispectral cameras separate the spectrum of light into divisions to enable more specific analysis. These are used for environmental studies and precision agriculture.

Light detection and ranging (Lidar) equipment sends a pulsed laser to measure topography or structures for precise measurement. Lidar provides accurate measurements for mapping and surveying.

Sonar equipment sends sound waves to detect objects and is primarily associated with drone collision avoidance. Many drones have forward sonar to prevent in-flight collisions and downward sonar to assist in landings.

A variety of devices to detect hazardous materials are being adapted for drones. These have been used to respond to hazmat incidents where the chemicals were either unidentified or too dangerous for first responders to be involved. Such sensors include Geiger counters for ionizing radiation, as well as other sensors relevant to radiation health and safety threats.

Sound and Lighting

Drones are required to have collision avoidance lighting for twilight and night flights (the latter require an FAA waiver, which is discussed further in Chapter 5). They may also incorporate lighting to assist in illuminating nighttime and poor visibility conditions.

Drones can carry loudspeakers for communication, warnings, and other applications. As an example, these are used at some public beaches to warn swimmers of strong currents or sharks. Microphones can also be attached or suspended from drones for ultrasonic and auditory monitoring and communication. These have been used in post-disaster search-and-rescue operations to locate earthquake survivors.

Other Payload Equipment

In addition to data collecting, drones can be outfitted to carry other types of equipment, usually to perform a physical task. While most of these are likely outside of the needs of planners, it is good to know about the wider range of drones' capabilities as they grow more versatile.

Robotic arms provide the drone with the capability of manipulating objects and operating other equipment. These have been used in the post-disaster recovery of the Fukushima nuclear facility, where drones replaced workers who would be exposed to dangerous levels of radiation.

Sprayers are another type of payload. Precision-agriculture drones are being developed for aerial application of fertilizers, pesticides, and herbicides. Drones are also being equipped with chemical sprays for a variety of animals that pose safety threats, including sharks and bears, as well as disease vectors, such as mosquitos. There are a variety of drone designs that incorporate equipment for fire suppression. Disaster-recovery drones can be equipped to spray a mixture of seed and fertilizer to revegetate areas damaged by fire or flood. The COVID-19 pandemic has prompted interest in using drones for large-scale disinfection of areas such as stadiums. (More about the use of drones for pandemic response can be found in the sidebar on pp. 78–79).

Drones can be equipped with a variety of mechanisms to enable delivery and pickup. Delivery techniques include landing the drone to detach a package, dropping the package in flight at low level or releasing it from a suspended cable, or dropping the package with a parachute at higher altitudes.

UAS Gear

There are a few additional items that drone pilots will find useful in UAS operations.

Portable landing pads can be invaluable in creating a safe and stable area for drone takeoff and landing, particularly when operating in grassy or dusty areas. The landing pad prevents the possibility of UAV blades catching tall grass or other vegetation and possibly damaging the machine, and it helps prevent dust that might be kicked up by rotor movement from getting into the body of the drone.

Sunshades or shields can be used to reduce glare and provide shade for the screen of the drone controller, whether a typical remote control or a phone or other mobile device. Being able to see the screen is crucial for pilots, so a sun shield is helpful in bright, sunny conditions.

Batteries and MicroSD cards are mentioned above, but drone operators should consider purchasing multiples of both. Swapping out spent batteries for fresh ones and full MicroSD cards for new ones enables pilots to extend drone flights beyond a single battery charge or MicroSD card's data capacity. In cold weather, warming devices for extra batteries are important, as the drone may not be able to draw power from a cold battery.

UAS SOFTWARE

UAVs typically incorporate two types of software: aeronautics and applications. Aeronautics software is focused on UAS operations, and applications software assists in the UAS utility—what the UAV is designed to do.

Drones software for avionics is advancing towards increased flexibility, programmability, and autonomy. Originally, the pilot would need to control all aspects of operating the drone from takeoff to landing. Today there is a wide variety of automated flight modes controlled largely by integrated GPS systems, allowing the pilot to focus on specific application operations. The sidebar on pp. 24–25 provides a list of common UAS flight modes (Figure 2.7, p. 24).

There are two primary UAS modes for "mission" software: passive data gathering and interactive applications.

Sensing, Mapping, and Surveying. Drones used for passive data gathering have onboard programming to guide the UAV over a predetermined flight path to gather imagery for mapping. This is typically an overlapping pattern of flight paths to gather data to create a photomosaic that can be later combined to create any number of final deliverables, including orthophotos, 3-D images, Lidar maps, thermal infrared images, or multispectral maps. UAS provide an ideal platform for surveying, and many are now designed specifically for this application. It should be noted that aerial surveys must be prepared by a licensed surveyor.

Robotics. As drones transition from passive data gathering to interactive applications, specific software programs are being designed to enable semi- and fully-autonomous robotic functions, such as delivery and pickup systems or highly complex object manipulation.

UAS SAFETY FEATURES

The primary concern for all UAS operations is safety: that of the public, property, and the crew responsible for conducting operations.

Safety issues can be addressed to some extent within drone technology itself. The following drone features help make operations safer.

Drone Failsafe Features. All professional-grade UAVs have several failsafe features, including auto-land and return-to-home programming that ensures the drone will either land immediately (as in a depleted battery condition) or fly back to the point of origin if there is a lost link (loss of communication with the remote controller). These technologies are becoming more resilient and adaptable to various conditions using sonar or optical obstacle avoidance equipment. A less common failsafe feature is a parachute that can be activated automatically or by operator command. Also, drones with six or more rotors are designed to be able to make an emergency landing with the loss of one or two motors.

Obstacle Avoidance. Many professional-grade UAVs are equipped with sonar or optical obstacle avoidance systems that prevent them from collisions in flight and when landing. The sonar systems send pulsed soundwaves that, when bounced back from an obstacle or ground, make the drone stop its flight. Some programs allow the drone to continue its course by flying over or around the obstruction. Newer systems use complex optics to recognize when the drone is approaching an obstacle or the ground.

Geofencing. Geofencing is a program that prevents drones from entering restricted airspace, such as the five-mile radius of a controlled airport. This software can be programmed to include other sensitive land uses and disabled if required for approved purposes. Geofencing can also be designed to prohibit the drone from flying too close to the pilot in command. This type of geofencing is sometimes called a "safe circle."

CONCLUSION

This chapter provides a detailed look at the current state of UAS equipment and technology. But technological development is expanding all facets of UAVs, equipment, programming, and operations. To planners new to the world of drones, selecting a UAS that is capable of the widest range of applications, offers the highest level of mission flexibility, has the lowest purchase and operating costs, and incorporates the most desirable characteristics can seem a daunting task. To help make these decisions, Chapter 4 offers additional guidance on selecting UAVs, equipment, and software.

Such decisions about equipment and technology will be informed by their intended uses. Planners will need to identify platforms and payloads that are appropriate to their specific missions, such as site analysis, GIS mapping, infrastructure inspection, and many others. The next chapter provides a comprehensive overview of drone applications most relevant to planning work.

CHAPTER 3

UAS APPLICATIONS FOR PLANNING

Good planning requires good data, and there are many tools available to collect pertinent data. Uncrewed aircraft systems (UAS) can provide planners with a way to obtain aerial data that is easier, more cost-effective, and more targeted than similar efforts may have been in the past. Drones give an elevated perspective on the data we see every day.

As noted in Chapter 2, UAS are sometimes referred to as "platforms," as they provide a way to emplace sensors typically used from the ground or fixed positions, such as cameras and scanners, in the skies and other difficult-to-reach spaces.

The aerial capabilities of drones are myriad; there are currently more than 400 commercial applications for unmanned aircraft systems, and new uses are continually emerging. For planners, this technology expands capabilities for spatial analysis, environmental assessment, infrastructure evaluation, development monitoring, and many other functions. These passive data-gathering uses will continue to be augmented with interactive uses in environmental impact mitigation, infrastructure repair, urban design modeling, and more.

This chapter explores the most relevant applications of drones for planning purposes. To help planners better understand the wide range of drone uses, and to help them coordinate with other users, the chapter also briefly reviews relevant drone applications for other planning-adjacent or local governmental functions. The chapter also touches on the benefits drones provide to planners across many different jurisdictional, geographic, and professional contexts.

UAS PLANNING APPLICATIONS

The examples below illustrate a variety of UAS functionalities relevant to planners working in a wide range of planning contexts—in the public sector for both small and large jurisdictions, or in the private sector for planning and design firms.

Site Analysis and Visualization

The value in observing the built environment from an elevated perspective has long been understood, and aerial photography has a long history. The oldest surviving aerial photo in the world was taken in Boston from a hot air balloon in 1860 by James Wallace Black (Figure 3.1); this image is currently housed at New York City's Metropolitan Museum of Art. In

Figure 3.1. Balloon view of Boston, taken October 13, 1860, by James Wallace Black (Metropolitan Museum of Art, Gilman Collection, Purchase, Ann Tenenbaum and Thomas H. Lee Gift, 2005)

1906, George R. Lawrence attached a 50-pound camera to nine large kites and documented the earthquake destruction in San Francisco (see Taylor 2016).

Today, UAS aerial reconnaissance provides planners with situational awareness from an elevated viewpoint that is often more comprehensive than one at ground level. Drones provide the "big picture" for many land planning projects that have a scale or topography that does not allow for a comprehensive ground-level view of the entire project.

There are two types of image perspectives that drones provide: oblique (images taken at an angle), and nadir (images taken from directly above). From these perspectives, users can generate various value-added products such as georectified orthomosaics, digital surface models, 3-D models, aerial videos illustrating time and motion, and others.

Oblique aerial images (Figure 3.2) illustrate the relationships between various land uses and convey this information to decision makers and the public far better than narratives or maps. These views are especially valuable in cases where the areas of interest are remote, inaccessible, obscured by vegetation or structures, or highly complex.

Nadir aerial images (Figure 3.3) give a "bird's-eye view" of the land and provide an overall perspective. This is particularly useful in cases where the areas of interest are large and unobscured by canopies or other covers. Maps and orthomosiacs are typically derived from nadir photos.

Orthophotos are invaluable in preparing geographic information systems (GIS) mapping, measurements, and surveying. They must be geometrically corrected, or rectified, to eliminate distortions in perspective that result from displaying a three-dimensional surface as a two-dimensional image, as well as the angle that the photo was taken from (Figure 3.4, p. 33).

UAS can provide highly accurate terrain mapping from photogrammetry (the science of making measurements from photographs) and orthomosaics. Various software programs are available that can plan a drone flight to take hundreds or even thousands of photos of a site or structure. These aerial photos are then stitched together to create an orthomosaic or orthomontage, which can then be used in mapping and GIS applications. The images are corrected (orthorectified) as described above for camera angle, lens distortion, and topographic relief. The resulting images are highly accurate and ideal for construction monitoring, environmental analyses, land management, surveying, and land-use planning.

3-D modeling uses the same approach but requires many more photos from various angles. These oblique photos are stitched together, this time resulting in a 3-D model that can be used to view the site from any angle, make fly-through videos, and create 3-D printed physical models. These are ideal for public meetings and presentations.

Photogrammetry may be supplemented or replaced by Lidar (light detection and ranging) data. A drone-based Lidar system uses remote sensing and a pulsed laser to record billions of highly accurate (within one inch) geolocated points, creating a 3-D "point cloud" of the captured natural and built environment.

While a Lidar-based drone system is typically more costly and complex than one used for photogrammetry, it is advantageous in particular situations. If topographic information is needed in an area with dense vegetation, for example, photogrammetry cannot obtain accurate ground-surface information. The light pulses from the Lidar system can penetrate between branches and leaves, creating an accurate surface model. Lidar point clouds also allow for specific classification (by color and class) to easily distinguish different

Figure 3.2. Oblique image of Camp 18, a small tourist attraction in Oregon (Ric Stephens)

Figure 3.3. Nadir image of Camp 18 (Ric Stephens)

elevations, materials and vegetation, specific site features, or various categories of the built environment (Figure 3.5).

The capture, processing, digitization, manipulation, and analysis of both 3-D photogrammetry and Lidar models is a complex process that traditionally has been handled by specialized departments within surveying and engineering firms. However, in recent years this has become far more accessible to other industries due to the availability of prosumer and commercial drones with integrated sensor technology (see Chapter 2) and software such as Pix4D (www.pix4d.com), a suite of programs designed to transform a wide range of aerial data into accurate georeferenced maps and models.

Lastly, drones can show the fourth dimension: time and motion. Drones can be programmed to take sequential photos or used to take high-definition video for projects that need to examine change over time. Integrated GPS tracking systems and waypoint navigation, commonly built into the software of most modern commercial drones, allows the user to record a specific flight pattern and repeat the exact maneuvers autonomously on a subsequent flight, enabling a precise time-lapse examination of the evolution of a site or landform over time within the same framework. Examples include traffic studies, construction monitoring, and flood tracking.

The dimension of time and motion may also be used for post-construction evaluation of the usage of a site or landscape. Drone footage taken at given intervals in a newly constructed public park, for example, can offer macro-level insights to planners or designers into volume and usage patterns of people within various programmed areas within the park. However, considerations for privacy and nuisance (which will be described in Chapter 5) should be considered whenever aerial data or imagery collection involves the public.

Aerial reconnaissance also enables expanded site analyses through various sensors (e.g., thermal infrared cameras) and imaging techniques (e.g., 3-D modeling). These tools enhance land-use planning and urban design by providing a deeper understanding of the site and relationships with the proposed project.

Figure 3.4. An uncorrected orthophoto (left) shows perspective distortions; a rectified orthophoto (right) flattens and scales the entire image. (Penn State University, OPEN.ED@PSU)

GIS Mapping and Modeling

Drones excel in creating GIS data with low-altitude, precision imaging. UAS GIS mapping capability combined with other sensing tools and overlays can create powerful applications for land-use planning. GIS mapping and modeling further provides a valuable tool to evaluate development potential for specific sites.

There are five key benefits to GIS mapping: (1) cost efficiency savings, (2) improved decision making, (3) better documentation, (4) enhanced communications, and (5) geographic management. GIS maps improve efficiency in planning and design by consolidating multiple layers of information such as zoning, utilities, soils, and others. They improve decision making by visually depicting land-use relationships not evident from ground level. They provide better documentation of existing, proposed, and built projects. They communicate complex land-use and development concepts to offi-

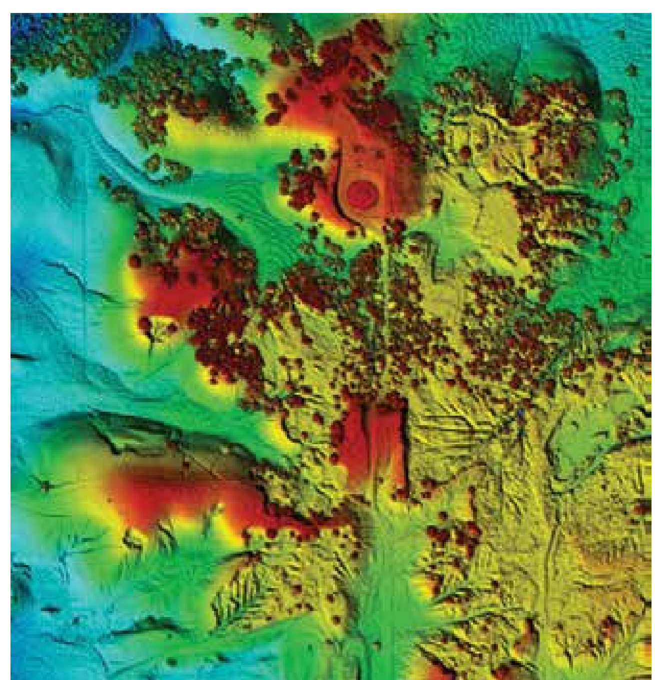

Figure 3.5. Lidar digital surface model, classified by elevation (Penn State University, OPEN.ED@PSU)

PHOTOSIMULATIONS USING UAS AERIAL PHOTOGRAPHY

Ric Stephens

The primary graphic for land-use planning and development is a map or plan that uses numerous conventions to illustrate land use, elevations, and more. These are ideal to convey critical measurements and spatial relationships, but they fall very short of providing a visualization of the built project.

Drones provide planners with the opportunity to create photosimulations of potential development scenarios from an oblique aerial perspective. These are commonly used in planning to show what a new structure would look like after construction. The "before" and "after" photos are valuable visualization tools for streetscapes, public spaces, urban development, and design.

As part of collaborative design projects with various Oregon cities, the Oregon Department of Land Conservation and Development, and the University of Oregon, I designed a variety of photosimulations to illustrate scenarios relevant to city sustainable development, urban resiliency, and regeneration.

The photosimulations were made by taking oblique aerial photos of the development site from an unmanned aerial vehicle at about 50 feet (15 meters) above ground level. Typically, many photos are shot from different angles. These photos can be "stitched" together with editing software, and a panorama can be made by taking photos in 360 degrees. Using other photos available online and photo editing software, a composite is made of a potential development alternative.

Figure 3.6. Photosimulation of German-style zebra-stripe crosswalk and heraldic traffic circle, Mt. Angel, Oregon (aerial photography and photosimulation by Ric Stephens, University of Oregon)

Figure 3.7. Photosimulation of an emergency vertiport, Scappoose Industrial Airpark, Oregon (aerial photography and photosimulation by Ric Stephens, WHPacific, Inc.)

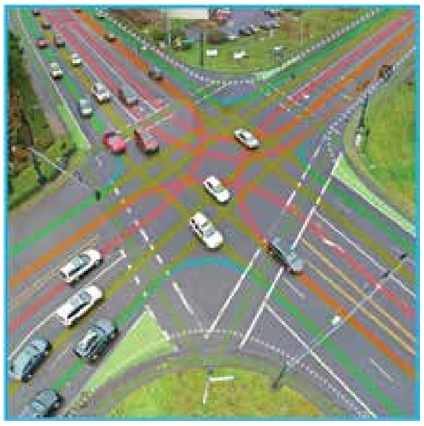

Figure 3.8. Walker Road/Murray Boulevard intersection turning movements, Beaverton, Oregon (aerial photography and photosimulation by Ric Stephens, WHPacific, Inc.)

In an example from the Bavarian-themed downtown streetscape of Mt. Angel, Oregon, the photosimulation shows how an intersection with a typical U.S. parallel striped crosswalk would look with a German zebra-stripe crosswalk and heraldic traffic circle (Figure 3.6, p. 34).

Another example, from the Scappoose Industrial Airpark Resiliency Plan (https://spbresiliency.org), depicts an emergency vertiport for electric vertical takeoff and landing (VTOL) aircraft and unmanned aircraft to provide disaster supplies and emergency evacuation (Figure 3.7, p. 34).

Photosimulations can also be designed to illustrate other types of planning information, such as site plan overlays, urban design elements, and transportation networks. The Walker Road/Murray Boulevard photosimulation is an example of an existing intersection with a color path overlay showing turning movements (Figure 3.8).

UAS photosimulations provide planners with effective and efficient tools for a wide range of planning purposes. The examples shown here are only the beginning.

cials, the public, and clients. And finally, they enable better project management through aerial monitoring.

UAS operations improve on all of these GIS mapping benefits by lowering the cost of aerial imagery to allow more frequent and higher-precision data-gathering flights. This can be especially important when accurate imagery is required for a project or location but typical data sources have become outdated due to recent project activity or other large-scale changes.

For large-scale projects, 3-D modeling also expands on these benefits with comprehensive visualization of development alternatives and the ability to accurately measure distances, areas, and volumes.

Photosimulations

Through editing drone images, photosimulations can be created to illustrate land-use and planning scenarios. Photosimulation is the technique of combining actual photographs with superimposed photos or illustrations to visualize changes in the urban or natural landscape. These are commonly used to depict the appearance of future development or structures such as new buildings, telecommunication towers, and other structures.

UAS photography provides an opportunity to create photosimulations from various perspectives to show project aesthetics or visual impacts. These images create powerful visualizations for public meetings and hearings, and they are also ideal for the promotion and marketing of new development. The sidebar on pp. 34–35 provides several examples of UAS photosimulations for planning purposes.

Project Management and Development Monitoring

UAS aerial reconnaissance is an ideal tool for project management and development monitoring. Sequential photos can document construction, environmental management, transportation flows, and other urban planning processes. Oblique aerial photos can also show development progress, environmental changes, traffic flows, and many others. Orthomosaics can provide measurable changes in distance, area, and—when made into 3-D models—volume.

Transportation and Traffic Applications

UAS can be especially useful for documenting and tracking transportation projects and systems, which often span great distances. Entire transportation networks can be surveyed and documented for existing conditions assessments and asset inventories (such as dirt and salt stockpile location and

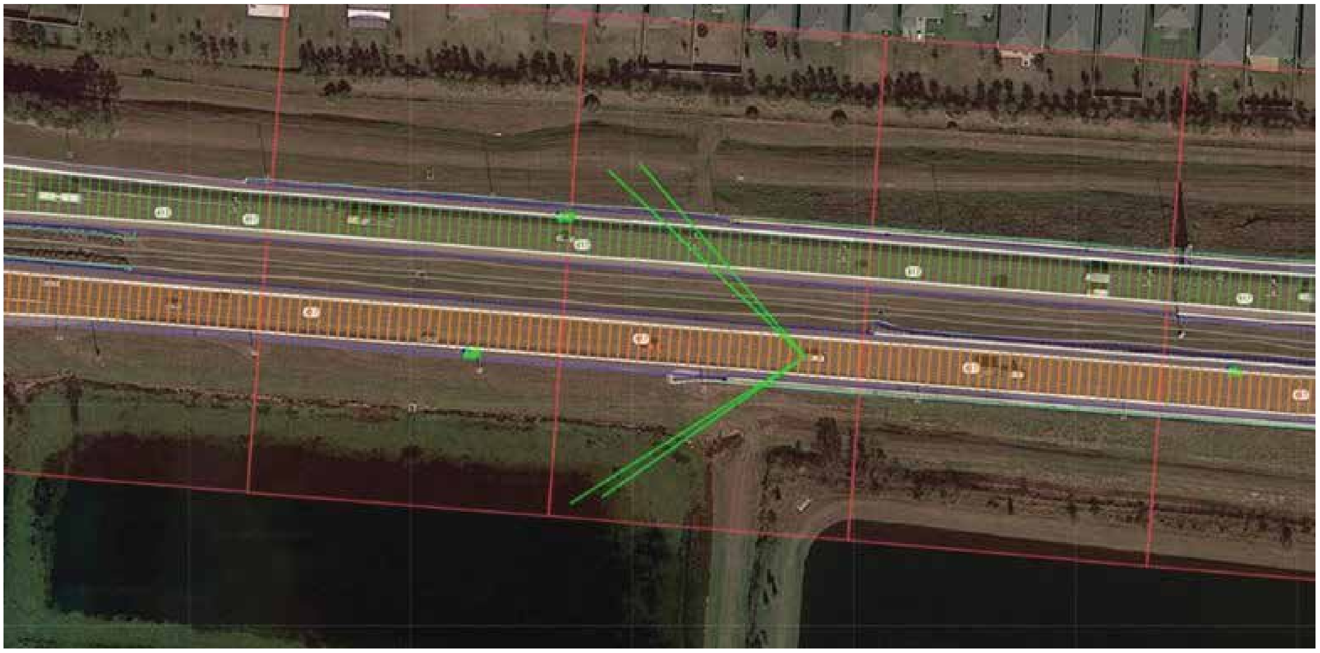

Figure 3.9. UAS imagery used to analyze line-of-sight along a roadway network to direct CCTV camera placement and study potential impacts on autonomous vehicles (Maser Consulting)

sizes for winter storm management), as miles of roadway can be quickly and easily flown by a drone.

Such data may be used for more than one application. Figure 3.9 shows an image from a traffic study completed for a Florida community that analyzed line-of-sight data along roadways to direct the placement of CCTV cameras, allowing for remote viewing and monitoring of traffic conditions across the entire transportation network. The same data was used for a study of potential autonomous vehicle (AV) use of the roadway network to help determine how current corridor conditions might impact future AV use.

Aerial imagery from drones can be used to document as-is conditions before the beginning of a project, such as highway reconstruction or roadbed resurfacing, and to track ongoing project progress. UAS can be used to monitor traffic flows around roadway construction projects and track congestion points and traffic volume at different times of day to help manage construction work timing to reduce impacts on traffic flow.

UAS can also be used to monitor traffic volumes and flows for special events being held in communities; the real-time data they provide can help identify areas of congestion to allow personnel to better manage traffic flows and access points and determine alternate routes if necessary.

Disaster Planning and Recovery

Pre- and post-disaster analysis and documentation are vital for urban resiliency, emergency response, economic relief, future disaster preparedness, reconstruction, and recovery. Drones are invaluable in providing this information. Aerial photography can provide damage assessment data for flooding, fires, earthquakes, hazmat spills, and many other disasters. This is not only critical for post-disaster recovery planning, but for documentation for U.S. Federal Emergency Management Agency (FEMA) and insurance claims that require damage assessment.

Detailed UAS mapping and GIS data provide a solid foundation for recovery planning and reconstruction. The value of drones in disaster planning is evidenced by their use in all major disaster operations over the last decade. They have been used by first responders and, more recently, planners for situational awareness and disaster mapping during and after disaster events. Examples include the following:

- **Hurricanes:** Drones have been used in hurricane recovery to document the extent of destruction (Figure 3.10, p. 37), as well as to locate and isolate issues within telecommunication, energy, and transportation sectors, and for public outreach.

Figure 3.10. UAS documentation of post-hurricane destruction (Maser Consulting)

Figure 3.11. UAS documentation of critical infrastructure flooding (Maser Consulting)

- **Tornadoes:** Drones can be used to document damage and access problems, provide initial evaluation of affected areas, and identify other risk areas.
- **Flooding:** UAS imagery can document the extent of flood damage and identify areas that could suffer negative environmental impacts due to flooding. The aerial perspective drones provide can also help emergency responders identify alternate routes around and through flooded areas. Flooding can prevent access to vital critical infrastructure and facilities; drones can be used to assess the damage in these areas, better preparing recovery, repair, and rescue crews for what will be needed for those areas as they become accessible (Figure 3.11).
- **Wildfires:** Planners are using drones to assess fire hazard areas and post-disaster damage throughout the western United States. Specialized drones are currently being used to locate "hot spots" with thermal imaging cameras, evaluate and redesign underground powerlines with Lidar, and even to reforest burnt areas by dispersing seeds coated in fertilizer. In Lebanon, UAS will be used as part of a "Smart Forest" tool using artificial intelligence and Internet of Things technology to proactively monitor and protect forests from wildfires (Wray 2020).

Recent international examples of drone use in disasters include post-disaster evaluation after the Tohoku earthquake in Japan, with specific recovery emphasis on debris assessment and logistics; drones were also used to inspect and—with robotic arms—make minor repairs to the Fukushima nuclear reactor. After the Haiti earthquake in 2010, drones were used for post-disaster evaluation with specific emphasis on temporary shelter and infrastructure assessment, and they are currently used for emergency medical delivery throughout the Caribbean.

More information about drones' use in emergency management is described later in the chapter.

Community Engagement

The data and imagery collected by UAS can be used in a variety of ways to engage the community in a planning process or project. From aerial maps and views to fly-over videos of sites as they currently are and as they are envisioned to be, drones enable quick and cost-effective creation of compelling displays and materials to help the public envision the impacts and outcomes of plans and projects.

The use of aerial imagery—particularly video—to present existing oblique site imagery, diagrammatic overlays, or photomontages is perhaps the most common drone-based strategy that planning departments are currently using. This level of visual communication has been highly advantageous for use in public meetings, whether as a part of public presentations, for use as 3-D models that can be explored in real time, or as a part of web-based tools to disseminate information and obtain valuable public input about proposed development scenarios.

Drone technology and its capability to produce highly accessible imagery is becoming more ubiquitous and necessary in the current COVID-19 (and eventual post-COVID) age, in which remote public participation processes have supplemented or replaced the traditional in-person public meetings. As described in the sidebar on pp. 38–39, technology that enhances the visual comprehension of the planning and development process will play a pivotal role in the remote participation process to ensure accessible and engaging inputs. Tools such as these can solicit a broader level of participation and more reliable outputs, resulting in more accurate representation of a community's vision for the future.

UAS AS A TOOL FOR COMMUNITY ENGAGEMENT

Sara Egan, AICP, and Maddie Clark, Design Workshop, Inc.

Today, people gather information in short segments through push notifications on smart devices, social media, and text messages. The average webpage visit lasts less than a minute—and most viewers leave a page within 10–20 seconds. This creates a challenge for planners and designers who depend on stakeholder input to drive the design process. In a world saturated with digital stimuli, designers need to leverage tools to make the most of stakeholders' time and available attention span. This requires visual storytelling techniques that are clear and concise, that entertain, and that even elicit emotion.

In contrast to webpage visits, the average length of a video watched is 2.7 minutes. This creates an opportunity to employ drone technology to create better community and stakeholder engagement processes. While UAS are largely used for site analysis, bird's-eye imagery and video from drones can enhance storytelling to bolster community engagement and deepen the clarity and communication of design ideas. As planners and designers tasked with translating stakeholder desires into project outcomes and built products, it is critical that our communication methods reflect the way people consume information.

Drone video and imagery can serve as a base for iterating concepts in AutoCAD or 3-D rendering software. These tools can be further leveraged to create short videos to clearly communicate the intent as well as the context of proposed designs, allowing viewers to quickly recognize key locations and understand multiple layers of information. And by embedding videos into online surveys, participants can engage in a dynamic online experience—one that is more likely to retain their attention and attract input (Figure 3.12).

The Alton Great Streets project, located in the St. Louis region, employed these tools for a virtual public workshop

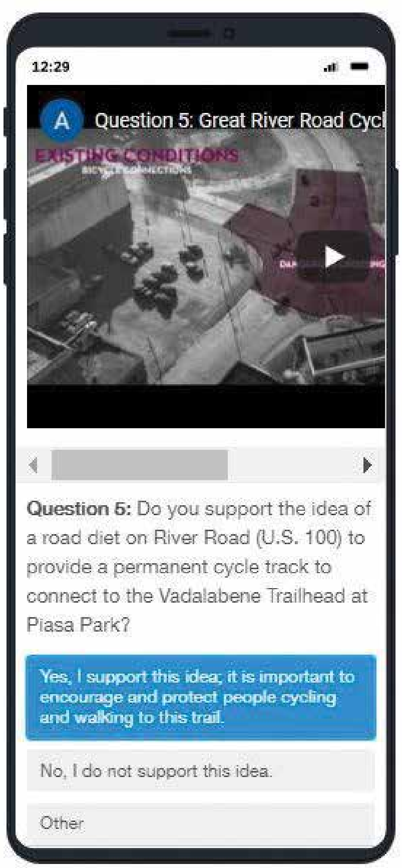

Figure 3.12. Smartphone capture of video imagery incorporated into an online survey (Design Workshop)

Figure 3.13. YouTube captures of imagery used in the Alton Great Streets public engagement process (Design Workshop)

during COVID-19. Throughout the design process, photogrammetric topography along with bird's-eye imagery captured by drones was used to build 3-D models and quickly iterate and visualize alternative plans. By combining drone imagery and 3-D models with time-based media, the team was able to clearly represent the complex relationships of the proposed plan concepts (Figure 3.13, p. 38). Participants in the process thought the videos clearly and seamlessly conveyed the ideas. One participant noted, "The videos were a great tool to assist in making an informed decision."

While videos can be invaluable additions to project websites and surveys, they can also enhance the in-person meeting experience. By capturing complex planning and design ideas and alternatives in concise videos, planners can streamline presentations, leaving more time to engage with stakeholders, cycle ideas, and build partnerships—enabling more two-way and collaborative communication to occur.

Community engagement tools are intended to facilitate recommendations that best serve a community. Drone imagery and video can make input methods more engaging, tactile, entertaining, accessible, and comprehensible. These methods result in better participation and ultimately, more likely plan and project implementation.

PLANNING-ADJACENT UAS APPLICATIONS

Planning is a collaborative process, and planners interact with numerous professions and organizations. Many other agencies and private-sector firms use drones in ways that are complementary to planning applications. The following are a few of these planning-adjacent uses.

Emergency Management

The ability to save lives is a compelling reason for agencies to adopt UAS technology. There is a long list of key functions for drones in emergency management.

- **Emergency reconnaissance and response:** This function will typically be managed by first responders such as fire, police, and paramedics. However, in large-scale disasters, planners with drone expertise will also be needed to meet the demands for this service.
- **Emergency payloads:** Midsize drones can carry one or two pounds of emergency supplies, and this delivery approach may be vital in some disaster scenarios.
- **Communications:** In addition to delivering walkie-talkies or cell phones, drones can also provide direct communication through speakers and microphones.
- **Search and rescue:** Drones can search for victims in remote areas or hazardous sites more safely and efficiently than ground search teams. In addition, drones equipped with thermal imaging cameras can locate persons at night through their heat signatures.
- **Structural damage and risk analysis:** After a disaster, affected structures and properties pose potential health and safety threats. Drones can safely assess damaged areas and structures.
- **Accident/criminal investigation:** For accidents and criminal acts, drones can provide valuable documentation and evidence.
- **Logistics support:** In many post-disaster situations, there is a need to coordinate equipment and materials for emergency services and recovery. Drones can play a key role in identifying safe evacuation and delivery routes, sites for shelter and helicopter delivery, materials inventory, and more.
- **FEMA/insurance documentation:** Documentation showing damage to property is critical for disaster victims, and drones provide excellent imagery of land and structural impacts.
- **Disaster mapping:** As already noted, drones can easily be used to create GIS maps for mapping disaster sites to aid in recovery.

Figure 3.14. UAS thermal and multispectral imagery of city trees showing their relative health (Ric Stephens; website screen capture courtesy of DroneDeploy)

- **Disaster recovery/regeneration**: In addition to GIS mapping for recovery, drones provide a wide range of recovery and regeneration functions, as noted above.

These applications will typically be managed by FEMA or local emergency management organizations, but planners will be active in assisting in these efforts. Planners who have become certified remote pilots may also be essential to conducting each of these functions.

Code Enforcement and Environmental Protection

Drones can be used to assess rear- and side-yard violations, obstructions and unpermitted buildings, and many other types of code violations. Aerial images can be obtained to inform code enforcement staff and inspectors of unpermitted development, environmental impacts, multipollutant point sources, and more. Follow-up aerial imagery can document development removal or modification, environmental impact mitigation compliance, and other types of remediation. However, as discussed further in Chapter 5, there are many potential legal ramifications to using drones to inspect private property, so careful consultation with legal counsel is critical if a local government wishes to explore UAS for these uses.

Environmental Assessment

Drones provide several specialized technologies for environmental assessment. They can be equipped with multispectral and thermal imagery cameras, as well as a variety of other sensors. Some of the environmental assessment functions these sensors can provide include the following:

- acoustical metering to locate and monitor noise pollution
- air, soil, and water pollution detection and monitoring
- invasive species monitoring and control
- radiation detection, monitoring, and response
- thermal energy heat loss studies
- thermal pollution
- vegetation classification and health assessment
- wildlife inventory, tracking, and protection

For example, with an optical camera and a thermal imaging sensor a drone can map city trees and show their relative health. In Figure 3.14, healthy trees are shown as green,

Figure 3.15. UAS documentation of infrastructure conditions at the otherwise inaccessible base of a hydroelectric dam (Maser Consulting)

while areas stressed by drought, overwatering, or pests are visualized as red-orange for contrast. The relatively low cost of UAS mapping also allows for multiple operations to provide analyses over varying and more frequent time periods.

Infrastructure Inspection

Using drones to inspect infrastructure is more efficient, accurate, and safer than exposing personnel to hazardous environments or conducting helicopter operations in adverse conditions. UAS are currently being used by local, state, and regional government agencies as well as contract services to inspect bridges, towers, railways, and many other facilities for structural integrity, post-disaster impacts, and other measurements.

Bridge and overpass inspections may require travel lane closures—which negatively impact traffic flow—to accommodate the "snooper trucks" and other equipment needed to allow personnel to inspect the undersides of these structures, or may require personnel to climb tall structures to visually check for structural integrity. Drones can help provide these services more quickly, efficiently, and accurately, and with no safety risks.

Drones can also be used to assess infrastructure in places where people cannot safely or easily go. Figure 3.15 shows UAS imagery of the base of a hydroelectric dam for which the water was temporarily lowered for inspection, revealing possible damage and structural concerns; boats and helicopters were not options for accessing this location.

Surveying

UAS provide an effective and efficient alternative to ground and light aircraft surveys. They are capable of surveying challenging terrain and provide highly accurate measurements with a high degree of operational flexibility. It should be noted that using drones for aerial surveying requires professional engineering and surveying licenses.

The most common survey applications for UAS are site condition documentation, topographic mapping, tree count surveys, volumetric evaluations, and as-built or reality modeling. Drones can also supplement traditional ground surveying in areas that are dangerous or hard to reach for ground survey crews.

UAS APPLICATIONS FOR DIFFERENT PLANNING CONTEXTS

Drones are efficient and effective tools for planners in a wide range of contexts, from small to large jurisdictions, rural to urban areas, and public or private sectors. All planners can use drones to supplement their data collection efforts in ways that specifically target their needs, in contrast to relying on open-source datasets that might be out of date or incomplete. Doing this results in better data-based, more cost-effective planning.

Using drones in urban areas raises certain challenges. FAA rules prohibit the use of UAS over people without specific authorizations and waivers. In populous urban areas, drones can be a distraction or trigger concerns over privacy. In heavily urbanized areas, skyscrapers and tall buildings can obscure GPS signals, causing UAS failsafe features and autonomous flights to be unreliable. Wind shear can also be magnified in urban areas. These are all obstacles that can be overcome, however, with proper mission planning, understanding of UAS capabilities and equipment limitations, training of personnel, and appropriate risk mitigation procedures. Drones are valuable tools—but as with all tools, they should be used in appropriate cases where they add value or increase safety, not in contexts that increase liability and risk with little to no value added.

As noted above, UAS are particularly useful for data collection in difficult or hazardous terrain, allowing operators to minimize risk to personnel on the ground and ensure accurate and reliable data collection of those areas. Tidal zones are a particular area for which the speed at which UAS can acquire data provides significant benefit, allowing rapid collection of information during low tide.

Planners working in small jurisdictions are often tasked with a wide array of public services and limited budgets. A multifunctional drone is an efficient and cost-effective tool that provides a wide range of planning and other related applications, assisting planners with numerous tasks including those not anticipated at the time of purchase. Examples could include photographing public events, teaching planning to schoolchildren, creating a 3-D model of a local structure, and even finding a lost pet.

Although having another person as a visual observer is ideal, drone operations can be conducted by a single remote pilot, making this technology accessible to local government agencies with a single planner who has passed the FAA remote pilot test (see Chapter 4 for information on staffing a UAS program and Chapter 5 for further discussion of FAA certification requirements). For small jurisdictions with limited budgets, drones provide many of the services provided by helicopters and light aircraft at a fraction of the cost, with no risk to pilot safety and reduced noise and safety impacts to residents in the vicinity.

For larger jurisdictions, individual departments or agencies can use different types of drones with specific features and programming. For example, the planning department may use multirotor drones for general planning purposes and fixed-wing drones for mapping and GIS data collection, while the public works department may use multirotor drones for infrastructure inspection and fixed-wing drones for road and utility assessment. Drones are a good tool to be used when accurate data is needed from hard-to-reach areas, or when the amount of data needed could overwhelm a small team using traditional methods.

The private sector has been quick to realize the multiple applications available. Private-sector consulting firms that receive planning tasks on short notice can use drones to quickly collect data and analyze it in ways that otherwise would require outside resources beyond their control. Using UAS to create and control data gives planning consultants the ability to start planning and assessment phases earlier in a project life cycle.

CONCLUSION

This chapter offers planners an overview of the many ways UAS can be used to augment planning functions. With rapidly evolving UAS technology, current drone applications will become commonplace, and new applications will expand planning services further in the future. Drones that were acquired for site analysis may be also used to provide viewshed analyses, parking inventories, and other products. Multispectral, infrared, 3-D modeling, and other functions may be combined in new ways to understand the natural and built environment.

Now that planners are more familiar with the many uses of drones, it's time to talk about how they can get started on implementing UAS operations for their jurisdictions or companies—the subject of the next chapter.

CHAPTER 4

IMPLEMENTING UAS OPERATIONS

As explored in the previous chapter, drones can provide effective and cost-effective support for a wide range of planning functions and different planning contexts. But despite the benefits of using uncrewed aircraft systems (UAS), the public sector has been relatively slow to adopt this technology.

Many factors contribute to this. Concerns over safety, liability, and public relations can challenge local governments' appetites to adopt potentially controversial UAS technology. Program costs, including those for equipment and training, can add up. And for effective use of UAS, planners must carefully consider such administrative elements such as federal and state regulatory compliance, data management protocols, operational policies and procedures, and interagency coordination.

The many different factors involved in setting up an in-house program may seem formidable. This simply means, however, that planners must carefully consider the best way to move forward with drone implementation. Once agency needs and program components are considered, planners may find it is easier to establish a basic UAS program than they initially thought. The sidebar on pp. 46–47 offers the perspective of one practitioner on the experience of setting up an in-house drone program for a consulting firm.

The main question for planners will be whether to hire drone services or whether to pursue an in-house approach of adding drone functions to planning department or company operations. This chapter examines what questions planners should consider when deciding how to implement drone usage, and it explores the various considerations involved in hiring a drone contractor or building in-house drone capacity.

IN-HOUSE OR CONSULTANT?

As noted above, the primary question a planner or planning agency is faced with when considering the use of drones is whether to establish an in-house UAS program or contract the work out to vendors and consultants.

The key to answering this question is carefully considering what services or deliverables are needed, when they are needed by, and what the direct benefits and risks of conducting this work in-house versus using an outside consultant might be. A UAS program requires UAS equipment; how much budget is available for purchasing a uncrewed aerial vehicle (UAV) and associated sensors and software? Staffing considerations are also important: who will conduct flight operations for an in-house program? The UAS operator will need to have familiarity with UAS equipment and operations, a certain level of technical expertise, and FAA certification, which translates into training requirements on top of the time needed to pilot UAS missions. For some agencies, especially those that are small, the time commitment necessary for UAS operations will have a direct opportunity cost on the other projects and duties of those individuals designated as UAS pilots or flight crew.

One way to explore UAS use is to start by hiring a consultant for a pilot project or a limited scope of services. In working with a consultant, planners can learn more about what is involved in UAS operations and get direct experience of what capabilities and deliverables a drone can bring to their work without a substantial investment in equipment, staff time, or training.

For those agencies or firms that have decided to integrate UAS into their planning work, a hybrid model in which some UAS work is done in-house and some is contracted out is generally preferred. This allows a municipality or private firm to handle quick jobs internally with minimal investment, which often results in a quick return on that investment, while contracting out more complicated projects that could require significantly more expensive or specialized equipment.

GETTING STARTED WITH UAS IN PLANNING AND DESIGN

Emily McCoy, Design Workshop, Inc.

Drones are quickly becoming a critical tool in the designer and planner toolbox. Although using UAS for professional survey-quality data requires a high level of investment in resources and time, this technology can be a valuable tool to map existing conditions and produce compelling photographs and video for planning and design projects. The thought of executing a UAS program in your practice can be daunting, but with a few pointers and discussion of lessons learned, implementing a UAS program can be straightforward and relatively inexpensive.

There are four main components in implementing a successful UAS program: (1) the drone itself, (2) software to process the UAS imagery, (3) a pilot licensed by the Federal Aviation Administration (FAA) for commercial use of a UAS under Part 107 rules, and (4) insurance.

Drones are increasingly becoming less expensive and more sophisticated. UAS can range in cost from $500 to $50,000; however, a powerful drone with a high-quality camera can be purchased for around $1,500. A high-grade yet moderately priced drone will have good stability; a high-performance camera with video features such as active tracking, where the camera can follow objects and people; and a sturdy build. Extra features such as obstacle avoidance sensors and long-range data transmission are worth the extra costs.

Regardless of UAS quality and cost, batteries only last for around 20 to 30 minutes. Have at least three batteries along with a sturdy, waterproof carrying case, and use a car charger to charge batteries while you fly to extend your time in the field. Many drones can be controlled with a controller that links to a smart phone or tablet. The only downside of using these devices is sun glare, but you can purchase shields to use on sunny days. Don't forget a portable landing pad to protect propellers from materials like grass and stone during takeoff and landing. Lastly, all drones must be registered and labeled with their registration number through the FAA for a very small fee (currently $5).

To transform drone imagery into 2-D and 3-D mapping and models through photogrammetry, a third-party software is usually required. These software agreements are usually subscription based and range in cost from $50 to $300 per month. There are add-ons for GIS as well. These software platforms are critical for efficiently processing data and maximizing the capabilities for your drone. They can perform such functions as planning autonomous flights with assistance on flight times and batteries needed, processing data into elevation imagery and point-cloud models, and performing analysis such as cut and fill calculations and assessing plant health.

Most importantly, a drone program requires a FAA-certified drone pilot (Figure 4.1). To become a licensed Remote Pilot in Command (RPIC) for commercial operations, you need to meet the minimum qualifications and pass a knowledge test. Many resources are available to help you prepare for the exam. (More information on RPIC testing requirements and exam preparation is provided in Chapter 5.)

Once you pass the exam, you are issued a temporary license within seven to 14 days and a permanent license will be mailed to you within a month or so. You must renew your license by taking a renewal test every two years. Although the testing requirements may sound cumbersome, they are critical to ensure that

Figure 4.1. The drone flight crew: a Remote Pilot in Command and field technician (Design Workshop)

drone operators understand how to fly safely and in accordance with the rules. Aside from testing, it takes several flights to become a skilled drone pilot. Start small and always be extra cautious. If you are motivated, you can go from studying to flying as an RPIC as little as one month.

Be aware that as a new pilot it may take time for you to establish best practices for flight missions before you have high-quality imagery for use on projects. Because of limited battery power, flights are most efficient when they are carefully planned. Time of day and weather conditions are critical to beautiful high-resolution imagery. For orthophotographs, capture imagery when the sun is directly above to avoid shadows, and fly during the traditional "golden hours" after sunrise and before sunset for other imagery.

Apps such as the FAA's B4UFly (www.faa.gov/uas/recreational_fliers/where_can_i_fly/b4ufly) are essential for safe operations so that you can quickly assess whether or not you are in controlled airspace or if there are any other special conditions that may prevent safe flying. Recently these apps have integrated rapid procedures for asking for and being granted access to controlled airspace—a major improvement from the usual process for clearance, which can take days or months.

Once you have completed your flight mission, you will download data from your drone or its memory card to process the data and imagery. This is a relatively fast process. Data upload can take 10 to 15 minutes, and the third-party software can take anywhere from 30 minutes to several hours to process the data, depending on how much data you have and at what resolution you want it exported.

Once processed, the data and imagery can be fine-tuned in an infinite amount of ways, such as creating video or using the imagery as bases for diagrams, depending on the purpose of your project imagery. Drone imagery can easily be exported to programs such as AutoCAD, Revit, Rhino, Sketchup, Photoshop, InDesign, Illustrator, After Effects, and GIS, among others.

Finally, insurance is a must-have. Before you purchase extra insurance, which you can do relatively inexpensively on a flight-by-flight basis, check with your current insurance provider to see if you are already covered for any damage your drone may do to personal property or people should it crash. New pilots should opt for the drone replacement insurance offered with drone purchase. This will cover replacement costs if you crash your drone.

UAS offers practitioners another option in the Swiss army knife of design and planning tools that maximizes efficiency and creativity in the planning and design process. With motivation and a few thousand dollars of start-up costs, a drone program can easily be implemented in your practice. Remember that drone mapping cannot replace survey-quality information and mapping unless you have a professional drone mounted with sensors such as Lidar. For basic existing conditions analysis and high-quality imagery, however, drones offer a compelling way to tell stories of people and places from new perspectives.

CONTRACTING WITH A UAS CONSULTANT

For smaller agencies and agencies which may infrequently need UAS services, contracting with the private sector is a viable option. As noted, contracting with a UAS consultant is also a way for agencies to test the waters of drone use without committing to significant investments.

As an initial step, it is vital for an agency to put policies and vendor requirements for drones into place to ensure that UAS work will be of high quality and that liability is managed at the appropriate levels. This is a very new and dynamic field, and the range of experience and expertise varies dramatically among UAS firms and pilots.

In addition, state and local regulations for UAS use vary widely from place to place, and the implications of this cannot be overstated. For example, the state of North Carolina requires that aerial mapping be done under the direct supervision of a licensed surveyor, while other states have different laws defining professional responsibility and liabilities. Hiring a UAS consultant without a full understanding of local legal, regulatory, and operational requirements on the part of both the agency and the consultant could have serious consequences.

Agency Considerations

There are several key factors to consider when vetting a UAS contractor. The first thing to look for is that the firm is properly insured. UAS use has potential risk. Although drones are typically small and light, they have a high damage potential if they fall from the sky. The lithium-polymer batteries that power them are highly volatile and can combust in a high-impact crash. Additionally, fast-spinning motors and sharp propellers create a safety hazard for nearby persons.

As drone technology and accessibility has rapidly evolved, so has the insurance industry. Aviation insurance for UAS has become a niche market that tailors coverages specific to drone use, offering legal liability (personal injury, property damage, medical expenses, premises liability, etc.) and physical damage protection to the UAS system itself.

In the event of a crash, the cost of damage can exceed what the firm is capable of paying out of pocket. This is why liability insurance is imperative. The amount of coverage needed will vary based on the areas over which the drones will be flying (e.g., flight over or near critical infrastructure such as power lines will require higher coverage, while flying over an empty field will require less). Planners should work with their agency's risk management staff or legal counsel to determine what level of liability coverage is appropriate.

Another factor to research is the consultant's experience. Metrics a planner can use to gauge experience include the following:

- Total number of flights
- Total flight time
- How long the company has provided UAS services
- Additional ratings (e.g., general aviation licenses, specific risk management or safety training, surveying licenses)

A company with more experience is more likely to perform tasks properly and safely than a company with less. However, a more experienced company may charge more for their services than a less experienced firm. Planners should consider the scope of their needs and select a company with enough experience to get the job done safely and effectively.

UAS contractors may offer broad services or specialize in particular sectors. For example, one company may concentrate on providing aerial footage for architectural clients to be used for marketing purposes, another may cater to construction inspection services, and another may concentrate on the surveying and photogrammetry sectors. This level of specialization is more common in larger urban markets with a higher number of UAS companies, more competition, and higher availability of potential clients and contracts. Smaller markets often require UAS contractors to offer a wider range of services. Planners must have a comprehensive conversation with any potential UAS firm about their capabilities to ensure they line up with the agency's needs.

It is also important to make sure the company has the correct equipment and knowledge to provide the data required. UAS are most often used to carry optical payloads (i.e., photo and video cameras), but in the event a less common type of data must be collected, the firm will need to have the appropriate equipment.

UAS consultants typically offer post-production services to aid in the planning and public engagement process, such as photo and video editing, marketing and graphic design, photomontage production, or 3-D modeling and rendering. Many smaller agencies may not have the capability to provide these services in-house.

Additionally, planners need to ensure the data the consultant will deliver will be of a high-enough quality for the required purpose. For photos, features like megapixel count, resolution, and sensor size will determine the quality of the collected data. On the other hand, bigger data is not always better. Remember that any data collected for an agency will also need to be managed and stored. Extremely high-resolution aerial images will require exceedingly large data storage capacities, so planners should determine the appropriate level of data collection required for the project or program.

Finally, the professional experience of the operator will also directly impact the types and validity of the data being collected. Requirements for different types of data collection (e.g., for surveys) vary by state and are generally covered by state professional license boards for professional surveyors and engineers.

Writing an RFP

It is a universal truth that an RFP for professional services is only as good as the thought put into it. The more clearly the scope is defined, the better the companies proposing services can target and cost the project, as well as identify the right tools to bring to the table.

An RFP for UAS services should always include the following:

- Specific data or deliverables required
- Intent of the data or deliverables
- Accuracy requirements (if required)
- Task schedule
- Budget
- Data management requirements
- Required consultant experience
- Professional licensure required for data or deliverable certification (if applicable)

When scoping a project, planners should also think about additional potential uses for—or users of—the data. What other entities within a municipality or organization might have an interest in the project or data to be collected? For example, if the planning department is starting a planning project to freshen up a vital downtown area and is seeking basic drone imagery to capture the area as-is, might the public works or transportation departments, permitting office, or public affairs office have uses for this same or similar data? Expanding the scope of an RFP beyond a single project or data collection event to meet the needs of multiple actors might require very little additional effort or cost on the part of the vendor and deliver a larger cost savings to the municipality or organization.

If an agency is confident in a UAS contractor's quality of services, considering an RFP as a "recurring services contract" for all drone-related services within a given period of time may increase logistical efficiency for the client and contractor, rather than crafting a separate RFP for each project.

Selecting a Consultant

When selecting UAS firms, the agency should look for a detailed proposal demonstrating that a firm matches its needs and meets its requirements. Agencies should consider the following criteria, as well as other factors appropriate to the service required:

- **FAA certification:** Does the consultant meet the minimum federal requirements and hold the remote pilot certifications needed to operate drones commercially?
- **Federal and state regulatory compliance:** Does the consultant comply with all federal regulations, as well as additional requirements specific to your state?
- **Air traffic control approval, if required:** Some areas near airports, military installations, and other key areas require special waivers or authorizations to conduct UAS operations.
- **FAA waiver(s), if required:** Special FAA waivers might be required for UAS operations, depending on the time of day and weather conditions, as well as the weight of the aircraft.
- **LAANC approval, if appropriate:** This is a rapid way of getting certain airspace clearances if needed. See the sidebar on p. 50 for more information on this program.
- **Appropriate equipment for the contracted task(s):** Make sure the consultant has the right sensors, software, and UAV for the services you are seeking.
- **Appropriate technical qualifications for the contracted task(s):** Again, if the consultant will be providing mapping, survey, or engineering documents, are they appropriately licensed for your geographical region?
- **Statement of lost link and other emergency procedures:** Does the consultant have a standard operating procedure (SOP) and a safety management system? SOPs and safety procedures are discussed in further detail later in this chapter.
- **Verified insurance coverage by the operator and agency:** Work with agency risk management personnel to establish an appropriate minimum insurance requirement. Some vendors use on-demand insurance and pay as they go; this is generally a sign they are not a consistent provider. Higher limits of liability may suggest that the consultant has more experience, as higher liability limits are required for higher-risk projects, such as those involving utilities or critical infrastructure.

The agency legal counsel should prepare the contract with these and any other items specific to the UAS operation.

LAANC

To ensure air traffic safety, drone flights in the United States are prohibited within five miles of airports (Class B, C, D, and E controlled airspace) unless approved by the FAA. The Low Altitude Authorization and Notification Capability (LAANC, pronounced "lance") program is an online, automated application and approval system for drone pilots requesting to fly in controlled airspace.

FAA-certified remote pilots may access the LAANC website and complete an online form requesting a waiver to fly within controlled airspace at a specific location, altitude, and time. The request is only for an airspace waiver; all other flight regulations remain in effect. The algorithm analyzes the drone flight information, airport traffic pattern, and other airspace data sources. If there are no potential conflicts, the waiver is granted immediately.

Pilots wishing to fly drones within controlled airspace not covered by LAANC must apply for a waiver directly to the FAA. This manual process may take up to 90 days for an approval or denial.

As of this writing, more than 700 airports and 500 facilities are within the LAANC system, covering more than 80 percent of eligible airspace. A current listing of LAANC-compatible airports is available online at www.faa.gov/uas/programs_partnerships/data_exchange/laanc_facilities.

It is vital to do your homework when selecting a consultant. Even though a third party will be operating the UAS, the planner or agency is still ultimately responsible for liability risks, project timelines, and final deliverables. Choosing the wrong consultant is like hiring the wrong employee: there will be lost time, lost money, and lost confidence in the projects that they are working on.

As a relatively new industry with services that may vary widely, the general market rate of fees and rates of UAS contractors may also vary widely. Factors that will affect fees may include the type of service provided (e.g., photography, videography, photogrammetry, Lidar), the complexity and size or acreage of the project site, the distance of the project site from the firm's office, the metro area in which the services are provided, and the duration of the project timeline. Obtaining a handful of aerial still photos of a one-acre site may only require a fee of a few hundred dollars, while documentation of a large and long-range regional planning study over a six-month timeframe with both photography and video requirements may incur fees that are significantly higher.

Working with a Consultant

When working with a UAS consultant, transparency and clear scope guidelines are critical. Not only will this encourage feedback and improve the process, it will allow the exchange of ideas and solutions to accomplish the given tasks with more efficiency and better understanding.

Transparency on a project is critical so the consultant can bring the appropriate tools, help provide alternative solutions if needed, and use their expertise to streamline the workflow. Clear, open, and ongoing communication allows for both parties to be involved in continuous process improvement and minimizes the chance that vital deadlines are missed or that unneeded time or resources are being expended that do not lead to the end goal.

Developing a detailed project scope and ensuring a clear understanding of both parties of the deliverables from the onset are the most critical components of successfully working with a consultant. This helps to manage expectations on both sides and clearly defines the outcomes that are anticipated. Poorly written scopes and misunderstandings about project deliverables are leading causes of friction, change orders, and increased costs. A detailed scope of services that outlines the anticipated procedures, project information, personnel involved, and final deliverables is important. Furthermore, the scope should also provide for any items that are excluded or considered "additional services" beyond the agreed-upon scope of work. For example, travel expenses and mileage may be included in the lump sum or hourly fees, or they may be considered additional or reimbursable expenses beyond the base scope of work.

Quantifying the anticipated deliverables can also reduce the need for change orders. For example, deliverables for a downtown streetscape study for a 1.5-mile stretch of roadway might comprise 30–40 preliminary photos, taken from approximately 200 feet above ground level (AGL) elevation, for initial review; 15–20 final edited photos; and a minimum of two minutes of edited flyover video at approximately 300 feet AGL elevation in both directions along the streetscape during high-volume daytime traffic hours. Proactively defining detailed parameters within the scope of work will protect both the agency and contractor and minimize future change orders.

DEVELOPING AN IN-HOUSE UAS PROGRAM

After considering the possible benefits that UAS capabilities offer, a planning department, agency, organization, or municipality may decide that it wants to establish an in-house UAS program. The rest of this chapter provides planners with some guidance on the different elements of UAS programs and considerations in their establishment.

In preparation for future UAS development, agencies may wish to start with a simple program using an inexpensive UAV. Public education and involvement can be important in building local acceptance of and enthusiasm for drone use. Early successes can help build the case for additional resources to further expand UAS operations. At all stages, planners and agencies should work to develop a UAS program that allows for growth and flexibility.

Plan and Program Structure

A good place to start when exploring the establishment of an in-house UAS program is to conduct a needs assessment for the department or organization. What value can a UAS bring to the agency's mission and functions? What routine tasks could a UAS do more quickly, efficiently, or cost-effectively? What new opportunities might a UAS offer to expand an agency's practice or improve its outputs? What fiscal, technical, and human resources might already exist within the organization to support UAS operations?

Planners should be sure to look beyond the planning department when working through this exercise. What other departments or staff might find value in UAS operations, and what opportunities exist for cross-departmental collaboration and resource pooling? For example, public works may be interested in using drones for project management and transportation may want to use them for traffic studies. In some communities, especially larger jurisdictions, these conversations may already have started in other departments.

Identifying the right people to manage the UAS program, consistently evaluating and documenting its effectiveness, and preparing updates for program stakeholders is important. Some government agencies have high turnover rates, and if the staff person selected to be the UAS program manager leaves, this can be a significant setback requiring a program reset. Establishing redundancy among personnel to ensure a program is not directly reliant on one or two individuals is an important component of program success and longevity.

If a local government wants to develop (or has already established) more than one UAS program, these programs should be under a single umbrella of standardized policies and procedures. This will result in safer, more economic, more efficient, and better-coordinated operations. Creating an interdepartmental UAS team that consists of department representatives and all agency remote pilots will help standardize operating procedures, equipment, and training. A central location should be established for the management of technology, operations, and regulatory concerns. Some local governments have housed UAS programs within the GIS department as a centralized location for multiple government programs and functions, as described in the sidebar on p. 52.

As is the case when hiring UAS consulting services, appropriate risk management and liability coverage is critical in establishing an in-house UAS program. Municipal or organizational insurance policies should be amended to reflect coverage for UAS operations. Virtually all national insurance carriers have liability policies that address drones.

Budget

There are several primary costs to consider for a UAS program. These are relatively easy to quantify if the agency has a clear direction on the applications and services needed. Agency budgets for UAS will vary greatly depending on several different factors, including geographic size of the jurisdiction, environmental and topographic diversity of the jurisdiction, the scope of services that will be performed, and the frequency of required flights. Larger and more diverse jurisdictions, more applications, and more frequent flights will require larger budgets.

The primary costs associated with UAS operations fall into two categories: technology and staffing. Agencies will need to purchase equipment, including the UAV itself and its remote control, batteries, accessories, and case. Different pay-

UAS AND GIS

Alice Pence, GIS Analyst III, Port of Portland

You've completed your first UAS mission successfully and now have all sorts of exciting data. Now what?

Today, the functions of spatial analysis and planning intertwine so much that the roles of planners and GIS professionals often overlap. This is helpful when it comes to using the data from a drone mission for a planning project, whether that be a 3-D-model fly-through of a proposed downtown design with new buildings and road network or an analysis of elevation and vegetation change within an environmental mitigation area. Planners have the knowledge and expertise to understand the changes coming to a city or the potential impacts of a project or plan, and GIS analysts have the tools and skills to be able to bring it all together.

As a GIS professional I have worked in agencies that implemented UAS operations with the GIS department as the main contact point of mission planning and data management. Team members were drawn from other departments, including planning, engineering, environmental and natural resources, public relations, and human resources. This diverse, interdisciplinary approach to a UAS program broadened the scope of projects and helped implement the program throughout the organization. A GIS department can be a good home for a UAS program because it also hosts the analysis tools and data management applications that can store and retain project raw data and outputs.

UAS projects can bring substantial value to an agency and benefit not only planners but also other stakeholders who also needed that information and never realized the opportunities that drone data can provide. When working for a smaller municipal government, I was approached by the environmental department to help with an environmental monitoring project in one of the city's local environmental mitigation parks. The 250-acre park needed to be visually inspected for flooded areas caused by beaver dams, invasive species outbreaks, and new channelizations of the creek. Using a drone, we were able to divide the park area into different mission areas and in only three days had taken aerial imagery of the entire area.

After the flights, using a combination of GIS tools, including Pix4D and ArcMap, the environmental team now had access to current, high-resolution imagery of the park; digital elevation models with contours to show elevation change; and vegetation indexes that could show differences in trees and other vegetation types. It took about a week for the team to analyze this data, find the locations that needed attention, and send crews directly to those spots—instead of the three to four weeks of full eight-hour days that would have otherwise been required to survey the entire area to find the few places that needed remediation. And because this mission used an automated flight pattern, it could be easily repeated in in different seasons and by different drone operators.

By combining the forces of the GIS department, the surveyors, the planners, and the environmental team, we were able to use drones to take a task that could have taken well over several months to complete and provide all the information needed in about a week. And having an in-house UAS program saved the costs of outsourcing the drone flight and the data analysis.

Planners should be sure to reach out to GIS staff early and often if they are thinking of using drones or need help with analysis of drone aerial imagery and data. GIS professionals have a wealth of spatial data knowledge and skills—and they also have the connections to assist in finding any additional tools or other support required to provide the results that planners need.

loads and sensors (e.g., cameras, different spectrum detectors) will be required based on the agency's program. Budgets should also consider ongoing maintenance costs and anticipate equipment repairs or modifications. Software to process data (e.g., GIS mapping) and data services costs must also be considered. Data storage often represents an unexpected cost, as the size of data drones can collect dwarfs traditional methods, and agencies' abilities to store, access, and manage multiple types of data can range greatly.

In terms of human resources, the agency will need at least one UAS pilot, who must be certified as described in Chapter 5, and ideally another flight crew member, such as a visual observer or a field technician. Depending on the agency's UAS program, additional technical office staff, such as a GIS mapping professional, may also be required. Time costs of staff spent flying drone missions and processing data should be considered, as well as costs of initial and ongoing training. Staffing is covered in more detail below.

Equipment

There are more than 500 commercially available drones on the market today, and the number will increase geometrically with the advent of standardized operating systems, 3-D printing, and hybridization.

Different agencies may require specific UAV characteristics, such as the ability to land on water. Table 4.1 (p. 54) offers a list of key features for consideration. Drone prices reflect the quality and number of these features, with the most critical being the UAV size (and resulting payload capability), sensors (camera, Lidar, etc.), and software (programmability, sense and avoid, etc.).

A recommended approach to choosing the right equipment is to start with the desired end results and move backward. Consider the intent of the UAS program, the deliverables envisioned as product outcomes, and the software that will be used for these. Based on that information, identify the sensors capable of producing the intended results. Then, look at what UAVs other agencies or UAS companies are using to do similar projects, keeping in mind costs, maintenance, and reliability—and budget. This will help narrow the field to a few selections to choose from.

Agencies should purchase equipment specific to the key tasks identified in the program. As noted in Chapter 2, UAS technology is evolving so rapidly that equipment may become quickly outdated. It can be a difficult decision for a small agency to purchase equipment knowing that it may be significantly devalued and behind the technology curve within a year. The rapid pace of advances, however, also results in continuous price decreases for equipment as it becomes less current. As much of this evolution involves the addition of new technologies or capabilities, last year's UAV model may still be perfectly capable of meeting the basic needs of a planning department's UAS program. The initial needs assessment should have addressed the agency's current needs and anticipated near-term needs, so keep this in mind as you look for the technology needed to accomplish these tasks.

Agencies should purchase equipment that is widely and typically used for the applications their programs will entail. Automation capabilities, payload capacities appropriate for required sensors, and future manufacturer support are more important than a "premium" version of a standard product. Agencies should look for UAV platforms with the largest flexibility for multiple functions and programming.

It is also important to consider the long-term growth of the UAS program. Review program return on investment to develop timelines for considering the upgrading of equipment. Expanding a UAS fleet with more UAVs and additional capabilities will be invaluable for a sustainable program moving into the future.

Equipment maintenance is important. Although drones have few moving parts, those parts are critical to safe flight. Staff must monitor the condition of the UAV's airframe, motors, propellers, and batteries, as well as mounts and sensors, and they must be replaced when damaged or fatigued. Agencies should keep logbooks and track each battery for its age and flight hours. Since each model will have different levels of durability, there is no general rule as to when to replace batteries and other parts; operators should consult equipment manuals, manufacturers' guidance, and even consultants' expertise to ensure they stay on top of maintenance needs.

A good maintenance practice is to routinely examine parts and cycle them out of service when they show signs of significant wear. For propellers, this will be major nicks, cracks, or scratches. For batteries, this will be swelling, visible external damage, or a noticeable decline in charge capacity. While it may be economical to keep these parts in service as long as possible, there is a higher risk of failure by using fatigued parts. When in doubt about a part, planners should lean on the safe side and replace it. The cost of a lost drone or damage to property or persons will be significantly more than the ongoing costs of basic maintenance.

Staff and Training

If agencies will be operating their own UAVs, they will need to have at least one in-house remote pilot. Having two certified operators on staff allows for alternation between the two to

TABLE 4.1. CONSIDERATIONS FOR DRONE SELECTION

Drone Characteristic	Commentary
Aquatic functionality	For coastal regions and areas with large bodies of water, a drone's ability to land on water can be important.
Camera resolution and interchangeability	The camera resolution and other features will be essential in the quality of photography and videography. If the agency is also interested in other sensors such as thermal imaging cameras, interchangeability is important.
Durability	Bad landings are a common occurrence, and fragile drones are prone to more severe damage when these happen.
Flight time	For many years, the maximum UAV flight time has been about 25 minutes, regardless of drone size or number of rotors. For large-scale UAS operations, a fixed-wing aircraft provides greater coverage as it can reach higher speeds.
Hover functionality	For many applications, the drone must be a multirotor so that it can hover. This is not possible with fixed-wing UAVs unless they have vertical take-off and landing (VTOL) capability. The ability to maintain a stable hover is also assisted by the drone's mass, with mini-drones being susceptible to instability in high winds.
Multifunctionality	In an ideal situation, a single drone could serve all agency needs by having a high level of programmability and interchangeable payloads. These UAS are naturally more expensive, and the agency should consider the cost/benefit ratio associated with more diverse and heavier payloads.
Payload options	Payload is the amount and weight of things a drone can carry. This may be cameras, sensors, packages for delivery/pickup, or anything else that is not associated with the UAS aeronautics.
Portability	If portability is desirable for fieldwork and transportation, a UAV should be selected that provides the optimum features with the most compact size and flight characteristics. Portability is often a tradeoff between convenience and payload.
Programmability	Some drones have extensive preprogrammed features and allow for additional programming. Others have limited programming and may not allow for user programming. Agencies at the least must ensure that the UAS can meet the flight and operational requirements for the desired applications, and ideally, the UAS will have the potential for new programming.
Sensors	The most common sensor is a camera capable of high-resolution still images (12 megapixel and greater) and videography (4K). Other common sensors are forward-looking infrared (FLIR) for thermal imaging, Lidar for laser measurement, and multispectral for environmental analysis. Each of these sensors can easily exceed the cost of the UAV itself.
Speed	As flight time is typically limited, speed can be essential for some UAS operations when large areas or distances are a factor.
Stability	As already noted, heavier drones tend to be more stable as their mass is more resistant to light to moderate winds. Some mini-copters can be relatively stable in moderate winds due to extremely responsive motors, but this may come with a reduction in flight time.
Weatherproofing	For UAS operations in high winds, high and low temperatures, rain, and snow, a weatherproof drone is essential. If these are constant operational conditions, a hexacopter or octocopter would be ideal as the greater number of rotors provides more reliability and safety.

Source: Ric Stephens

avoid burnout and adds a layer of redundancy, so there is a backup if one is out of commission or otherwise unavailable. If there is not that much work to be done, however, two pilots may be excessive. In high-risk flight environments or certain circumstances, drone operations may also require a visual observer to assist the pilot or additional personnel to manage interactions with the public.

UAS operators must be certified by the FAA. FAA certification under Part 107 is discussed in the next chapter. In addition, agency remote pilots must be competent in operating the UAS equipment and understanding the flight mission and operation objectives. They must be current (i.e., have a valid remote pilot certificate) and should be proficient (i.e., skilled in the required UAS operations).

To ensure their remote pilots have the necessary skills to be safe and responsible, agencies should require pilots to complete an initial agency-designed or approved training program and mandate continuous training for their UAS personnel. The training program should cover internal company policies that are not covered by the FAA regulations and incorporate some sort of practical flight test, as the FAA's Part 107 remote pilot exam does not require a flight test. The agency should establish minimum standards of performance for pre-flight operations, flight operations, and post-flight operations. Pilots should track demonstration of qualifications in a pilot log.

There are no official UAV training programs, but the Association for Unmanned Vehicle Systems International (www.auvsi.org) has a program to certify qualified pilots called the Trusted Operator Program (AUVSI n.d.). There are many private companies, universities and colleges, and special interest group programs that offer flight training. As there is currently no standards or accreditation system for these trainers, it can be difficult to distinguish between them. Reputation is important; reach out to other agencies, consultants, or other UAS experts and ask for recommendations based on their experiences. Planners should also be aware that there are many online resources available that UAS operators can use to help plan flight missions. Some of these are described in the sidebar on p. 56.

Operational Policies and Procedures

The combination of federal and state regulation on UAS can be complex and potentially conflicting. As will be described in Chapter 5, the federal laws governing national air space are clearly defined in 14 CFR Part 107. These, along with state laws, should form the foundation and framework to guide the agency's standard operating procedures (SOPs). In addition to regulatory compliance, UAS operations themselves can become extremely complex, so SOPs must be developed and defined in an operational manual to cover the spectrum of issues that can arise.

An SOP is a set of step-by-step instructions compiled by an organization to help UAS crews carry out complex routine operations. SOPs aim to achieve efficiency, quality output, and uniformity of performance, while reducing miscommunication and failure to comply with federal and state regulations. It is essential that public agencies—and strongly recommended that private firms—develop UAS SOPs that are compiled in a single document. The model operational manual presented in Appendix E offers a comprehensive example of an SOP, but each agency should evaluate its individual needs in preparing operational manuals that reflect all relevant regulations. The sidebar on p. 57 provides some state and local examples of UAS operations manuals and SOPs.

As noted throughout this report, safety is a key issue in drone use. Drones present a variety of potential safety hazards including collisions with other aircraft, structures, and persons; interference or disruption with critical infrastructure, including power plants, utility infrastructure, and airport operations; distractions to driving on highways and freeways; and criminal acts and terrorism. Drones should be treated as tools and aviation assets with strict policies and procedures for their use. Planning agencies can establish additional safety guidelines through an official safety code. See Appendix D for a model safety code.

Drone Countermeasures

Certain practices, known as drone countermeasures, act to track, limit, or halt drone usage and can compromise the safety of flight operations. These methods are being developed for law enforcement as a response to unlawful uses. There is a slim chance an operator will encounter any of these so long as their operations are legal, but it is helpful to know they exist. Drone countermeasures can be broken down into three categories: detection, disruption, and destruction.

Detection. As drones continue to be miniaturized, visually detecting them will become more problematic. Systems that detect, monitor, or track UAS often rely on radio frequency, radar, electro-optical, infrared, or acoustic capabilities, or a combination thereof. These capabilities detect the physical presence of UAS or signals sent to or from the UAS.

Disruption. Disruption techniques prevent the drone from properly functioning or being remotely controlled by the operator. "Jamming" is the technique of preventing the drone from communication with the operator or GPS

ONLINE UAS RESOURCES

A wide range of online resources that assist in operations planning is available for remote pilots. The following is a compilation of those that are frequently used by both public- and private-sector operators:

Airmap (www.airmap.com): This site offers a variety of airspace mapping tools and flight monitoring programs to help operators coordinate and scale drone operations in different airspace conditions.

B4UFLY (www.faa.gov/uas/recreational_fliers/where_can_i_fly/b4ufly): A partnership between the FAA and Kittyhawk, a drone operations software company, this mobile app offers interactive maps to help drone operators know where they can and cannot fly.

Dark Sky (https://darksky.net): This weather forecasting website provides detailed information to help with flight scheduling.

Drone Complier (www.dronecomplier.com): This service offers free and subscription rates for professional UAS services such as asset management and mission planning.

Drone Deploy (www.dronedeploy.com): This UAS subscription service offers software options targeted at different UAS functionalities.

Drone Insurance (www.droneinsurance.com): This firm offers drone operators the ability to purchase flight liability coverage for time periods ranging from one day to one year.

LiveATC.net (www.liveatc.net): This app enables operators to listen to local live air traffic and may be beneficial in monitoring operations in the vicinity of airports.

METAR & TAF Translator (www.iflightplanner.com/Resources/MetarTafTranslator.aspx): This interactive webpage allows users to provide weather data in meteorological terminal aviation routine (METAR) or terminal aerodrome forecast (TAF) formats to view color-coded, plain-language aviation weather reports.

SkyVector Aeronautical Charts (https://skyvector.com): SkyVector displays aeronautical chart mapping for the United States, airport information, and other resources for UAS flight planning.

Trimble GNSS Planning (www.gnssplanning.com/#/settings): This website provides satellite data useful in determining the optimal times for GPS connectivity in sites with challenging terrain.

UAS Data Exchange (LAANC) (www.faa.gov/uas/programs_partnerships/data_exchange): This FAA webpage provides information about the Low Altitude Authorization and Notification Capability (LAANC) program, which automates the application and approval process for airspace authorizations.

Wi-Fi Analyzer (https://play.google.com/store/apps/details?id=com.farproc.wifi.analyzer&hl=en_US): This app turns an Android phone into a wifi analyzer. UAS operators can use it to help prevent drone "fly-aways" caused by conflicting wifi channels.

Windy (www.windy.com): This weather website offers real-time wind data helpful for flight planning.

UAS OPERATIONS MANUALS

Planners do not have to reinvent the wheel when looking to develop an operations manual or SOP for UAS use. UAS operational manuals have been prepared by a number of federal, state, county, and municipal governments and agencies (Sawicki and Stephens 2018). Planners can review the examples provided below in addition to the model operations manual provided in Appendix D to get a better idea of what their SOPs should address.

Caroline County, Virginia, *Unmanned Aircraft System Operations Manual* (2019): www.vus.virginia.gov/media/governorvirginiagov/virginia-unmanned-systems/pdfs/sops/caroline/Caroline-County-Virginia-UAS-Operations-Manual-Jan-2019-ed.pdf

Connecticut Department of Transportation, *CTDOT Unmanned Aircraft Systems (UAS) Standard Operating Procedures* (2019): https://portal.ct.gov/-/media/DOT/documents/AEC/UAS/UAS_SOP_2019-04.pdf?la=en

Fairfax County, Virginia, *Program Manual, Unmanned Aircraft Systems (UAS)* (2019): www.fairfaxcounty.gov/uas/sites/uas/files/assets/documents/unmanned-aircraft-(uas)-draft-%20program-manual-%20(v3.1).pdf

Gaithersburg, Maryland, *Flight Operations Manual for Small Unmanned Aircraft Systems* (2018): www.gaithersburgmd.gov/Home/ShowDocument?id=4904

Hidalgo County, Texas, *Unmanned Aerial System (UAS) Program Policy* (2017): www.hidalgocounty.us/DocumentCenter/View/27908/UAS-Program-Policy?bidId=

Los Angeles Department of Public Works Bureau of Engineering, *Unmanned Aerial System (UAS) Flight Operations Manual* (2017): https://eng.lacity.org/sites/g/files/wph726/f/BOE%20UAS-Operations-Manual%20v1.6%20%20Final.pdf

Mountains Recreation and Conservation Authority, *Unmanned Aircraft Systems (UAS) Operations Manual* (2018): https://mrca.ca.gov/wp-content/uploads/2018/04/attachment4356_Attachment-.pdf

National Oceanic and Atmospheric Administration (NOAA), *Unmanned Aircraft Systems Operations* (2019): www.omao.noaa.gov/sites/default/files/documents/220-1-5%20UAS%20v7.0%20FINAL%205%20December%202019.pdf

Oregon Department of Transportation, *Unmanned Aircraft Systems (UAS) Operations Manual* (2017): https://digital.osl.state.or.us/islandora/object/osl:88796

Texas Department of Transportation, *Unmanned Aircraft System (UAS) Flight Operations and User's Manual* (2020): https://ftp.dot.state.tx.us/pub/txdot-info/avn/uas/user-manual.pdf

IT'S COMPLICATED . . . BUT NOT THAT COMPLICATED

The diversity of applications, inexpensive equipment and operating costs, and rapidly developing technology all combine to make drones an attractive and perhaps someday indispensable tool for planning. But if you feel there are too many unknowns, complexities, and obstacles in considering drone use, following these basic steps based on the rational planning model for developing and implementing a UAS program can help.

1. Identify what needs can be met and what opportunities can be realized with UAS.
2. Gather information on the following factors:
   a. Federal, state, and local laws and regulations
   b. Equipment and software
   c. Funding/financing
   d. Staffing
   e. Education/training
   f. Community/client outreach
3. Analyze the available and relevant options.
4. Create alternative program options for evaluation, such as contract services, staff development, or a combination of both, depending on your needs.
5. Select the optimum implementation program for your organization.
6. Implement the program with simple, initial flights to develop a foundation of success. Select projects that provide community or client value such as mapping. Consider safety, privacy, private property, and nuisance mitigation for all projects and ensure clear and open public communication. When appropriate, coordinate public participation.
7. Continually evaluate the program and revise as needed to match community concerns, governmental regulation, and UAS technology.

All new technologies require an initial investment in research, resources, and training. But taking the time to break UAS program implementation down into its component steps can help planners see that drones are just one more tool—a particularly effective and efficient one—in the planning toolbox.

satellites. "Spoofing" is sending conflicting signals to the drone to disrupt its programming or telemetry. "Hacking" is a more sophisticated technique whereby another actor takes control of the drone's command and control system, replacing the operator. Spoofing, jamming, and hacking pose serious threats to general and commercial aviation.

Destruction. Physical destruction of drones can be accomplished by an electromagnetic pulse, laser, microwave, launched net, shotgun or other projectile device, and—in the Netherlands—trained eagles. This is not an approach to be applied lightly. Because the FAA considers drones to be aircraft, shooting down a drone will come with the same penalties as shooting down a manned aircraft.

Disruption and destruction countermeasures are especially problematic as they will often result in the drone crashing, which creates a new hazard, especially if the drone has a dangerous payload.

Public Perception

Privacy is a top concern of the public when it comes to drone use. This can be defined as the state or condition of being free from being observed or disturbed by other people. Privacy is one of the more controversial issues with UAS as there is the potential to observe and record persons in ways that impact personal rights.

In 2015, President Barack Obama charged the National Telecommunications and Information Administration (NTIA) to establish a multistakeholder engagement process to develop a framework regarding privacy, accountability, and transparency for commercial and private UAS use (NTIA 2016). The resulting document, *Voluntary Best Practices for UAS Privacy, Transparency, and Accountability* (NTIA 2016), offers a set of best practices for both commercial and noncommercial data collection. Planners can start there and expand on those recommendations to best address their local contexts. Publishing a clear set of guidelines regarding the intent of UAS use along with self-imposed limitations can go a long way to easing public fears.

A related issue is nuisance, which can be defined as a use of property or action that causes inconvenience or damage to others, either individuals or to the public in general. Liability for private nuisance involves an invasion of private use and enjoyment of land. This is the primary reason for the prohibition of drones in national parks—the impacts to the enjoyment of the public caused by the visual distraction and noise created by drones. Planners should be careful to follow all safety and regulatory rules for UAS operations and avoid situations where drone use could cause potential nuisance impacts. Chapter 5 offers additional discussion of privacy and nuisance considerations in drone use.

Public Relations

The cultures and politics of different public agencies, regions, and population bases should be carefully considered when implementing a drone program. Several cities and counties have led very successful public outreach efforts during the initial stage of UAS deployment to inform the public about the benefits of using drones as well as the challenges and risks. The agencies that have done this have overwhelmingly seen success and public support.

In some cases, when agencies have not defined clear use cases or informed the public about UAS usage, they have seen public backlash against UAS programs stemming from misperceptions of what the drones were being used for. Media reports have highlighted the potential for illegal uses of UAS, which can lead to mistrust on the part of the public about drones, so it is important to be proactive and transparent about explaining how and why UAS are being used for planning-related applications.

For these reasons, agency UAS operations should be conducted in conjunction with a public information program to ensure residents are aware of the benefits of drone use and the safety measures being practiced by the agency. Drones may be seen as an invasive technology by members of the public, so being open and transparent about why UAS are being used and what they are being used for (and what they are not being used for) can go a long way towards defusing potential pushback or negative reactions. It is also true, however, that to many people drones represent an exciting and fascinating new technology, so sharing the capabilities of UAS may help build enthusiasm among the public and position the department or organization as innovative and forward-thinking.

A public information program is especially important for communities with airports and sensitive land uses (military installations, prisons facilities, certain landmarks, and parks), as the public should be aware of federal and state regulations restricting drone flights over and near these sites. The public information program must address public safety, privacy, private property rights, and nuisance concerns.

Data Management

Agency policies for UAS data management must conform to state and local government regulations. UAS data management should be integrated with existing agency policies and procedures. See Chapter 5 for some additional considerations regarding data management requirements.

In addition, drone data files can be extremely large, and this can present problems for storage and tracking. Mechanisms exist via editing and conversion software to help minimize data size, but the potential for data stripping and a reduction in imagery resolution should also be considered. Several national companies assist with these issues for smaller public agencies that do not have the necessary IT systems or on-site storage capacity. Again, it is important to right-size data collection so an agency is not paying to collect and store information it does not need or cannot manage or use.

IN-HOUSE DRONE PROGRAMS FOR PRIVATE-SECTOR PLANNERS

Drone use is becoming increasingly common among private-sector planning, engineering, and design firms, and many have added UAS applications to their suite of professional services offered. Not having some basic UAS capabilities could leave a private planning firm at a disadvantage when it comes to competing in the market. At the same time, an understanding of core company business and how UAS can complement and supplement these lines is important to carefully consider. Not every company needs—or wants—a drone.

As is the case for the public sector, private planning firms may first consider adding drone capacity to their organizations to help them do their planning work better. An in-house UAS program can mean faster, more extensive, more accurate, and more cost-effective data collection, with fewer variables and unknowns; no need to depend on another vendor's availability or reliability. The guidance for planning agencies provided in this chapter should also be helpful to private firms looking to add UAS capacity to support their planning and design work.

Private firms that develop in-house drone capacity may eventually wish to hire out these UAS-specific services to other organizations and local governments. Especially in these cases, the return on investment for establishing an in-house UAS program can be significant.

The appendices provide more information on the wide range of UAS applications, and the model safety guide and operations manual can be a starting point for developing a company's SOPs for its practices. However, the scope of establishing a professional UAS services operation is far beyond this report; planners should consult extensively with experts in the UAS industry if they are interested in pursuing this path.

CONCLUSION

The previous chapters in this report have provided planners with a basic grounding in the equipment and technology involved in UAS use and the many planning-related applications a UAS is capable of. This chapter offers guidance to help planners decide whether and how to implement UAS operations within their agencies or organizations. While there are plenty of factors to consider, especially in the genesis of a new program, it should be clear that these tools can be a significant supplement to any planner's arsenal.

The information provided here should be considered a starting point for planners in exploring the brave new world of drone use. Though it may seem intimidating, taking things one step at a time is key, as emphasized in the sidebar on p. 58. Start small by scoping a simple project and hiring professional UAS services to test the waters. Have other local governments or organizations in your area started using drones? Reach out to staff at those agencies, both to learn about their experiences with UAS use and also to collect recommendations for UAS consultants. Some of the best consultants may be able to rely on word of mouth among satisfied clients to keep their schedules full rather than using splashy advertising campaigns. The more information planners can gather about UAS operations and administration, the better informed and prepared they will be when adding drones to their professional practice.

Fundamental to all UAS operations, however, is a solid understanding of the rules and regulations that control drone use. This is the subject of the next chapter.

CHAPTER 5

UAS REGULATORY AND LEGAL CONSIDERATIONS

Before considering the use of drones in planning practice, planners must have a solid understanding of how they can and cannot be used. The rules and regulations that govern the use of uncrewed aircraft systems (UAS) are premised on how the Federal Aviation Administration (FAA) defines these machines and their operators.

Under the law, a two-pound UAS is an aircraft, no different from a Cessna 172 or a Boeing 737. In its official glossary of terms, FAA defines an aircraft as "a device that is used or intended to be used for flight in the air" (14 CFR §1.1). There is no mention of its size, crew, range, or mission—only that it is a mechanism that flies. Likewise, people who operate UAS are pilots, holding a credential granted by the FAA: the Remote Pilot in Command (RPIC) certificate.

The successful addition of UAS to the planner's toolbox will necessarily require the assumption of a new professional role, that of an aviator. To use a drone is to launch a flying machine into the most crowded and complex airspace system in the world.

In operating a drone or contracting for drone services, planners must understand and follow established rules and regulations—not just as individuals but as representatives of their employers, be they government agencies or private firms. Compliance not only protects other airspace users and people on the ground, but also the future potential of UAS technology and its benefits to society at large. This is true whether the planner is the pilot or contracts for drone services: the planner's employer will face civil liability if a contractor violates the rules and commits some action that results in a loss.

This chapter explains how UAS commercial applications, including planning-related operations, are regulated by the FAA, which has exclusive domain over the National Airspace System (NAS). It clarifies the role of state and local governments in regulating drone operations, and it offers examples of important legal considerations that planners should be aware of regarding the use of UAS, including trespass and nuisance, constitutional constraints, and temporary regulations that are likely to be enforced during emergencies.

COMMERCIAL VERSUS RECREATIONAL OPERATIONS

The FAA recognizes two types of UAS flying, irrespective of the capabilities of the aircraft itself: recreational and commercial.

Recreational operations are narrowly defined as piloting an aircraft for the enjoyment of flight in the moment that it is occurring. Commercial operations are defined as everything else—even if no money actually changes hands. An unpaid volunteer who uses their own drone to support search and rescue, for example, is a commercial operator according to the FAA, as is a farmer who uses a drone to scout their own fields—and so is a planner who uses a drone to obtain aerial imagery of a development site. Anything that provides any tangible benefit to the pilot; to any private, nonprofit, or government organization; or society as a whole is a commercial operation.

Different rules govern these different types of operations, and the sidebar on p. 64 provides some insight into the evolution of this regulatory framework. Commercial flights are regulated under Title 14 of the Code of Federal Regulations, Part 107 (14 CFR Part 107), whereas recreational activities are guided by Title 49 of the U.S. Code §44809. Both require operators to take a test to demonstrate their aeronautical knowledge—although the requirements under 14 CFR Part 107 are considerably more stringent—and both require that aircraft be registered with the FAA.

In the context of professional planning, all UAS operations are commercial operations. Flying under Part 107 as a commercial drone pilot, or RPIC, is frequently the best route to ensure legal and regulatory compliance. The process of becoming an RPIC is described in further detail

A BRIEF HISTORY OF DRONE REGULATIONS

When the first of today's UAS took flight in the early 2000s, the Federal Aviation Regulations (FARs) did not even contemplate their existence. Therefore, the pioneers who built and piloted those early hand-built machines drew upon the long tradition of aeromodelling—radio-controlled airplanes and helicopters—in the United States for regulatory guidance.

The first amateur radio-controlled flying competitions were held in the late 1930s, under the auspices of the Academy of Model Aeronautics (AMA). The organization still exists today as the national governing body for the hobby of model aviation, with 200,000 members and 2,500 affiliated flying sites nationwide. Over the past 80 years, the AMA has developed a robust safety program and amply demonstrated effective self-regulation of the community it serves.

The AMA's regulation of model aircraft was so successful over the decades that the FAA saw no need to issue additional rules. In 1981, the agency issued a single-page advisory document for model aircraft aimed at hobbyists that reiterated the AMA's own guidance. Many of the earliest pilots of small UAS had emerged from the hobby community and employed the same underlying technology as model aircraft to build their own drones—so they looked to the FAA's advisory circular for hobbyists as the legal basis for their operations.

The FAA explicitly rejected this reasoning in 2007 when the technological feasibility of private drone aircraft came into clear focus. UAS created a paradox: the same piece of technology could be used by hobbyists for enjoyment and by professionals to earn money or to support their professional endeavors. But the AMA brought substantial political pressure to bear, seeking to protect the traditional aeromodelling community from what it viewed as potentially intrusive regulation.

While the FAA deployed a variety of stop-gap measures, including special certificates for public agencies to use drones and waivers to permit their use in tightly controlled environments—such as closed film sets—it spent the next decade developing the rules and regulations that govern the commercial use of UAS today: 14 CFR Part 107.

in the sidebar on p. 66; resources to assist in obtaining RPIC certification are listed in the sidebar on p. 67.

There are other paths available. An organization can seek a certificate of authorization (COA) from the FAA, granting it the right to operate UAS within a geographically defined area without a qualified RPIC by establishing its own policies and procedures, including pilot certification. However, any such effort will likely require the assistance of an expert in aviation law and is subject to the vagaries of the FAA, which has the legal right to cancel a COA with immediate effect. Due to these complexities, the comprehensive operational and technical FAA review process, and prolonged approval timeline, the agency's goal appears to be to wind down the use of COAs in favor of certification under Part 107.

The final option is to have the UAS designated as a public aircraft. This was a more common solution for public safety agencies interested in operating UAS at the start of the previous decade that were seeking a waiver from the FAA, and it continues to play an important role in the testing and development of UAS, such as for autonomous air taxi systems.

FEDERAL UAS REGULATIONS

In Part 107, the FAA defines the regulations that govern commercial UAS operations in the United States. The full text of the regulation can be found in the *Federal Aviation Regulations/Aeronautical Information Manual* (FAR/AIM), published annually. What follows is a plain-language description of the rules under Part 107 and insights as to their interpretation and real-world application.

Each flight crew will consist of at least one Remote Pilot in Command (RPIC) and may include one, or more, Visual Observers (VOs). As previously discussed, an RPIC is a person holding a credential issued by the FAA to operate drones commercially in the United States. At least one must be present and participating in any UAS flight operation. The VO is a person designated by the RPIC for assistance, typically by helping to maintain a visual line of sight (VLOS) with the aircraft, as well as keeping an eye on the surrounding airspace for other aircraft and other emerging hazards. Apart from a pre-flight briefing provided by the RPIC, there is no training or credential requirement for a VO.

Each flight crew may only operate one UAS at a time. There must be at least one RPIC responsible for the operation of each aircraft aloft. If a mission requires three UAS to be flying at the same time, a minimum of three RPIC will be required, each constituting a separate flight crew.

The aircraft must be flown within plain visual line of sight (VLOS) of the RPIC or a VO. A member of the flight crew, either the RPIC or the VO, must be able to see the aircraft at all times. Corrective lenses are allowed, but enhancements to natural human vision, such as binoculars, are not. If the RPIC is not able to maintain VLOS because he or she is wearing a pair of video goggles or is concentrating on a video downlink, then a VO is required.

An on-board camera or first-person view (FPV) system cannot be used to satisfy the VLOS requirement. A video downlink, collision avoidance system, or other technical means cannot be used to fulfill the VLOS requirement under Part 107. The aircraft must be in plain view of the RPIC or the VO throughout the entire flight.

The RPIC shall conduct a pre-flight inspection of the UAS. This should include an inspection of the aircraft, ground control station, and other components for wear or damage, as well as verifying that control, video, and telemetry links are functioning correctly.

No person shall operate a UAS if he or she knows or has reason to know of any physical or mental condition that would interfere with its safe operation. Virtually all crewed aircraft pilots are required to undergo regular checkups administered by an FAA-approved aviation medical examiner to verify that they are fit to fly. The FAA elected not to place such a requirement on RPICs, instead relying on them to exercise their own good judgment regarding their physical and mental conditions. In addition to injury, illness, or medical incapacity, this rule also requires that UAS pilots be free from the influence of drugs or alcohol while operating an aircraft.

The RPIC may allow another person to manipulate the controls of the UAS, provided that he or she remains under the direct supervision of the RPIC. This rule is the equivalent of a private pilot allowing a friend to take the controls of a light airplane for a few minutes: a person who is not qualified to operate a UAS under Part 107 may do so, provided that the qualified pilot is ready and able to immediately assume control. Under this regulation, for example, an agency or organization could hire an outside RPIC to directly supervise all flights so long as the RPIC has the ability to immediately take direct control of the UAS to quickly address any situation they deem hazardous or otherwise problematic. However, as a practical matter, there are few circumstances in which an RPIC will be willing to be cast into that role, or in which their insurance will allow them to do so. The FAA makes clear that the RPIC is responsible for all aspects of the flight, including for civil and criminal penalties.

COMMERCIAL UAS PILOT CERTIFICATION

The process of becoming a commercial drone pilot, or Remote Pilot in Command (RPIC), is not unlike earning other professional credentials.

Applicants must take the standardized Airman Knowledge Test (AKT). The initial test consists of 60 multiple choice questions, and a passing score is 70 percent (or a minimum of 42 questions answered correctly). Testing centers are typically located at flight schools near smaller airports.

There are three prerequisites for becoming an RPIC:

- Applicants must be at least 16 years of age or older.
- Applicants must be able to read, write, speak, and understand English.
- Applicants must be physically and mentally capable of operating a UAS.

Applicants who meet those standards must register with the Integrated Airman Certification and Rating Application (IACRA). Visit the website at iacra.faa.gov to complete the registration process.

Next, schedule the exam at a local testing center, which can be found by visiting faa.psiexams.com.

The test is rigorous; those without a background in aeronautics should take a class or otherwise engage in significant study. Subjects covered on the test include:

- Part 107 rules and regulations
- The National Airspace System
- The effects of weather
- Aircraft loading and performance
- Emergency procedures
- Crew resource management
- Aeronautical decision making
- Pre-flight procedures

Applicants who pass the test will undergo an automatic background check by the Transportation Security Administration before receiving their certificates. To retain the RPIC certification, recurrent testing is required every two years by completing the Unmanned General Recurrent (UGR) knowledge test, which consists of 40 questions and also requires a minimum score of 70 percent to pass.

One thing that is not required to earn an RPIC certification is to actually pilot a drone. Whereas prospective private pilots and other pilot candidates require a "check ride" with an FAA-designated pilot examiner to demonstrate their real-world flying skills, the written test is the only requirement for RPIC certification.

STUDY RESOURCES FOR RPIC CERTIFICATION

The FAA has prepared a comprehensive report on the remote pilot exam. "Remote Pilot—Small Unmanned Aircraft Systems (Certification and Recurrent Knowledge Testing) Airman Certification Standards" (2018, FAA-S-ACS-10A) is available at www.faa.gov/training_testing/testing/acs/media/uas_acs.pdf.

The FAA's "Remote Pilot—Small Unmanned Aircraft Systems Study Guide" (2016, FAA-G-8082-22) provides an outline for studying for the remote pilot exam. The study guide is divided into 12 chapters with the following topics:

1. Applicable regulations
2. Airspace classification, operating requirements, and flight restrictions
3. (a) Aviation weather sources (b) Effects of weather on small unmanned aircraft performance
4. Small unmanned aircraft loading
5. Emergency procedures
6. Crew resource management
7. Radio communication procedures
8. Determining the performance of small unmanned aircraft
9. Physiological factors (including drugs and alcohol) affecting pilot performance
10. Aeronautical decision making and judgment
11. Airport operations
12. Maintenance and pre-flight inspection procedures

The study guide draws upon the document "Airman Knowledge Testing Supplement for Sport Pilot, Recreational Pilot, and Private Pilot" (2018, FAA-CT-8080-2) for exam question illustrations. This document is available at www.faa.gov/training_testing/testing/supplements/media/sport_rec_private_akts.pdf.

The study guide itself is available at www.faa.gov/regulations_policies/handbooks_manuals/aviation/media/remote_pilot_study_guide.pdf.

In addition to the study guide, aspiring RPICs should carefully review the federal regulations governing UAS operations: 14 CFR Part 107, *Operation and Certification of Small Unmanned Aircraft Systems*. Part 107 may be accessed through the Federal Register website at www.federalregister.gov/documents/2016/06/28/2016-15079/operation-and-certification-of-small-unmanned-aircraft-systems.

An additional important resource is the FAA's Advisory Circular 107-2, *Small Unmanned Aircraft Systems* (2016), which provides guidance for conducting UAS operations in the National Air Space in accordance with Part 107 regulations. It may be accessed at www.faa.gov/documentLibrary/media/Advisory_Circular/AC_107-2.pdf.

Other study resources beyond the FAA sources listed include guided online courses and third-party private publications.

During an emergency, an RPIC may deviate from any rule or regulation required to respond to the emergency. The RPIC should only exercise this privilege in circumstances where the UAS poses an imminent threat to the safety of persons or sensitive property and such action has the legitimate effect of mitigating that hazard. At the request of the FAA, the pilot is required to submit a report describing the nature of the emergency and his or her response.

The maximum altitude UAS are allowed to fly is 400 feet above ground level (AGL). This rule establishes what is referred to in the aviation community as a "ceiling" for UAS flight operations—an upper limit that, in this case, has been established to maintain separation between crewed and uncrewed air traffic. Under most circumstances, crewed aircraft should remain at an altitude of 500 feet AGL or greater, providing a 100-foot buffer. There is an exception to this rule: if the UAS is flying within 400 feet of a prominent structure, such as a tall building or a radio tower, it is permitted to fly to the height of the structure, plus 400 feet. Thus, if a UAS is being used to inspect a 300-foot broadcast antenna, the ceiling for that flight would be 700 feet AGL.

The maximum speed for a UAS is 100 miles per hour, or 87 knots. As a practical matter, this requirement does not place a significant limitation on real-world UAS operations. Typical multirotor platforms, the most common type of small, commercial UAS, have a maximum speed between 30 and 40 miles per hour.

The maximum take-off weight for a UAS, including fuel and payload, must be less than 55 pounds. This limitation is also largely irrelevant to commercial UAS operations. Most UAS weigh less than five pounds—many weigh less than two pounds—and the addition of a camera or other payload to a drone does not dramatically increase its weight. To put this in perspective for drone delivery service, of the more than 100 million products that are sold online every day, up to 91 percent weigh less than five pounds (Jenkins et al. 2017).

The minimum visibility for UAS operations is three statute miles. This is the same requirement that must be met for visual flight rules (VFR) operations by crewed aircraft. Once visibility drops below three statute miles, instrument flight rules (IFR) apply. Visibility can be gauged either by the pilot's own observations or by consulting the hourly weather reports (known as METARs) generated by a nearby airport.

The UAS must maintain a minimum of 500 feet of vertical separation and 2,000 feet of horizontal separation from clouds. This rule also mirrors the requirements for VFR operations by crewed aircraft. Cloud elevations are difficult to determine from the surface without specialized equipment, especially when multiple cloud layers are present. However, this information is included in the METARs published hourly by airports.

UAS operations are limited to daylight hours, between official sunrise and official sunset. Although this information is made available through the National Weather Service and other organizations, official sunrise and official sunset are established by the U.S. Naval Observatory in Washington, D.C. These official figures may differ from the time that the sun disappears from view in a given area, owing to local geography. UAS operations are also permitted during civil twilight, defined as a period one-half hour before official sunrise and one-half hour after official sunset, provided that the aircraft is equipped with a beacon visible for three statute miles.

UAS operations must be safe and responsible. Never fly in a careless or reckless manner. This rule, and its justification, should be self-evident. It allows the FAA to take action against a pilot who flies in a hazardous manner but complies with the other requirements of Part 107.

UAS are not permitted to fly over unprotected persons or moving vehicles. Unlike crewed aircraft, small commercial UAS do not receive airworthiness certificates from the FAA. Therefore, the regulations anticipate that they could fall out of the sky at any moment. As a two-pound object falling onto a person's head from 400 feet up or crashing through the windshield of a car traveling at highway speeds has the potential to cause serious injury or death, flights that create these possibilities are prohibited.

Operations from moving vehicles are not permitted, except in sparsely populated areas. Part 107 allows the pilot of a UAS to ride as a passenger in a terrestrial vehicle, such as a car, truck, or boat while it is moving, provided that someone else is driving and the operation is occurring in a rural area. Operations from a moving aircraft are not permitted.

Permission is required to operate a UAS in controlled airspace. All aircraft—including Cessnas, jetliners, and UAS—require permission to enter controlled airspace, which typically surrounds medium and large airports. Crewed aircraft receive permission through two-way radio communication with air traffic control (ATC). As discussed in Chapter 4, UAS pilots use a different system, called the Low-Altitude Authorization and Notification Capability (LAANC), which is accessed via the Internet, typically using a smartphone app. UAS operations are permitted in uncontrolled airspace without permission. No UAS operations are allowed in Class A airspace without special permission, which may be granted to the military or certain NASA flights. Planners should assume that no commercial flight that they will fly will ever receive such permission. However, this is an inconsequential prohibition, as Class A airspace only exists 18,000 feet above mean sea level (MSL). More information about U.S. airspace is provided in the sidebar on pp. 70–71.

UAS will yield the right of way to all other aircraft. This requirement includes yielding the right of way to other UAS. The FAA leaves unresolved how multiple UAS operators operating in the same airspace will determine the right of way, but a reasonable solution would be through conversation on the ground. Yielding the right of way with a UAS typically means bringing the aircraft to a hover at low altitude near the ground control station or landing until the other aircraft has departed the immediate area. Keeping watch for other air traffic is a prime responsibility of the RPIC and any VOs serving as members of the flight crew.

Be aware of crewed flight operations while operating a UAS near an airport. To avoid interfering with crewed air traffic, a UAS pilot operating near an airport must be aware of traffic patterns and approach corridors for all runways and landing zones. Situational awareness can be substantially increased by using a handheld aviation radio tuned to the control tower or common traffic advisory frequency (CTAF). Situational awareness may also be supplemented by mobile applications such as B4UFLY, an FAA-supported app that provides status indicators and interactive maps displaying information about controlled airspace, critical infrastructure, or other potential constraints that limit flight operation.

UAS are permitted to carry external loads. An external payload may be carried onboard a UAS, provided that it is mounted securely and does not adversely affect the aircraft's performance. Property may be carried for hire, so long as all other requirements under Part 107 are met and the operation occurs within the borders of a single state. As stated previously, no portion of the flight may occur over unprotected persons. Accordingly, items may be dropped from the aircraft, provided that sufficient care is taken to avoid causing injury or damage to persons or property on the ground.

UAS pilots are required to report accidents to the FAA. The threshold that triggers a mandatory report to the FAA is an accident that inflicts more than $500 of property damage (excluding damage to the UAS itself) or that inflicts a serious injury on a person (typically characterized by a loss of consciousness or requiring hospital treatment). The report must be filed with the FAA within 10 calendar days of the accident.

All UAS must be registered with the FAA or a foreign government. In almost all instances, registration can be completed online at faadronezone.faa.gov. Registration costs $5 and is valid for three years. Upon registration, the UAS will be issued a unique alphanumeric code that must be displayed on an external surface of the aircraft. A certificate of registration will also be issued in PDF format. This should be printed out and kept with the aircraft during all flight operations. A UAS registered in a foreign country may be operated under Part 107 in the United States, provided that the operator has obtained a foreign aircraft permit pursuant to 14 CFR Part 375 before commencing flight operations.

FAA is permitted to inspect UAS and associated documents. Upon request, a UAS pilot is required to make his or her aircraft and associated components available to the FAA for inspection. This includes flight and maintenance logs, registration, and the pilot's RPIC credential.

FAA WAIVERS

UAS operators may request permission to conduct operations that are not allowed under Part 107 by preparing a waiver application to the FAA (FAA 2019).

The underlying premise of the waiver process is as follows: the rules and regulations promulgated under Part 107 and other elements of the Federal Aviation Regulations (FARs) were established to ensure safety. If a UAS pilot can develop a set of procedures that will allow him or her to operate beyond the scope of the existing rules in a manner that is at least as safe as those regulations, the FAA will issue a waiver permitting the operation.

This provides a great deal of flexibility for remote pilots, but it comes at a significant cost: writing a waiver and getting it approved is a time-consuming process, and there are no guarantees at the end of it. The FAA reviews each one in exacting detail, and many are rejected on the first, second, or even third attempt. Success is likely to be contingent on possessing a degree of aeronautical knowledge that exceeds the minimum required to pass the Part 107 exam.

Among those waivers that have been approved, the overwhelming majority—about 90 percent—allow for operations at night. The remainder has been spread among the following categories:

- Operating in controlled airspace not accessible through LAANC
- Allowing a single RPIC to control multiple UAS simultaneously
- Operating when visibility is less than three statute miles or

AIRSPACE: AN INCOMPLETE EXPLANATION

Questions about the National Air Space (NAS) are the most frequently missed by aspiring Remote Pilots In Commands (RPICs) taking the Airman Knowledge Test to earn their credential under Part 107, and the reason is simple: the U.S. airspace system is incredibly complex. While some degree of understanding can come from self-study, genuine comprehension almost always requires face-to-face interaction with an instructor. There are literally layers upon layers of information conveyed through the sectional charts published every six months by the FAA—and unless you already know which magenta line means what, it's hard to know what you are looking at.

A full explanation of the NAS goes far beyond the scope of this chapter. However, a key concept to understand is that airspace is divided into six distinct categories, called classes (Figure 5.1). Four of these classes are defined as controlled airspace, requiring permission from Air Traffic Control (ATC) to enter. Of the remaining two, one is uncontrolled and the other shares characteristics of both but is regarded as controlled airspace for UAS operations.

Class A Airspace. As described previously, Class A airspace covers the entire landmass of the United States, beginning at an altitude of 18,000 feet mean sea level (MSL), which is referred to as the "floor" of the airspace. The ceiling of Class A airspace is at 60,000 feet MSL. This is the domain of commercial jetliners operating under the watchful eye of the FAA's 24 regional ATC centers. UAS operations are not permitted in Class A airspace.

Class B Airspace. Surrounding the nation's busiest airports, Class B airspace extends from the earth's surface to an altitude of 10,000 feet above ground level (AGL). These airports have control towers that are active 24 hours a day, 365 days a year. The configuration of Class B airspace is often described as an upside-down wedding cake, with the smallest tier touching the surface of the Earth around the airport, and progressively larger tiers extending further out from the airport at higher altitudes. These protrusions into the surrounding airspace are referred to as "shelves."

In most cases—but not all—the floors of these shelves are well above the 400-foot AGL limit established for UAS operations, so they are irrelevant to remote pilots. However, some portion of Class B airspace always touches the ground and therefore requires ATC permission via the LAANC system to enter.

In total, there are 37 airports located in Class B airspace, including Seattle, Los Angeles, Salt Lake City, Dallas-Ft. Worth, Boston, Atlanta, and Miami.

Class C Airspace. Class C airspace surrounds major airports that do not have sufficient air traffic to warrant a Class B designation. They also have control towers that operate around the clock. Class C airspace displays an upside-down

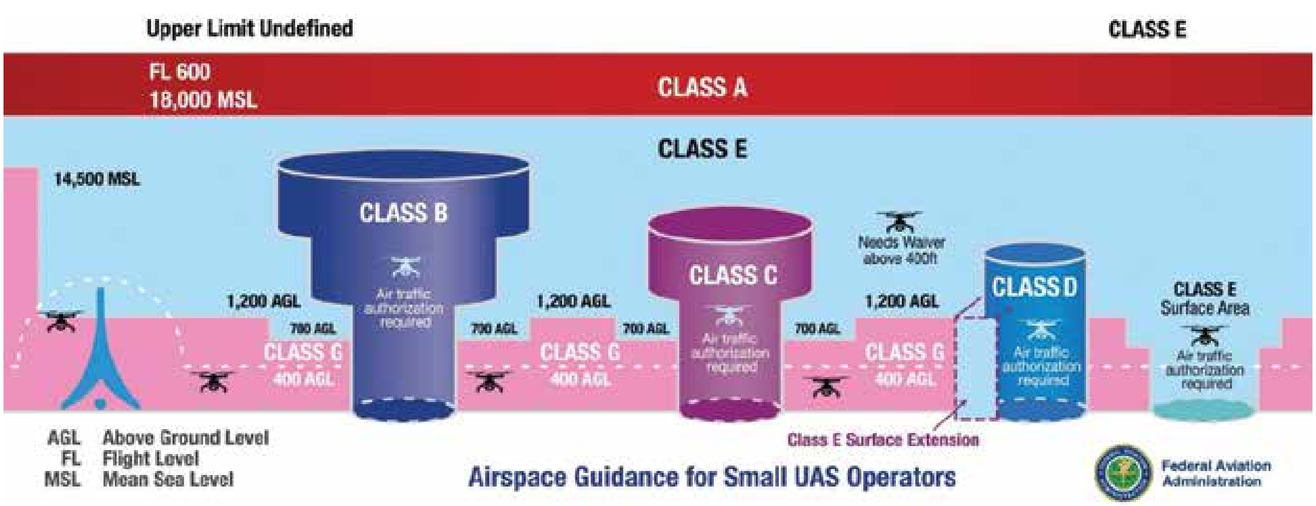

Figure 5.1. Airspace class diagram (FAA)

wedding cake structure similar to Class B airspace, but with a simplified shelf structure and a ceiling at 4,000 feet AGL. A portion of Class C airspace will always extend to the surface in the vicinity of the airport, requiring permission to operate a UAS in that area.

In total there, are 122 Class C airports. Examples include Indianapolis; Portland, Oregon; Mobile, Alabama; Oakland, California; Daytona Beach, Florida; Savannah, Georgia; Boise, Idaho; and Atlantic City, New Jersey.

Class D Airspace. Reserved for smaller regional airports, Class D airspace has a simplified cylinder structure with a ceiling at 2,500 feet AGL. These airports have control towers, but they are not necessarily active 24 hours a day. Class D is considered controlled airspace, so UAS pilots must obtain permission via LAANC before flying. There are nearly 500 airports in Class D airspace in the United States.

Class E Airspace. Class E airspace is unique among the airspace classifications for several different reasons. First, it fills in that portion of the sky that is not occupied by any other class of airspace. Across most of the country, Class E airspace has a floor of either 700 or 1,200 feet AGL, and a ceiling of 18,000 MSL, where it gives way to Class A airspace. However, in one specific instance, the floor of Class E reaches down to the surface: at airports without control towers that have instrument landing approach systems, allowing crewed aircraft to land under IFR conditions. Finally, while Class E is technically controlled airspace, in most cases crewed aircraft do not need permission to enter.

Because its floor is typically above the 400-foot AGL limit established in Part 107, Class E airspace is irrelevant to UAS operations, except where it surrounds airports at surface level. In such instances, it is regarded as controlled airspace for remote pilots, who require permission to fly.

Class G Airspace. First, a quick note: there is no such thing as "Class F" airspace—the FAA's alphabet skips straight to the letter "G."

Class G airspace extends across the entire territory of the United States up to a ceiling of either 700 or 1,200 feet AGL, except where Class B, C, D, or E airspace has a floor at surface level. Class G airspace is uncontrolled, and UAS operations are permitted in these locations without permission.

That said, it is important to note that there are nearly 20,000 airports located in Class G airspace. The overwhelming majority of these are small with minimal traffic, limited primarily to general aviation pilots flying light propeller-driven aircraft, crop dusters, and similar users. From an airspace perspective, it is perfectly acceptable to walk right up to the perimeter fence of one of these airports and launch your UAS to an altitude of 400 feet AGL.

However, this is where it becomes critical to have an understanding of airport operations—active runways, traffic patterns, approach corridors, and landing zones—a requirement that is made explicit in Part 107. Operating in the immediate vicinity of an airport in Class G airspace requires a high degree of aeronautical knowledge and planning, and it should only be attempted by experienced UAS operators.

Note that there is no requirement under Part 107 that UAS operations may only occur beyond a specified distance from any airport. For a brief period beginning in 2012, the FAA put a rule in place declaring that recreational pilots must not fly within five miles of any airport without first contacting ATC or the airport manager. This regulation has since gone by the wayside as UAS regulations have been refined and brought into alignment with existing airspace designations. Despite this, the "five-mile limit" has enjoyed remarkable staying power in the minds of UAS pilots, likely because of its simplicity.

Other Airspace Types. In addition to Class A, B, C, D, E, and G airspace, other categories can be superimposed on top of them: prohibited, restricted, military operations, and alert areas. Most of these have been put in place for reasons of national security or to allow military pilots to practice aggressive maneuvers that would pose a serious threat to nonparticipating aircraft. While some of these designations are permanent, such as the prohibited airspace surrounding the presidential retreat at Camp David, others are like light bulbs: they are switched on and off as needed.

Learning to distinguish between them and to recognize them on a sectional chart—along with countless other indicators, such as Victor airways, military training routes, magnetic deviation lines, VFR checkpoints, Mode C rings, maximum elevation figures, obstruction markers, radio beacons, and airspace boundaries—are among the skills that must be mastered to become a certified RPIC as well as a safe UAS pilot.

in close proximity to clouds
- Operating beyond visual line of sight
- Operating above unprotected persons on the ground
- Operations from a moving vehicle or aircraft

The FAA's declared goal is to respond to each waiver request within 90 days of receiving it. Waivers are valid for four years from the date that they are issued.

Planners who do not have a background in aviation apart from earning their Part 107 certificate may wish to seek advice from an expert with a professional background in the field to assist them in preparing a waiver application.

FEDERAL VERSUS STATE AND LOCAL REGULATIONS

Over the past decade, as UAS have become more numerous and capable, many state, county, and local governments have sought to regulate the use of this technology within their jurisdictions (see Essex 2016 for examples of state UAS regulations). While many issues have yet to be resolved by the courts in this area, there is one well-established doctrine that deserves attention: federal supremacy.

Identified in Article Six of the U.S. Constitution, the supremacy clause states that whenever federal law conflicts with a state or local law, the federal law takes precedence. As regards UAS operations and aviation more generally, this principle gives the FAA authority to regulate flight, training, and aircraft equipment—and denies state and local government the ability to address those same issues.

This principle has been tested in court and resolved in favor of the FAA in *Singer v. City of Newton* (284 F. Supp. 3d 125). The case was brought by Michael Singer, a physician, professor at Harvard University, and an RPIC living in Newton, Massachusetts. The city had passed an ordinance that placed various requirements and restrictions on UAS operations, including a ban on all flights over private property at an altitude less than 400 feet. As Part 107 establishes a ceiling for UAS operations at 400 feet, this rule effectively prohibited all flights in the city. Singer's suit claimed that the city's regulation intruded upon federal authority granted to the FAA through its rulemaking process, and the court agreed.

To assist local governments that want to regulate UAS without running afoul of federal supremacy, the FAA chief council has published "State and Local Regulation of Unmanned Aircraft System (UAS) Fact Sheet" (FAA 2015). This document clearly describes the FAA's responsibility for the safety of flight as well as the risks to persons and property on the ground from aircraft operations. Should local governments wish to address these areas through legislation, they are strongly encouraged to consult with the FAA to ensure that they do not overstep their authority.

However, the same document also acknowledges that other aspects of UAS operations may have implications for aspects of life that have traditionally been the domain of local jurisdictions, such as laws governing land use, zoning, privacy, trespassing, and law enforcement operations. In this context, the FAA states it is appropriate for local governments to pass laws requiring law enforcement to obtain a search warrant before deploying a UAS, or punishing the use of a UAS to intrude upon an individual's privacy, for example. However, even for these, local governments are well-advised to consult with legal counsel because the lines of authority are not bright. If there is any doubt as to whether a UAS operation will conflict with state or local laws, the planner should consult with legal counsel before conducting the flight.

Further, some states prohibit or limit the use of drones by state and private actors, and some limit the authority of local or regional governments to regulate drones or prohibit such regulation. For example, in Oregon, only the state may regulate drones; local regulation of drones is expressly prohibited. The National Conference of State Legislators collects information on state laws governing drones (www.ncsl.org/research/transportation/current-unmanned-aircraft-state-law-landscape.aspx; NCSL 2020). Planners should review these and similar collections to ensure they understand the regulatory landscapes in their local communities.

TEMPORARY FLIGHT RESTRICTIONS

For a professional planner, flight operations will likely occur in clear weather on an unhurried schedule. However, UAS can also be a powerful tool for disaster response. Planners may be called upon to deploy during or in the immediate aftermath of flooding, fire, violent storms, or other incidents that cause widespread destruction.

In the event of a large-scale disaster, it is very likely that the rules and regulations that govern aviation, including UAS operations, will be suspended by a temporary flight restriction (TFR). A TFR is issued by the FAA at the request of the federal, state, or local government to restrict flights in a specific geographic area for a limited period of time. The FAA regularly issues TFRs for a range of different reasons, most of them having nothing to do with disasters. For example, a

TFR is issued every time the president or the vice president visits a city outside of Washington, D.C. TFRs are also put in place for all major league sporting events, as well as air shows and space flight operations.

In the event a TFR is declared in response to a disaster, it will seek to achieve two separate goals. First, it allows for air operations inside the TFR that would otherwise not be permitted under FARs, such as rescue helicopters flying at treetop level or landing at improvised sites to evacuate injured survivors. Second, it prevents aircraft that are not participating in the emergency response effort from entering the area and potentially interfering with rescue and recovery operations.

By issuing a TFR in this scenario, the FAA hands off responsibility for the airspace to the agency that is coordinating the response to the disaster, such as a state or county office of emergency management. Aviation operations are then governed by an "air boss" connected to the local authorities, who functions like a fusion of the FAA and ATC in the disaster zone: establishing the rules and procedures that aircrews will follow, as well as deconflicting the airspace.

Before operating a UAS within the boundaries of a declared disaster, it is imperative that a planner makes contact with the air boss and clears all flight operations. Otherwise, the operation will be a serious breach of the FARs and could possibly endanger the lives of disaster victims and first responders on the ground and in the air.

Planners who anticipate the need to conduct UAS operations during a disaster or in its immediate aftermath should take the time now to learn about the Incident Command System (https://training.fema.gov/emiweb/is/icsresource) and to identify and meet with the officials who will fill the role of air boss. Building a relationship ahead of time will be a huge benefit when disaster strikes.

ADDITIONAL LEGAL CONSIDERATIONS FOR UAS OPERATIONS

UAS constitute fundamentally new technology and, as such, many of the legal, ethical, and regulatory issues surrounding their use remain as yet undetermined—either in the court of law or the court of public opinion. Individual planners will need to rely on their own good judgment and advice from competent legal counsel to make the best possible decision under the laws and ordinances of their local communities. However, even with careful planning and consideration, the risk of criminal and civil liability cannot be completely eliminated. This final section explores these issues.

Drone Trespass, Nuisance, and Privacy

State statutory and common law prohibit trespass on the property belonging to another as well as activity defined by state law as public and private nuisances. Some state constitutions and statutes regulate invasions of privacy (intrusion upon seclusion).

How drones fit into these laws is not yet clear. The scope of this complex area of law is beyond the reach of this chapter. However, it is important to recognize that potential liability issues exist. Planners with specific questions should consult with legal counsel with expertise in these areas of law.

A UAS operator might be accused of trespass, creating a nuisance, or unlawfully invading a person's privacy if he or she flies at a low altitude or repeatedly over private property, as could occur during an autonomous mapping mission, for example. As laws governing trespass, nuisance, and privacy vary among states and potentially among communities within states, it is impossible to establish a universally applicable framework to guide drone pilots. Again, consult competent legal counsel with relevant expertise before conducting operations that might encroach on the privacy, use, or enjoyment of a landowner's property.

To more broadly understand these issues, it is important to recognize that while the FAA has the authority to designate and control the NAS, that authority does not mean the FAA "owns" that airspace or gives it the right to take private property without just compensation, authorize trespass over private property, or authorize nuisances or privacy invasions. Flying within the scope of FAA rules and specific FAA permissions may provide a defense to allegations that a drone flight violated trespass, nuisance, or privacy laws, but this cannot be assumed to be a complete defense—or even a defense at all—in any particular case. Accordingly, the use of drones can expose one to liability for trespass, nuisance, and privacy invasion claims and can expose governmental entities to unconstitutional taking claims under applicable provisions of federal and state constitutions.

A 1946 case decided by the U.S. Supreme Court in the context of unconstitutional takings under the Fifth Amendment to the U.S. Constitution is instructive. In *US v. Causby* (328 U.S. 256 (1946)), a chicken farmer recovered damages against the federal government for low-flying military aircraft at 83 feet AGL that caused the farmers' chickens to jump on top of one another, smother one another, and die. The Court explained that the result of the low flights caused the "destruction of the use of the property as a commercial chicken farm." Even though the flights were authorized by the FAA and occurred in the NAS, the Court decided that there was still liability for taking private property without compensation under the Fifth Amendment because the flight also occurred within property considered to be private property—the "curtilage" owned by the landowner. The Court explained thus: "We have said that the airspace is a public highway. Yet it is obvious that if the landowner is to have full enjoyment of the land, he must have exclusive control of the immediate reaches of the enveloping atmosphere. Otherwise, buildings could not be erected, trees could not be planted, and even fences could not be run."

The Court went on to suggest that a partial taking would be recognized by certain activities in the NAS: "We would not doubt that, if the United States erected an elevated railway over respondents' land at the precise altitude where its planes now fly, there would be a partial taking, even though none of the supports of the structure rested on the land. The reason is that there would be an intrusion so immediate and direct as to subtract from the owner's full enjoyment of the property and to limit his exploitation of it. While the owner does not in any physical manner occupy that stratum of airspace or make use of it in the conventional sense, he does use it in somewhat the same sense that space left between buildings for the purpose of light and air is used. The super adjacent airspace at this low altitude is so close to the land that continuous invasions of it affect the use of the surface of the land itself. We think that the landowner, as an incident to his ownership, has a claim to it and that invasions of it are in the same category as invasions of the surface."

This case has been followed by many others and is still good law. Variations of it have been used by a variety of other courts to find similar liability in the context of traditional aircraft. The one thing that is clear from all such cases is that simply flying in FAA-designated navigable airspace does not automatically immunize the operator from liability for substantially interfering with the legitimate rights of others.

The issue often boils down to one of reasonableness—whether the burdens of the flight in question are so great that it is unreasonable, considering applicable principles of constitutional law, real estate law, nuisance, trespass, and privacy, to insist that those burdens be borne by the aggrieved private party.

There is no directly applicable legal precedent that definitively answers the scope of such potential liability involving drones. However, it is important to remember that the FAA has determined unequivocally that drones are aircraft—so it is reasonable to assume the standards that have been applied to traditional aircraft in these contexts will also apply to drones.

Administrative Searches

Some planners who work for state or local governments may want to use UAS for administrative searches for purposes of code compliance. Doing so is subject to the Fourth Amendment to the U.S. Constitution, which prohibits unreasonable searches and seizures, and parallel state constitutional protections. The rules for using drones for this purpose go well beyond the scope of this chapter. Before any program to use drones in administrative searches is enacted, it is important to consult with legal counsel to avoid federal and state civil rights liability and violations.

Data Retention Policies

Especially for planners who are employed by government organizations, it is crucial to recognize that video, still images, and other data gathered using a UAS will most likely be regarded as public records, subject to freedom of information requests from the general public or interested parties.

Data retention policies vary enormously across different state and local governments, and even among different agencies of the same government. Before commencing drone operations, it is critical to determine what rules will govern the use, retention, deletion, and public access to data derived from those activities. Planners should consult with their organization's general counsel or another competent attorney to determine what is appropriate.

Finally, as noted in Chapter 4, UAS are capable of generating a significant amount of data. This may have a non-negligible impact on the information technology services of a planner's agency or organization. To ensure that data retention policies can be met, a planner should engage with IT staff to verify appropriate computer storage will be available.

CONCLUSION

While the rapid advance of UAS technology over the past 10 years has created reliable aircraft with capabilities that are potentially game-changing for planners and the agencies and organizations that employ them, the development of legal, ethical, and community standards has not kept pace.

Drones have enormous potential to benefit planning activities, but they must be operated with care. This is vital to ensure reasonable, safe, and prudent operations. Planners must adhere scrupulously to the federal rules and regulations that govern their use and avoid running afoul of state and local ordinances concerning issues such as trespassing, privacy, nuisance, and data retention.

CHAPTER 6

THE FUTURE OF PLANNING AND DRONES

Uncrewed aircraft systems (UAS) technology is not new, but as this report has shown, it is proving to be increasingly relevant as a useful tool for many professions—including planning. The benefits UAS can provide should now be clear to any planner who intends to add this technology to their toolbox. That is not to say, however, that there is no more room for improvement. Ongoing investments in UAS technology mean that its capabilities are advancing at a rapid rate.

This concluding chapter describes current trends in UAS technology and their implications for planning practice, offers some additional examples of how UAS are being used both within and outside of the planning profession, and highlights the importance of drones as a tool for 21st-century planners.

UAS TRENDS AND IMPLICATIONS FOR PLANNING

UAS technology is continually evolving to become more robust, user friendly, and relevant for planning applications. Drones used to be expensive, difficult to fly, and not worth the effort, but now they are too opportune to ignore.

A number of trends in UAS equipment, operations, regulations, and opportunities for use continue to drive the effectiveness of this technology upwards.

Miniaturization. The avionics (electronic systems used on aircraft) required for complex UAS are being continually reduced in size, allowing for ever-smaller drones. Smaller drones are more easily transported and can be used in interior spaces. Hummingbird- and insect-sized nano-drone prototypes are being designed, though primarily for military purposes (Jackson 2017). Most planners will still be using larger drones to support the camera and sensor payloads that typical planning-related UAS applications require.

Customization. An emerging trend is the customization of drones through the ability to adapt them to various tasks through programming and ancillary equipment such as lights, loudspeakers, or robotics. Perhaps the most relevant customizable feature is the payload. As an example, different cameras have different strengths and weaknesses (e.g., low light capture, zoom levels, video frame rate, resolution, lens type). There is no single camera that is best suited for every job, but operators can swap different cameras onto the same drone based on the needs of the project. The same is true of sensors and other equipment types. Being able to customize a piece of equipment based on varying tasks is a huge benefit to all operators, especially planners.

Economies of scale. The mass production of drone technology has resulted in a continual reduction in costs similar to other technologies, such as electronics and optics. The rapid innovation cycles also create surpluses of outdated drone models that keep costs low for entry-level UAS. Additionally, 3-D printing is increasingly being used to quickly and inexpensively build new drone design prototypes, manufacture drone parts, and enable new designs that can only be fabricated by the 3-D printing process (Formlabs 2020).

Augmented and virtual reality. *Augmented reality* is a technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view. UAS use augmented reality images for flight planning, telemetry, and specific applications. This trend will continue and be supplemented by data from the Internet of Things to identify features and communicate actions.

Virtual reality is the computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors. Planners can use drones to capture the imagery needed to create 3-D fly-through virtual reality environments, and apply this technology to planning applications such as scenario

LEVERAGING UAS TO ADDRESS COVID-19 PANDEMIC RESPONSE AND RECOVERY EFFORTS

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Across the globe, communities are experimenting with UAS to serve a variety of pandemic use cases. These include: (1) social distancing and protective equipment reminders, monitoring, and enforcement; (2) virus detection; (3) delivery of essential equipment and goods; and (4) disinfecting or sanitation of public spaces.

The application of drones can raise a number of possible concerns, such as privacy, civil liberties, and the effectiveness of achieving desired health and policy goals. Additionally, the use of UAS could raise quality-of-life concerns, such as noise, aesthetics (visual pollution), and other community impacts that could create nuisances. Communities should consider these potential impacts when considering the suitability of UAS applications for pandemic and recovery efforts.

Protective Measure Reminders, Monitoring, and Enforcement

One UAS pandemic application is the provision of reminders and enforcement of stay-at-home, social distancing, and mask requirements. Countries including China, India, Morocco, and the United States are employing drones to monitor populated areas and issue auditory reminders for people to shelter in place, maintain social distancing, and wear masks (Soo Lingberg and Colum 2020; Raghunathan 2020; Agence France-Presse 2020; NBC New York 2020).

In California, the startup Airspace Systems has created a software application that enables public agencies to analyze video streams captured by drones and detect whether people are social distancing or wearing a face mask (Nellis 2020). While the software can process videos captured through ground-based cameras, it does not employ facial recognition technology nor store images. It can also generate aggregate data on how many people are maintaining six feet of social distancing and wearing masks. The system could further be used to target health messages to communities and cleaning crews, as well as help enforce quarantines and stay-at-home orders, depending on local, state, and national policies.

Virus Detection

Another drone pandemic application is "passive" virus detection. For example, communities in China's Liaoning Province are employing drones to help identify individuals with fevers (You 2020). In this use case, drones are typically equipped with a digital camera and heat-detecting forward-looking infrared to detect people's temperatures from a distance of 300 to 400 feet (Balona 2020; Sun 2020).

The use of drones for this use case can be highly controversial because a high temperature can be indicative of other health conditions, including the common cold. Furthermore, individuals who have COVID-19 may be asymptomatic and may not exhibit symptoms, such as a fever. In Westport, Connecticut, a planned police department pilot program employing drones to detect fevers and coughing in April 2020 was abandoned due to operational, health privacy, and data management concerns (Blair 2020).

Delivery of Supplies and Medical Services

A number of service providers are testing drone delivery for critical medical supplies, protective equipment, prescriptions, and COVID tests. In May 2020, United Parcel Service and CVS Pharmacy began using Matternet M2 drones to deliver prescription medications to a retirement community in Florida during a COVID stay-at-home order (Hawkins 2020). In North Carolina, Zipline partnered with Novant Health Medical Center to deliver medical supplies and protective equipment (Porter 2020). The FAA approved two round-trip routes, ranging from 20 to 30 miles, to carry up to four pounds of medical supplies, traveling at speeds up to 80 miles per hour. When the drones reach their destination, they drop supplies using a small parachute that provides contactless delivery.

Internationally, drones have been deployed in medical use cases since 2016 in Rwanda and 2019 in Ghana (Toor 2016; de León 2019). In Africa, Zipline has flown more than 1.8 million miles to airdrop medical supplies and ferry viral tests from more than 1,000 medical facilities, replacing the need for face-to-face contact. As of summer 2020, Zipline's fixed-wing drones have already made 30,600 medical supply deliveries in those countries since the start of the COVID-19 pandemic. In addition to delivering medical supplies, the company is transporting virus test samples from remote parts of Ghana that do not have testing facilities to laboratories in more populated parts of the country. The Zipline service is also being used to expand access to medical care for patients unable to travel due to COVID-19 quarantines, including delivering cancer drugs to patients in remote villages who are unable to travel to oncology centers due to the pandemic. In areas where the road infrastructure does not support deliveries, drones have reduced the transport time to access medical supplies and testing facilities from three days on a motorbike to 15 minutes.

In addition to medical use cases, drones can provide a form of contactless food and goods delivery. Prior to COVID, Wing, a drone-delivery service owned by Alphabet, received the first FAA approval for commercial package delivery in Christiansburg, Virginia. In addition to home delivery of medications from Walgreens, the service offers delivery of meals, snacks, and other merchandise, such as groceries. Merchandise is kept at a central Wing logistics facility. Orders can be made through the Wing app, which allows customers to chart progress of a drone on a map from its origin to destination. The service has also partnered with K–12 schools in Montgomery County, Virginia, to deliver library books and other resources to students studying from home due to the pandemic (Wing Medium 2020).

Sanitation and Disinfection of Public Spaces

Some cities are using drones to sanitize and disinfect large public facilities, such as roadways, plazas, indoor buildings (i.e., government centers and jails), and recreational facilities. In the United States, drones use U.S. Environmental Protection Agency–approved chemicals authorized to protect against the virus. Communities in China (Jilin, Shandong, and Zhejiang), France (Cannes), Honduras (Tegucigalpa), Indonesia (Surabaya), South Korea (Daegu), and United Arab Emirates (Dubai) are repurposing agriculture drones originally intended for crop dusting to sanitize public spaces. For example, in Dubai, drones have been used to sterilize 129 municipal sites and 23 public areas as part of the city's sanitation program. The drones can fly 10 to 15 minutes on a full charge and cover approximately an acre per hour (Bourke 2020). Proponents of this use case suggest that drones may be able to disinfect larger areas with less labor, although more testing and research are needed. However, other sources question the efficacy of this practice and note the potential for negative public health outcomes and environmental pollution (WeRobotics 2020).

UAS Opportunities and Challenges for Planning and Policy

While COVID-19 has the potential to increase public familiarity with UAS applications, drones can be controversial. While drones offer some lifesaving functions, privacy advocates have expressed a number of concerns including the potential for drones to employ invasive surveillance technologies such as night vision, Lidar (laser detection), infrared sensors, and other equipment to create 3-D maps; monitor individual behavior; accumulate and share sensitive medical information (i.e., temperature checks and contact tracing); and collect information from mobile phones. Others have expressed apprehension that drones manufactured in foreign countries could be used to conduct illegal surveillance.

Awareness of UAS capabilities in the context of COVID-19 can help to inform planners and policy makers as to how they might leverage such technologies to support the public good, while balancing a range of possible challenges. Better understanding UAS opportunities and challenges can help identify possible benefits in the context of pandemic response and recovery efforts, as well as opportunities to address possible concerns.

DRONES: LOW-COST PLANNING TOOLS, FACILITATORS OF STEM STUDENT ENGAGEMENT

Kathleen Schwind, MIT Special Interest Group in Urban Settlement

Enabling remote or small villages to effectively own and operate drones lessens their need to hire professional services to conduct targeted overhead surveys through aerial videos. But the use of UAS can also facilitate community engagement in planning activities and contribute to the STEM (science, technology, education, and math) and planning education of young people.

In 2017, the MIT Special Interest Group in Urban Settlement (SIGUS) partnered with Amún Shéa, an innovative school in Perquín, El Salvador, on a project aimed at generating models that would be useful to the village's future planning endeavors while simultaneously engaging the youth in the community through the planning process. Six SIGUS members, most of whom were graduate students from MIT, were involved in the project, which was supported by the Perkin Educational Opportunities Foundation (PEOF; www.peofoundation.org).

PEOF is located in Morazán, El Salvador, a region known for a self-perpetuating cycle of poverty exacerbated by isolation and civil war. This nonprofit was founded in 2007 with the goal of "community enrichment through education in Central America"; it believes that the key to breaking this cycle is educating the youth in the community and instilling an "entrepreneur spirit and know-how" in their students (PEOF n.d.). PEOF built Amún Shéa to help students use investigation and research to "construct solutions to very real local developmental problems and… becom[e] the change maker within their homes and communities."

The village of Perquín is located near a river in a lush and vibrant rainforest, making it a prime spot for bird watchers, environmentalists, and research teams. The village had ambitions to grow as a tourist and research destination, with a long-term plan of producing single-source cacao. However, the village also had the foresight of wanting to expand sustainably in a way that did not harm the natural wonders that it wanted to capitalize on. It needed data for the region to help it plan wisely and sustainably for the future.

The initially envisioned SIGUS project was to generate a 3-D model of the village of Perquín using a Phantom 4 drone and Pix4D software. SIGUS members would use the drone to safely and accurately document the structures within the village from a variety of angles, using Pix4D to generate camera positions and a series of waypoints for the autonomous flights (Figure 6.1). These images would then be correlated through photogrammetry software and common points identified, creating a "cloud" that the software uses to create the model.

Inspired by the central mission of PEOF, MIT SIGUS expanded the vision of their original mapping task to include Amún Shéa students in the project.

The SIGUS team began by holding a two-week UAS workshop for Amún Shéa students, whose ages ranged from 10 to 17. The team taught students about six key parts of UAS comprising both technical and planning elements: aerodynamics and the importance of drone design, rules and regulations for UAS flying, flying skills, mapping with a drone while surveying desirable and undesirable characteristics, learning how to repair drones, and advanced flying skills. At each stage, team members worked with the school's administration,

Figure 6.1. 2-D aerial image of Perquín taken by the Phantom 4 drone (MIT SIGUS)

faculty, and students to create an engaging and hands-on environment, fostering a space for these young students to learn about these machines.

At the heart of the workshop was the creation of the 3-D model, which engaged the students in a way that encouraged them to take notice and ownership of their community layout. The team asked the students to walk around the village in groups and document beneficial characteristics (such as streetlights, clean roads, or well-built houses) and characteristics that needed to be changed (such as holes in the road or unkempt streets). Meanwhile, the team used the Phantom 4 to generate aerial images of the village and prepare them for analysis.

Back in the classroom, the students used the notes and observations from their field study to mark the locations of beneficial and problematic characteristics on the aerial images of the village generated by the drone (Figure 6.2). The SIGUS team worked with the students to identify patterns in the locations of "good" and "bad" characteristics. The characteristics that needed change were then sorted by how soon they needed to be addressed and how much it would cost in time, money, and manpower. The team then gave each student an image of the village and asked them to draw items that would make the space safer and more welcoming.

The final products of this exercise were lists of projects that could be easily undertaken by the community immediately, in the near future, and the far future, in addition to an inventory of what resources were needed to address the near- and far-future concerns.

The depth of observations made by the students was impressive. They took real pride in and ownership of their neighborhoods, carefully analyzing what could be done to improve the safety and effectiveness of the area. The easy-to-read imagery from the UAS helped facilitate the engagement of the students in these planning activities. The project gave the village planners a technical tool to work towards sustainable expansion, and—arguably, just as importantly—it fostered a sense of ownership and "big-picture thinking" among the students. Youth engagement in planning is a key element in the longevity and quality of life in small communities.

Figure 6.2. Students place markers where they noted "good" and "bad" characteristics in their community using the aerial images taken by drone earlier that day (MIT SIGUS)

The UAS planning workshop was important for another reason. Drones not only make planning easier and more cost-effective, especially for small communities, but they further bridge the gap between planning and more technical fields. STEM disciplines are beginning to dominate educational systems in the United States and around the world. To keep up with the rapidly changing technology that increasingly defines the work world, countries must train people with the skills and technical literacy needed to feed their workforce. Fun, hands-on STEM-based workshops like this one expose students early in their academic careers to the accessibility of STEM as well as the future of the planning field.

The feedback from this project was extremely positive. School official expressed strong interest in holding additional similar workshops and asked the SIGUS team to return and continue the partnership.

Too often organizations from the developed world impress their ideas and models on the developing world, especially in rural communities. Forming a close and successful relationship with all partners involved in a project is crucial, especially for STEM-based initiatives. Through a partnership instead of a business transaction, MIT and PEOF were able to work side by side, learning from each other while respecting both sides' realms of expertise. And by using a UAS to carry out this project, the team not only minimized survey costs, but also created a space for young people to become involved in the community planning process while gaining exposure to valuable 21st-century STEM fields.

planning, collaborative design, and more innovative and effective public engagement programs (Howard and Gaborit 2007; Ferarri 2018).

Networking and autonomy. Drones are becoming more autonomous. More and more flight functions are being determined by UAS avionics. Future drones will likely be designed to accomplish most or all of their functions without any human intervention. This suggests ample potential for UAS use to become more efficient. The ability to send out two or more drones simultaneously for mapping or surveying work, for example, will halve or even further reduce the time it takes to do that job.

Improved safety features. Drone aerodynamics and avionics continue to make this technology safer, and the Federal Aviation Administration (FAA) is increasingly approving waivers for flights that go beyond current UAS regulations justified by increased safety measures. Future failsafe measures, lighter construction, frangible materials designed to break apart to reduce impact force, and other features will improve the safety of drone use.

Conversely, however, the ability for drones to be weaponized or flown in ways that present new safety hazards is also increasing. Drone countermeasures will need to be developed concurrently with other UAS technologies to safeguard the public from intentional as well as accidental threats.

Interactivity. Several years ago, there were about 40 popular uses for drones, and these were mostly associated with aerial reconnaissance. Today the number has increased tenfold and the further evolution of UAS technology will likely be accompanied by a continuous expansion of applications.

Most current planning-relevant applications represent passive data gathering, but the future of UAS will be interactive—they will be capable of manipulating objects. It is also likely that future drone applications will be more interpersonal and autonomous, providing specific services for individuals.

Regulations. The FAA is currently refining UAS regulations to establish the relationship of drones to the national airspace system and the urban environment. Regulations may expand and evolve as advances in UAS technology allow drones to meet specific safety and networking capabilities required for UAS traffic management, or the management of low-altitude uncontrolled drone operations conducted beyond the visual line of sight of the drone operator (FAA 2020b).

UAS are currently prohibited from a variety of operations, including the following:

- Beyond visual line of sight (BVLOS)
- More than 400 feet above ground level
- Nighttime flight
- Multiple UAVs per pilot
- Speeds of more than 100 miles per hour
- Flying over people

All of these are currently possible with an FAA waiver, as discussed in Chapter 5, but waivers can be difficult and time-consuming to apply for, and some waivers, such as for BVLOS, are almost impossible to obtain.

The FAA is currently researching technology and exploring regulatory avenues that will lift some of the above restrictions; one example is its "Remote ID" initiative, which will allow a UAS in flight to provide identification information that can be received by other parties (FAA 2020a). This may open up the possibility of easier approval for BVLOS and nighttime operations.

UAS uses. This PAS Report has focused on UAS applications that are directly relevant to the practice of planning. As noted elsewhere in this report, however, the different types of UAS applications number in the several hundreds (see Appendix C for a list of UAS applications in a wide range of fields) and that number keeps growing. The evolution of UAS technology is driving new capacities, and drones are being used to take on an increasing number of service functions, including package delivery and even autonomous air travel.

As emphasized throughout the report, UAS represent a multifunctional technology that can be used in many ways to get work done more safely, efficiently, and cost effectively. A good example of how drones can be used in a wide variety of innovative ways to respond quickly to changing or novel circumstances is provided by the sidebar on pp. 78–79, which describes how UAS are being used by cities around the world to respond to COVID-19.

PREPARING FOR A SMARTER FUTURE

We live in a world of accelerating change and disruption. The pace of technological innovations, the disruption by the COVID-19 pandemic, and the increase in natural disasters due to climate change are just a few examples of the constant changes the world is facing today.

Planners help communities navigate change and prepare for an uncertain future. For planners to continue spearheading this process, keep up with the pace of change, and stay relevant in the 21st century, agility and technological advancement are becoming ever more important. Planners need to understand the technologies that are being deployed in their communities, especially in this era of smart cities, automation, and big data. Learning how to use certain technologies, such as UAS, in their work enables planners to become more agile: they will not just be better able to respond to a changing world, they will be prepared before disruptions happen. Upskilling planners towards more technological advancement will be crucial to raise the voice of planning in the future.

UAS should also be used as a tool for engagement and education. Many colleges and universities are using drones as part of planning education to help their students gain vital technological skills and hands-on experience with UAS applications and functionality. The sidebar on pp. 80–81 shares the experience of MIT planning graduate students in using drones to not only provide valuable planning tools for a rural village in El Salvador, but also to engage local schoolchildren in improving their community while gaining exposure to critical science, technology, education, and math (STEM) skills.

The applications for UAS are substantial and growing. Drones represent a highly useful technology that can help planners do their work more safely, efficiently, and cost-effectively. The information and guidance in this PAS Report are intended to provide planners with the knowledge they need to determine whether UAS can enhance their planning practice and, if so, to take the first steps towards UAS implementation. As planners prepare to navigate the ever-increasing technological and societal changes of the 21st century, drones should be a tool in the planning toolbox that all practitioners know when and how to use.

APPENDIX A. UAS ABBREVIATIONS

This list of common UAS abbreviations is drawn from Stephens 2018.

AAM: advanced aerial/air mobility
AGL: above ground level
ALT: vertical distance from ground
ATC: air traffic control
ATM: air traffic management
BLOS: beyond line of sight
BVLOS: beyond visual line of sight
C2: command and control
CFR: Code of Federal Regulations
COA: certificate of authorization (also certificate of waiver)
D&A/DAA: detect and avoid
DSA: detect, sense, and avoid
ESC: electronic speed controller
eVTOL: electric vertical take-off and landing aircraft
FAA: Federal Aviation Administration
FAR: Federal Aviation Regulations
FLIR: forward-looking infrared
FMRA: FAA Modernization and Reform Act of 2012
FPV: first-person view
GPS: Global Positioning System
HUD: heads up display
IACRA: Integrated Airmen Certification and Rating Application
L&R, L/R: launch and recovery
LAANC: Low Altitude Authorization Notification Capability
LIDAR: light detection and ranging
LOS: line of sight
LZ: landing zone
MSA: minimum safe altitude
MSL: mean sea level
NAS: National Airspace System
PIC: pilot in command
POI: point of interest
RAM: rural/regional air mobility
RC, R/C: radio controlled/remote controlled
RID: remote identification
RPIC: remote pilot in command
RTH: return to home
RTL: return to launch
SAA: sense and avoid
sUAS: small unmanned aircraft systems (FAA)
UA: unmanned/uncrewed aircraft
UAM: urban air mobility
UAS: unmanned/uncrewed aircraft system
UAV: unmanned/uncrewed aerial vehicle
UTM: UAS traffic management system
VLOS: visual line of sight
VO: visual observer
VRS: vortex ring state
VTOL: vertical take-off and landing aircraft
WP: waypoint

APPENDIX B. UAS GLOSSARY

This list of common UAS terminology is drawn from Stephens 2018.

above ground level (AGL): See altitude.

aircraft principal axes: An aircraft in flight is free to rotate in three dimensions: pitch, forward (nose) up or down about an axis running from left to right; yaw, forward (nose) left or right about an axis running up and down; and roll, rotation about an axis running from front to back (nose to tail). See Figure B.1.

airfoil: A surface designed to aid in lifting or controlling an aircraft by making use of the air currents through which it moves.

altitude (ATTI): The height measured from directly above ground (AGL) is the absolute altitude. The height measured from mean sea level (MSL) is the true altitude.

ATTI mode: Flight mode in which the altitude is set but lateral movement is not stabilized when the controls are released.

autonomous aircraft: An aircraft that does not require pilot intervention in flight operations.

autonomous operation: An operation during which a remotely piloted aircraft is operating without pilot intervention in the management of the flight.

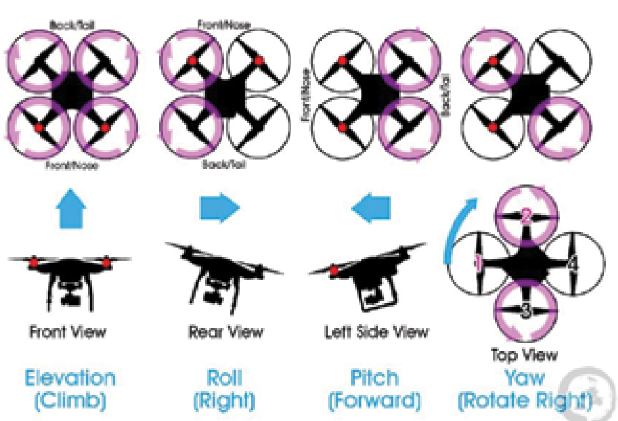


Figure B.1. Aircraft axes and motions (Ric Stephens)

autopilot: The component of an aircraft that is capable of guiding movement of the aircraft without real-time human guidance.

avionics: The science and technology of electrical and electronic devices in flight.

ceiling: Height above ground or water of the base of the lowest layer of cloud below 20,000 feet (~6000 meters) that covers more than half of the sky.

certificate of authorization /waiver (COA): An FAA grant of approval for a specific flight operation.

collision avoidance: Action taken to prevent flying into a fixed object or another aircraft. See also *detect, sense, and avoid.*

command and control (C2): The exercise of authority and direction by the pilot. Also called *communication, command, and control* (C3).

command and control range: The distance between ground control station and aircraft at which positive control of the aircraft can be maintained.

commercial operation: An aircraft operation conducted for business purposes other than commercial air transport (e.g., mapping, security surveillance, wildlife survey, aerial application).

control station (CS): An interface used by the remote pilot or the person manipulating the controls to control the flight path of a UAS.

crew member: A person assigned by an operator to duty on an aircraft during a flight duty period.

detect, sense, and avoid (DSA): The capability to see, sense, or detect conflicting traffic or other hazards and take the appropriate action to comply with the applicable rules of flight. DSA can be defined as: Detect: Is something there? Sense: Is it a threat or target? Avoid: Maneuver to miss. Also called *detect and avoid* (D&A) and *sense and avoid.*

drone: An aircraft without a pilot on board that is remotely controlled by a person on the ground.

drone park: Large area dedicated to UAS recreation or research and open to the public for free or a usage fee.

envelope: The maximum performance parameters of an aircraft.
failsafe function: If a lost link occurs, the aircraft enters failsafe mode and in it either returns to launch or lands autonomously.
Federal Aviation Administration (FAA): The division of the U.S. Department of Transportation that inspects and rates civilian aircraft and pilots, enforces the rules of air safety, and installs and maintains air-navigation and traffic-control facilities.
firmware: The control program for the aircraft.
first-person view (FPV): A technique that enables an operator to assume a cockpit view using a display screen or video goggles, with a wireless, real-time connection to an onboard video camera.
fixed-wing aircraft: An aircraft capable of flight using forward motion that generates lift as the wing moves through the air. Also called *airplane*, *aeroplane,* or *plane*.
flight plan (FP): The operator's plan for the safe conduct of a UAS flight based on considerations of aircraft performance, other operating limitations, and relevant expected conditions on the route to be followed. Also called *operational flight plan*.
flyaway: Unintended flight outside of operational boundaries (altitude/airspeed/lateral) as the result of a failure of the control element or onboard systems. Flyaways do not have or do not initiate failsafe mode to return to launch.
flyaway protection system: A system that will return the aircraft safely to the surface or keep the aircraft within the intended operational area when the command and control link between the pilot and the aircraft is lost. See *failsafe function*.
formation: Flying several drones or swarm that form a shape or pattern. When flown close together, this is a *tight formation* (also called *creative pattern*).
frangible: Designed to break, distort, or yield on impact to present minimum hazard.
geofence: A virtual barrier indicating how far a UAS can fly from its home point. Geofence settings are usually height above ground as well as total distance from the home point.
gimbal: A mechanism, typically consisting of rings pivoted at right angles (3-axial stabilized), for keeping a camera or other instrument horizontal during flight.
Global Positioning System (GPS): The global system of U.S. navigational satellites developed to provide precise positional and velocity data and global time synchronization for air, sea, and land travel.
GPS mode: Flight mode where the craft will remain in the altitude, position, and orientation that it is in when the controls are released. Also necessary for automatic return to home.
gyro: A device used to help stabilize the yaw of a helicopter or multirotor.
hexacopter: An aircraft with six main rotors.
hobby-grade: Another word for drones that are a step up from toys.
hobbyist: Noncommercial, recreational model aircraft pilot. Also called *aeromodeller*.
homing: See *return to launch*.
hover mode: A flight mode in which an aircraft maintains a specified altitude and position via GPS, often related to a point of interest.
incident: An occurrence, other than an accident, associated with the operation of an aircraft that affects or could affect the safety of operation.
intelligent orientation control (IOC): Usually, the forward direction of a flying multirotor is the same as the nose direction. By using intelligent orientation control, wherever the nose points, the forward direction has nothing to do with nose direction. In *course lock flying*, the forward direction is the same as a recorded nose direction. In *home lock flying*, the forward direction is the same as the direction from home point to the multirotor.
Low Altitude Authorization Notification Capability (LAANC): A collaboration between the FAA and industry that directly supports UAS integration into the airspace.
line of sight (LOS): Small aircraft for which the person in control must be in direct sight of the aircraft so that radio signals can be transmitted between the controller and the aircraft. Most larger aircraft are not line-of-sight aircraft because the radio signals that control them are bounced off satellites or manned aircraft.
line of sight command and control link: Aircraft system operating within visual and radio range.
lost link: Loss of command and control link contact with the remotely piloted aircraft such that the remote pilot can no longer manage the aircraft's flight.
minimum safe altitude (MSA): Floor of the public domain for airspace. In general, people's property ends at the highest point of the underlying land's trees, buildings, fences, or how high the owner can use the airspace in connection with the land.
mission plan: The route planning, payload planning, data link planning, and aircraft emergency recovery planning for a flight.
model aircraft: As defined by the FAA, an unmanned aircraft that is capable of sustained flight in the atmosphere, flown within visual line of sight of the person operating the aircraft, and flown for hobby or recreational purposes.

multirotor: An aircraft with two or more main rotors. Also called *multicopter*.
National Airspace System (NAS): The common network of U.S. airspace, comprising air navigation facilities, equipment, and services, airports, or landing areas; aeronautical charts, information, and services; rules, regulations, and procedures; technical information; and manpower and material.
octocopter: An aircraft with eight main rotors.
operational control: The exercise of authority over the initiation, continuation, diversion, or termination of a flight in the interest of safety of the aircraft and the regularity and efficiency of the flight.
operator: A person, organization, or enterprise engaged in or offering to engage in an aircraft operation.
payload: All elements of a remotely piloted aircraft that are not necessary for flight but are carried for fulfilling specific mission objectives.
person manipulating the controls: As defined by the FAA, a person other than the Remote Pilot in Command (RPIC) who is controlling the flight of a UAS under the supervision of the RPIC.
pilot in command: The person in direct control of the aircraft. See *remote pilot*, *remote pilot in command*.
pitch: See *aircraft principal axes*.
point of interest (POI): A target location for the capture of remotely sensed data by an aircraft's sensors (video, still, or multispectral imagery). Also called *region of interest*.
prop guards: A light frame extending beyond the radius of the rotors as a protection measure.
propeller: A mechanical device for propelling the aircraft, consisting of a revolving shaft with two or more broad, angled blades attached to it. See *rotor*.
quadcopter: An aircraft with four main rotors. Also called *quadrocopter*.
range extender: A communication device on the remote controller that increases the distance the aircraft can fly while maintaining its link with the controller.
remote controller: The handheld device used to operate the UAV. It typically consists of a radio transceiver, GPS, and flight controls; it may also include FPV screens and camera controls.
remote pilot (RP): The person who manipulates the flight controls of a remotely piloted aircraft during flight time.
Remote Pilot in Command (RPIC): As defined by the FAA, a person who holds a remote pilot certificate with a UAS rating and has the final authority and responsibility for the operation and safety of a UAS operation conducted under Part 107.
remotely piloted aircraft system (RPAS): term used by the International Civil Aviation Organization to refer to UAS.
return to launch (RTL): The return of an aircraft to its original launch location, often performed as a safety procedure in the event of a technical malfunction or emergency. Also called *homing* or *return to home*.
roll: See *aircraft principal axes*.
rotary-wing aircraft: A flying machine that uses lift generated by wings called rotor blades that revolve around a mast. Also called *rotorcraft*.
rotor: A hub with several radiating airfoils (blades) that is rotated in an approximately horizontal plane to provide the lift for a rotary-wing aircraft. See *propeller*.
route plan (RP): A set of waypoints for the aircraft to follow.
situational awareness (SA): An all-encompassing term for keeping track of what is happening when flying.
stabilization mode: A flight mode that allows the operator to fly an aircraft manually but self-levels the roll and pitch axes.
stick: A flight control feature on the remote controller. Typically, there are two sticks to control power and orientation/direction.
tip path: The path in space traced out by the tips of the rotor blades.
track: Flight path of an aircraft above the ground.
translational lift: Additional lift provided by lateral movement as opposed to hovering; helps prevent vortex ring state.
tricopter: An aircraft with three main rotors.
uncrewed aerial vehicle (UAV)/uncrewed aircraft system (UAS): nongendered alternative terms for drones.
unmanned aerial vehicle (UAV): FAA term for an aircraft without a human pilot aboard; its flight is controlled either autonomously by onboard computers or by the remote control of a pilot on the ground or in another vehicle.
unmanned aircraft system (UAS): FAA term for an uncrewed aircraft and associated elements (including communication links and the components that control the aircraft) that are required for the pilot in command to operate safely and efficiently in the national airspace system. Also called *small unmanned aircraft system* (sUAS) if less than 55 pounds.
unmanned aircraft system traffic management (UTM): As defined by NASA, a system that would enable safe and efficient low-altitude airspace operations by providing services such as airspace design, corridors, dynamic geofencing, severe weather and wind avoidance, congestion management, terrain avoidance, route planning and rerouting, separation management, sequencing and spacing, and contingency management.
vertical take-off and landing (VTOL): The capability of an aircraft to take off and land vertically, transferring to or from

forward motion at heights required to clear surrounding obstacles; generally applied to rotary-wing aircraft although also possible by some fixed-wing aircraft.

visual line of sight (VLOS): Sufficient unaided (corrective lenses and sunglasses excepted) visual contact between a pilot in command and an unmanned aircraft to enable the pilot in command to maintain safe operational control of the aircraft, know its location, and be able to scan the airspace in which it is operating to see and avoid other air traffic or objects aloft or on the ground.

visual observer (VO): As defined by the FAA, a person acting as a flight crew member who assists the RPIC and the person manipulating the controls to see and avoid other air traffic or objects aloft or on the ground.

vortex ring state (VRS): A dangerous condition in which air vortices can form around the main rotor of a helicopter; air that moves down through the rotor turns outward, then up, inward, and down through the rotor again. This recirculation of flow can negate much of the lifting force and cause a catastrophic loss of altitude. Also called *settling with power* and *recirculation*.

waypoint (WP): A specified geographical location used to define an area navigation route or the flight path of an aircraft employing area navigation.

yaw: See *aircraft principal axes*.

APPENDIX C. UAS APPLICATIONS

This list of UAS applications is drawn from Stephens n.d.

AGRICULTURE, AQUACULTURE, SILVICULTURE, AND VITICULTURE

Crop theft prevention
Fish school detection and monitoring
Forest inspection, management, regeneration
Harvest monitoring and control, selective harvesting
Herding, herd inventory, herd tracking
Infrared hydrology and vegetation analysis
Pest, plant disease, and weed/invasive species detection and control (crop dusting, pesticide application)
Precision agriculture: fertilizer management, irrigation monitoring and control, pollinating, seeding
Vineyard and winery management

ARCHEOLOGY

3-D mapping, imaging, modeling
Site documentation and mapping (cemeteries, digs, landmarks, petroglyphs)
Thermal imaging

ARCHITECTURE, ENGINEERING, AND URBAN PLANNING

3-D imaging, pre-construction virtual views
Construction documentation, management, monitoring
GIS data capture
Highway/railroad inspection and monitoring
Infrared building/tower heat-loss detection
Laser scanning and distance/area/volume measurement
Parking management
Pavement assessment
Site analysis
Streetlight analysis
Structural inspections and measurements (aqueducts, bridges, buildings, cell towers, dams, gas/oil platforms, landmarks, pipelines, pressure tanks, power lines, rail track beds, roofs, runways, solar panels, transmission lines and rights-of-way, wind turbines)
Surveying
Transportation analysis, traffic flow analysis, traffic monitoring
Urbanization monitoring
Views (from proposed structures), viewshed impacts

ART

Artistic lighting, music broadcast
Cinematography, photography, videography
Culture recordation, intangible culture heritage preservation
Painting, murals
Performance

BUSINESS

3-D modeling, 3-D printing
Aerial advertising, lighting, skywriting
Building painting, window washing
Chemical applications (aerosol and liquid)
Delivery (cargo, documents, dry cleaning, food, groceries, prescription drugs)
Inspections (aircraft, chimney, customs, flare stack, industrial facilities, meat plants, nuclear plants)
Insurance claims adjustments
Inventory/asset management
Litigation imagery
Oil and mineral exploration, mining management
Property appraisal

Photography/video services (real estate marketing, weddings)
UAV sales, leasing, service
Wayfinding, parking search, building/room finder

EARTH SCIENCE

3-D and aerial terrain surveying, mapping, modeling
Geophysical survey, geotechnical research
Hydrology, hydrometric mapping
Magnetic field survey
Quake fault discovery
Radiation measurement
Volcanic ash measurement, volcano monitoring

ENVIRONMENTAL SCIENCE

Air pollution, power plant emission, smoke, radiation analysis and monitoring
Algae proliferation monitoring
Animal/pest deterrent, predator control
Animal rights protection (anti-fishing, anti-hunting, anti-poaching, anti-whaling)
Atmospheric and hydrospheric research
Audio/noise measurement
Camera trap transmission and collection
Chemical/scent/pheromone dispersal
Coastal/oceanography research (tidal zone modeling, current modeling, sea level rise monitoring, sandbank shift, coastal water quality, saltwater infiltration)
Environmental compliance and protection
Environmental impact assessment
Erosion detection and monitoring
Fisheries, marine sanctuary monitoring and management
Global warming monitoring
Herd/school inventory, health/stress monitoring, tracking
Iceberg/ice pack monitoring
Infrared hydrology and vegetation analysis
Insect infestation/invasive species monitoring, warning, control
Landfill monitoring
Oil spill tracking
Plant identification, monitoring, disease detection, canopy management
Water sampling and testing
Wild horse herding
Wildlife biotelemetry, inventory, protection, research, management

HEALTH AND SAFETY

Airborne pathogen, biological agent detection
Aircraft collision avoidance, airport bird-strike deterrence
Audio surveillance
Avalanche prevention and rescue
Disaster assessment, management, relief
Disaster prediction, warning, measurement
Driving and detour directions
Early warning systems
Emergency beacon
Emergency communications, emergency response team coordination
Emergency lighting, medical, and equipment supply and delivery
Federal Emergency Management Agency (FEMA) documentation
Fire detection and prevention, firefighting
Flood risk assessment
Flotation aid drop
Forest fire surveillance and mapping, fire retardant application, controlled burn fire prevention
HAZMAT, land mine/unexploded ordnance detection and inspection
Leak detection (gas, chemical, radiation, water)
Neighborhood watch
Personal safety/person with disability/child monitoring and managing
Power restoration
Radiation detection and cleanup
Search and rescue, missing child and pet locator
Shark repellant dispersal
Ship collision avoidance
Vector detection, monitoring, control

INFORMATION TECHNOLOGY

Aerodynamics/aeronautics/aviation/avionics research and development
Airborne 3G, wifi, WiMax
Biometric scanning
GPS
Laser sensors, Lidar, radar, ultrasonic sensors
Sound level measurement and monitoring
UAV testing and demonstration

METEOROLOGY

Atmospheric sensors
Climate/climate change/greenhouse gas monitoring
Cyclone/hurricane/tornado/typhoon genesis, tracking, measurement
Snowpack measurement
Solar flare, ultraviolet monitoring
Storm chasing
Weather forecasting and measurement
Weather modification, cloud seeding

PHOTOGRAPHY AND VIDEOGRAPHY

360-degree photography and video
Aerial photography, videography, webcam, live/streaming media
Cinematography
High-altitude imagery
Multispectral sensing, forward-looking infrared and near-infrared sensing, thermal sensing and imaging, infrared surveillance
Nature photography and videography
Night vision
Orthographic photography, photogrammetry, photosimulations
Photography and video projection
Time-lapse photography and video

SECURITY AND LAW ENFORCEMENT

Accident investigation and analysis
Air traffic management
Border patrol
Civil unrest, conflict monitoring, anti-looting control
Crime scene investigation, crime scene photography, crime forensics
Criminal surveillance and tracking
Crowd control, event security
Drugs, explosives detection
Fire/arson investigation
Graffiti, trespassing deterrence
Gunshot triangulation
Home security
Human trafficking control
Illegal ship bilge venting detection
Infrared lighting
Maritime surveillance, port security
Night lighting
Night vision surveillance
Perimeter security
Stolen vehicle tracking
Terrorist attack assessment and response
Traffic speed enforcement
VIP monitoring, security

SPORTS, RECREATION, AND ENTERTAINMENT

Aerial sports, aerobatics
Aroma dispersal
Audio (microphone or speakers)
Drone competitions, games, racing
Exploration, orienteering, location scouting
Falconry, hunting
Pyrotechnics
Scavenger/treasure hunts
Tourist guide
Virtual reality flying, virtual tours
Wildlife viewing

APPENDIX D. MODEL UAS SAFETY CODE

For many organizations, preparation of a comprehensive operations manual is not necessary or even desirable as it requires administration and maintenance that may exceed the capacity of the organization. As authorized personnel or public remote pilots may have occasion to fly for these organizations, a general safety code may be tailored to provide specific measures to ensure responsible UAS operations. This model safety code provides a template that can be amended to suit the specific needs of an organization and can be modified as the organization's UAS operations expand or evolve. If the organization develops a customized UAS program, the safety code may become part of a larger operations manual (see Appendix E for a model operations manual).

This model safety code is based on the safety code prepared for Portland Community College by risk manager Robert Gabris, emergency management instructor Jane Ellis, and UAS instructor Ric Stephens.

GENERAL

All uncrewed aircraft systems (UAS) flights must be conducted in accordance with Federal Aviation Administration (FAA) 14 CFR Part 107, this safety code, and any additional rules specific to the flying site.

1. Uncrewed aircraft (UA) will not be flown:
   a. In a careless or reckless manner.
   b. At a location where UA activities are prohibited.
2. UA pilots will:
   a. Yield the right of way to all human-carrying aircraft.
   b. See and avoid all aircraft, and have a visual observer (VO, "spotter") for all flights.
   c. Not fly higher than four hundred feet (400 feet) above ground level (AGL).
   d. Not fly within five miles of an airport without permission of the airport control tower per Part 107.
   e. Only fly UA with an agency-approved pilot in command (PIC).
   f. Not exceed a takeoff weight, including payload, of 55 pounds.
   g. Ensure the aircraft is registered per FAA requirements.
   h. Not operate UA while under the influence of alcohol or while using any drug that could adversely affect the pilot's ability to safely control the UA consistent with Part 107.
   i. Not operate UA carrying pyrotechnic devices that explode or burn, or any device which propels a projectile or drops any object that creates a hazard to persons or property.
3. UA will not be flown in agency sanctioned activities or events unless:
   a. The aircraft, control system, and pilot skills have successfully demonstrated all maneuvers intended or anticipated prior to the specific event.
   b. Flown by an agency-approved remote pilot in command (RPIC) or an uncertificated person manipulating the controls (PMC) supervised by an agency-approved RPIC.
4. All pilots shall avoid flying directly over unprotected people and sensitive structures and shall avoid endangerment of life and property of others.
5. A pre-flight check in accordance with the manufacturer's recommendations or agency's checklist will be completed before each flight.
6. At all flying sites, safety lines must be established in front of which all flying takes place.
   a. (a) Only personnel associated with agency UAS operations are allowed at or in front of the safety line.
   b. (b) At air shows or demonstrations, a straight safety line must be established.
   c. (c) An area away from the safety line must be maintained for spectators.
   d. (d) Intentional flying behind the safety line is prohibited.
7. Excluding takeoff and landing, no UA may be flown outdoors closer than 25 feet to any individual, except for

the RPIC, PMC, VOs, and personnel associated with UA operations.

8. The person manipulating the controls of a UA shall:
   a. Maintain control during the entire flight, maintaining visual contact without enhancement other than by corrective lenses prescribed for the pilot.
   b. Comply with the directions given by the agency-approved RPIC.
   c. Not fly using the assistance of a camera or first-person view (FPV) without an FAA waiver.
9. FAA waivers may only be applied for by the appropriate agency representative.
10. Interpretations and deviations must be approved by the appropriate agency representative.

APPENDIX E. MODEL UAS OPERATIONS MANUAL

Planning organizations with UAS programs should adopt a UAS operations manual to ensure public safety, employee safety, and regulatory compliance while carrying out UAS activities. The UAS operations manual should provide guidelines for safety, remote pilot qualifications and training, standard operational procedures, equipment inspections and maintenance, emergency procedures, and activities conducted by non-agency personnel.

The following model UAS operations manual was modified by Ric Stephens based on the Unmanned Aircraft System (UAS) Operations Manual *prepared for the California Department of Fish and Wildlife. Additional examples are included in the sidebar on* *p. 57* *to provide further resources for creating a planning organization's UAS operations manual.*

CONTENTS

1. INTRODUCTION

To ensure public safety, employee safety, and regulatory compliance while carrying out UAS activities, this UAS Operations Manual (manual) provides standard operating procedures. While this manual may not address all potential UAS activities, it is intended to be the baseline for agency UAS policy and it applies to all agency UAS activities conducted by agency personnel or contractors during their job duties.Wherever possible, this manual draws its terminology and best practices from the Federal Aviation Administration (FAA), other federal and state government entities, and other industry leaders.

1.1. Use of This Manual

This manual provides details of procedures and requirements necessary to safely and efficiently conduct UAS activities. The procedures and requirements outlined in this manual are intended to comply with FAA regulations for the use of small UAS weighing less than 25 kgs (55 lbs.).

The procedures described in this manual apply to all agency UAS activities. Depending on the nature of the task, the agency UAS Coordinator may prescribe additional requirements as needed. If regulations referenced in this manual change, or safer and more effective operational methods are developed, it is the responsibility of all agency UAS operations personnel to notify and provide input to the UAS Coordinator to effect changes to this document. This manual and the policies and procedures provided herein will be reviewed regularly and updated as needed.

Agency UAS operations personnel shall study this manual and have a working knowledge of the policies and procedures contained herein. A copy of this manual and all relevant forms shall be available at every location where agency UAS operations are conducted.

1.2. UAS Safety

Safety is the fundamental consideration in all agency UAS activities. This agency requires a culture of open reporting of all safety hazards. It is imperative that management not initiate disciplinary action or retaliate against any personnel who, in good faith, disclose hazards, safety incidents, or other concerns.

It is the duty of every crew member involved in agency UAS activities to contribute to the goal of continued safe operations. This contribution may come in many forms and includes always operating in the safest manner practicable and never taking unnecessary risks. Any safety hazard, whether procedural, operational, or maintenance related, should be identified as soon as possible after, if not before, an incident occurs. Any suggestions in the interest of safety should be made to the Pilot in Command (PIC) or the agency UAS Coordinator.

Agency UAS activities are to be conducted in a manner that provides an accident-free workplace, including no harm or damage to people, biological resources, equipment, or property, and to make every effort to respect the public's privacy. This agency encourages monitoring UAS regulations, technology, practices, and laws to ensure best safety practices are continually incorporated into the organization.

Ultimately, each agency UAS crew member is responsible for their own safety. Everyone is responsible for knowing their own limitations and should inform their supervisor immediately when a task or conditions are beyond their capability or training, or if they believe a situation is unsafe.

2. SCOPE AND OBJECTIVES

The scope of this manual includes all operations conducted by UAS personnel and applies to all locations where UAS activities may be conducted. This manual is also intended to achieve the following objectives:

- Facilitate administration of UAS activities
- Ensure the safety of UAS crew members and the public when conducting UAS activities
- Establish minimum guidelines for qualifications, safety, training, security, and operational procedures when conducting UAS missions
- Ensure that impacts to biological resources are minimized
- Ensure that operations of UAS do not intrude upon the rights of the public

The following procedures apply to all personnel, including its agents, engaged in UAS activities during their job duties. These procedures are intended to protect personnel and the public from hazards associated with UAS activities.

When operating a UAS, all personnel will abide by FAA flight regulations and guidelines and receive the proper authorizations as outlined in this manual. UAS activities are carried out only by teams of trained employees.

3. DEFINITIONS, ROLES, AND RESPONSIBILITIES

This section defines applicable terms, prohibited activities, and outlines the roles and responsibilities of each employee directly involved in UAS activities.

3.1. Abbreviations and Definitions

See Abbreviations and Glossary appendices.

COMMENT: See Appendix A (UAS Abbreviations) and Appendix B (UAS Glossary) of this report.

3.2. Roles and Responsibilities

The agency UAS personnel roles consist of the UAS Coordinator, Certified UAS Pilot, Pilot in Command (PIC), Visual Observer (VO), Camera Operator, and support personnel. UAS-related duties, to the extent applicable, should be included in the duty statement of all UAS personnel.

3.2.1. UAS Coordinator

The agency UAS Coordinator is an employee trained in all aspects of UAS regulation and operation. The agency UAS Coordinator's responsibilities include, but are not limited to the following:

- Overseeing the scheduling and planning UAS activities in a safe manner and in accordance with the UAS Operations Manual and policy
- Reviewing and authorizing UAS Project Requests prior to any UAS activity
- Reviewing the UAS Project Request with the assigned crew
- Serving as the point of contact for any UAS crew member's concerns about the safety of the UAS activities
- Providing notification to the FAA of any accidents following UAS activities in accordance with organization policy and FAA regulation
- Maintaining the organization's UAS authorization from the FAA
- Maintaining and reporting flight logs per FAA requirements
- Keeping this manual up to date with applicable regulatory changes

3.2.2. UAS Crew

A UAS crew will consist of, at a minimum, a Certified UAS Pilot in the role of PIC for the mission, and a VO. Additional personnel may also be present as support crew members, including a Camera Operator. The responsibilities of each position are detailed below.

3.2.2.1. Pilot in Command (PIC)

The PIC is a Certified UAS Pilot serving as the PIC for a specific mission. The PIC is the crew leader and is directly responsible for mission safety and objectives. During the flight, the PIC's primary duty is to focus on flying the aircraft safely until it is back on the ground. The PIC leads on-site pre- and post-flight UAS activities and is responsible for the following activities:

- Piloting UAS flights for the mission
- Overseeing all on-site UAS activities and ensuring that all activities are being carried out in a safe manner
- Operating the UAS safely and effectively in accordance with the manufacturer's approved flight manual
- Establishing coordination with personnel that will be on-site
- Coordinating with biologists to establish potential risks to biological resources in the operations area
- Terminating UAS activities at any time due to unsafe or changing conditions encountered prior to or during operations
- Conducting and documenting briefings (i.e., tailgate safety meetings) addressing hazards specific to the UAS with site operations personnel; this includes on-site pre-flight assessment of weather conditions and identification and management of all persons in the area that may be affected by the UAS activities
- Verifying that copies of the UAS Project Request, UAS Project Authorization, UAS Operations Manual, and all related FAA documents are present and available on-site
- Performing thorough pre-flight inspections of the aircraft and transmitter and ensuring that all equipment and settings are in order prior to initiating flight
- Designating a location or locations where the Visual Observer (and support personnel) shall be stationed
- Ensuring the UAS is flown within visual line of sight (VLOS) and lower than 400 feet above ground level (AGL)
- Terminating UAS activities if a manned aircraft enters the immediate area and any possibility of conflict exists
- Logging the mission and documenting any accidents, near misses, or unanticipated hazards that occurred during flight and any lessons learned
- Ensuring that a copy of the Flight Log(s) is filed with the UAS Coordinator after each project

3.2.2.2. Visual Observer (VO)

The VO is responsible for aiding the PIC with a dedicated set of eyes and ears during UAS missions. The primary communication during flight is between the PIC and the VO. The VO is responsible for the following activities:

- Keeping their eyes on the UAS and continuously scanning the airspace where the UAS is operating for any potential aircraft or collision hazards and maintaining a see-and-avoid awareness of the position of the aircraft and the surrounding airspace through direct visual observation
- Assisting the PIC in identifying any potential hazards or changing conditions that may affect the mission or the safety of persons or property
- Communicating to the PIC the active flight status of the UAS and any hazards that may enter the area of operation so that the pilot can take appropriate action
- Watching and listening for any abnormal sounds or flight characteristics being exhibited by the UAS

- Being prepared to carry out emergency plans and procedures in the event of an emergency incident or accident

3.2.2.3. Support Personnel

Support personnel refers to employees that are part of the UAS crew providing added support to the PIC or VO. The support personnel's duties are similar to the VO's responsibilities. Support personnel are responsible for the following activities:

- Following the instructions of the PIC during UAS activities
- Helping to maintain a "sterile cockpit" environment for the PIC and the VO, such that they have minimal distractions, by keeping conversations out of their earshot and ensuring any spectators do the same
- Monitoring airspace and site conditions that could adversely affect UAS operations
- Being prepared to carry out emergency plans and procedures in the event of an emergency incident or accident

One of the support personnel may be designated as a Camera Operator. The Camera Operator may use an optional additional radio control transmitter that operates only the UAS onboard camera. The Camera Operator coordinates closely with the PIC and is typically stationed next to the PIC along with the VO.

4. QUALIFICATIONS AND TRAINING

Employees engaged in UAS activities shall possess the necessary certifications, training, and experience as defined in this manual and will maintain a professional level of competency and proficiency to safely perform the assigned work.

4.1. UAS Pilot

Prospective UAS Pilots must possess both the appropriate knowledge and sufficient skills to legally and safely operate UAVs. To request that personnel be trained and certified as an agency UAS Pilot, a supervisor must fill out a UAS Pilot Request form.

The following qualifications are required to be a UAS Pilot:

- FAA Remote Pilot Certificate
- State driver's license
- Training in all specific details of the UAS to be operated including normal, abnormal, and emergency procedures
- Appropriate hours of logged flight time on the UAS to be operated
- Passing a practical pilot proficiency test

The FAA Remote Pilot Certificate is required to satisfy a knowledge component. It can be obtained by either:

1. Taking and passing the Remote Pilot Knowledge Test (Unmanned Aircraft General—Small) at an FAA-certified testing center, or
2. If the staff member holds a Part 61 manned pilot certificate, with a completed flight review in the preceding 24 months, successfully completing the "ALC-451: Part 107 Small Unmanned Aircraft Systems (sUAS)" course and examination.

A state driver's license is required to ensure staff has adequate vision for UAS operations. A signed medical note from a licensed medical professional indicating that the staff has sufficient corrected visual acuity to pass the vision screening required for a state driver's license may be substituted for a state driver's license.

To satisfy the skills component, staff must log appropriate flight time on equipment similar to what they will be flying for the organization (similar flight configuration, similar sensor package, etc.), and pass a practical pilot proficiency test administered by staff approved by the agency UAS Coordinator.

Appropriate flight times and required skills will be determined and documented for each UAS operated by the organization.

Flight time can be accrued at work using agency equipment if an approved agency UAS Pilot is with the prospective pilot during the flights and is ready to take over if needed.

The organization may provide a basic UAS training course to allow for the accrual of this flight time. Flight time may also be accrued with just a VO at a location that has been designated by the UAS Coordinator as a training location.

Flight time may also be accrued outside of work with non-agency equipment so long as the equipment and flight times can be appropriately verified and the UAS Coordinator has approved the equipment.

As a guideline, no more than one-third of the required flight time should be accrued with autonomous flights.

After obtaining the FAA Remote Pilot Certification, staff will be considered a Provisional UAS Pilot and can legally fly according to the FAA regulations. This allows the Provisional UAS Pilot the legal means to fly at work under the supervision of a certified agency UAS Pilot while gaining the required flight hours and experience prior to becoming a certified agency UAS Pilot.

Once documentation of all requirements is provided to the UAS Coordinator, an agency UAS Pilot Certificate will be issued, authorizing the new UAS Pilot to operate UAS for the organization.

4.2. Visual Observer

The following qualifications are required to be an agency UAS Visual Observer (VO):

- State driver's license or signed note from a licensed medical professional indicating that the staff has sufficient corrected visual acuity to pass the vision screening required for a state driver's license
- Pass the online FAA ALC-451 course, "Part 107 Small Unmanned Aircraft Systems (sUAS)"

4.3. Training and Records

The key to continued safe operations is to maintain a professional level of competency. The UAS Coordinator will maintain a file for each UAS Pilot and VO that contains documentation of pertinent documents, training, and experience. It is the UAS Pilot's responsibility to verify their training file contains at a minimum:

- A copy of their FAA Remote Pilot Certificate
- A copy of their state driver's license or medical note
- Agency flight proficiency testing documentation
- Agency UAS Pilot Certificate
- Accurate and up-to-date flight log, including any incidents
- Records of any extended training

4.3.1. Recurrent Training

UAS Pilots are required to keep their knowledge and skills up to date to maintain operational eligibility. The FAA Remote Pilot Certificate is valid for 24 months, and pilots must recertify every 24 months.

All UAS Pilot flight time must be logged with the UAS Coordinator. Minimum flight time of 3 flights per 90 days must be logged to stay current.

The flight proficiency test must be passed every 24 months.

4.3.2. Degree of Suitability

Employees must demonstrate to the UAS Coordinator's satisfaction a continued high degree of suitability for participation in UAS activities. Demonstration includes, but is not limited to, the following factors:

- Comfort and competency while in flight
- Contributions to the objectives of the UAS mission
- Compliance with the standards of the UAS Operations Manual
- Willingness to work in a team-oriented environment
- Acting in a safe manner always

4.3.3. Good Judgment

UAS Pilots are prohibited from operating an aircraft in a careless or reckless manner that could endanger the life or property of another. UAS Pilots are expected to exercise good judgment and conduct themselves in an ethical, responsible, lawful, and safe manner with respect to other UAS crew members, personnel on-site, and the public.

4.4. Suspension

Any previously certified UAS Pilot who does not meet the ongoing eligibility requirements described above shall be suspended from UAS activities. UAS Pilots may be reinstated by the UAS Coordinator if they demonstrate acceptable compliance with the aforementioned requirements.

5. OPERATIONAL PROCEDURES

5.1. Requesting a UAS Project

Prior to any UAS project, the project proponent will submit a UAS Project Request form to the UAS Coordinator.

The general elements of the UAS Project Request are:

- Site location name, county, and region
- Site map with target areas outlines, potential access and launch sites identified, and land ownership identified
- Agency land manager permission, if the project is on agency-owned land
- Site physical description, with potential hazards identified
- Purpose and objective of the UAS project
- Name, location, and emergency phone number of the nearest hospital

5.2. Review and Authorization of a UAS Project

The UAS Coordinator or a UAS Pilot will assess the viability of the proposed project by completing the UAS Project Authorization form. This assessment identifies any potential hazards associated with the UAS activity, and describes measures to eliminate, guard against, or avoid those hazards.

The UAS Project will not move forward until the UAS Project Authorization has been signed by the UAS Coordinator. At a minimum, the assessment shall include a description of the following items and potential hazards and corresponding safety measures associated with each of the items:

- Airspace check verifying via the agency, UAS restricted areas map, or other appropriate sources that the project is in authorized airspace
- Property ownership assessment and verification of owner permission, if required
- Site access and launch location(s) for optimum visual line of sight during operations
- Overhead obstructions, including power lines, trees, buildings, communications towers
- Privacy rights issues within identified flight boundaries
- Additional comments pertaining to any hazards or safety measures associated with the UAS activity

Crew members involved in UAS activities are encouraged to visit the site location if possible prior to conducting the mission to assist in preparing the UAS Project Authorization.

A copy of both the UAS Project Request and the approved UAS Project Authorization will be kept on hand during any UAS projects.

5.3. Pre-UAS Project Procedures

At a minimum, the following procedures will be used in pre-UAS project planning preparation. The UAS Coordinator may require additional site-specific requirements.

5.3.1. UAS Crew Assignment

The UAS Coordinator will assign a UAS Crew for the project. This will include at a minimum a PIC and a VO. Additional crew will be assigned as needed.

5.3.2. UAS Operations at an Agency Property or Facility

For UAS operations within an agency land or facility boundary, the UAS Project proponent shall contact, and obtain permission from, the appropriate agency land or facility manager before submitting the UAS Project Request. Any restrictions or limitations required by Title XIV of the State Code of Regulations or the land manager must be documented and noted on the UAS Project Request form. The UAS Coordinator will confirm this permission with the land or facility manager. No UAS Project shall be conducted at an agency land or facility without the expressed permission of the land or facility manager.

5.3.3. UAS Operations at Non-Agency Properties

For UAS activities planned on lands not owned or managed by the agency, appropriate permission is required and must be obtained by the UAS Project proponent and noted on the UAS Project Request form. For state, federal, or local government lands, check with the appropriate authority to determine if permission or notification is required. If possible, engage with the law enforcement authority responsible for the area of interest. For private lands, written permission must be obtained from the landowner. If possible, the landowner, or their representative, should be on-site during the project.

5.3.4. UAS Operations Requiring an FAA Waiver

For flights requiring any deviation from Part 107 regulations, a waiver must be obtained from the FAA. The following list are flights that require a waiver and the relevant Part 107 Section.

Fly a UAS from a moving aircraft or a vehicle in populated areas	§107.25 – Operation from a Moving Vehicle or Aircraft
Fly a UAS at night	§107.29 – Daylight Operations
Fly a UAS beyond your ability to clearly determine its orientation with unaided vision	§107.31 – Visual Line of Sight Aircraft Operation
Use a visual observer without following all visual observer requirements	§107.33 – Visual Observer
Fly multiple UAS with only one remote pilot	§107.35 – Operation of Multiple Small UAS
Fly a UAS without having to give way to other aircraft	§107.37(a) – Yielding Right of Way
Fly a UAS over a person/ people	§107.39 – Operation Over People

Fly a UAS: • Over 100 miles per hour ground speed • Over 400 feet above ground level (AGL) • With less than 3 statute miles of visibility • Within 500 feet vertically or 2,000 feet horizontally from clouds	§107.51 – Operating Limitations for Small Unmanned Aircraft

A waiver is also required to fly near airports (controlled airspace). The waiver may either be from the FAA or through the LAANC (Low Altitude Authorization and Notification Capability) program.

COMMENT: The LAANC program currently allows pilots to apply online for a waiver near all major U.S. airports. The program accelerates the waiver process and is continually being expanded to include more airports throughout the country.

5.3.5. UAS Pre-Flight Checklist

Prior to heading out for a UAS Project, the crew will check off the items on the agency Flight Checklist and Log form to be completed in-office. This includes:

- Check airspace
- Check for Notices to Airmen (NOTAMs) and Temporary Flight Restrictions
- Charge batteries and other equipment
- Check weather forecast
- Ensure required documents are in hand for flight, including any waivers

All items shall be checked off prior to conducting any flight activities.

5.4. On-Site UAS Flight Procedures

5.4.1. Safety Briefing

Prior to UAS operations, the PIC will conduct an on-site briefing for all personnel (UAS crew, property owner, and any other staff or observers). It will include a review of the UAS Project Request and Authorization, tasks to be undertaken, sterile cockpit procedures, safety procedures, any unusual hazards or environmental conditions, and modifications of standard procedures, if necessary.

5.4.2. UAS Flight Checklist

Prior to every flight, the crew will check off every item on the agency UAS Flight Checklist and Log form not already completed in the office. This includes the following items:

- Conduct safety checks, including the precautions listed in section 5.7.1 below
- Recheck for Notices to Airmen (NOTAMs) and Temporary Flight Restrictions
- Ensure required documents are in hand for flight including any appropriate FAA waivers
- Record current weather conditions
- Check airspace for aircraft and other hazards immediately prior to flight
- Equipment prep and inspection
- Pre-flight power-ups and settings check
- Ensure the launch area is clear of people and other hazards
- Low-altitude flight test

All items shall be checked off prior to conducting any flight activities.

5.4.3. Flight Procedures

During UAS Flights, all FAA regulations will be followed. Additionally, the following rules will apply:

- A PIC and a VO must be present for all flights.
- The PIC or the VO must always maintain visual contact with the UAV.
- A sterile cockpit environment must always be maintained.
- If a manned aircraft enters the proximity of the UAS mission, the UAV will be landed until the manned aircraft is outside of the area.
- In the event of any unplanned in-flight situation, contingency plans will be followed immediately.
- On landing, power-down and checklist procedures will be followed immediately.

5.5. Post-UAS Flight Procedures

Upon finishing a UAS project, the PIC will be responsible for submitting a completed agency UAS Flight Checklist and Log summarizing the flight activities with the UAS Coordinator. The PIC will download and file the data from the project to a shared file location specified by the UAS Coordinator.

COMMENT: Many agencies have state or local government regulations regarding data management. This section of the Operations Manual should be consistent with these requirements.

5.6. Privacy

The use of the UAS potentially involves privacy considerations. Absent a warrant or exigent circumstances, UAS projects shall adhere to FAA altitude regulations and shall not intentionally record or transmit images of any location where a person would have a reasonable expectation of privacy (e.g., residence, yard, enclosure). Operators and observers shall take reasonable precautions to avoid inadvertently recording or transmitting images of areas where there is a reasonable expectation of privacy. Reasonable precautions can include, for example, deactivating or turning imaging devices away from such areas or persons during UAS operations. Additionally, unintended imaging overlap into private lands should be trimmed from final image products prior to public release or use in reports.

5.7. General UAS Safety Procedures

The procedures described in this section apply to all agency UAS activities. Depending on the nature of the task, the UAS Coordinator may prescribe additional requirements as needed. Agency UAS crew members who fail to follow these safety procedures will be subject to disciplinary action and may have their UAS privileges revoked. Safety rules do not exist as a substitute for common sense, sound judgment, and a continuing concern and vigilance for maximum safety.

The UAS Coordinator will be responsible for the coordination of the regular review of this manual.

5.7.1. Safety Precautions Applicable to All UAS Activities

It is the duty of every crew member involved in UAS activities to contribute to the goal of continued safe operations. This contribution may come in many forms and includes always operating in the safest manner practicable and never taking unnecessary risks. Any safety hazard, whether procedural, operational, or maintenance related, should be identified as soon as possible to avoid incidents. It is the responsibility of every crew member to ensure the following, unless otherwise authorized:

- UAS operations are limited to daylight hours (official sunrise to official sunset), although civil twilight (30 minutes before sunrise and 30 minutes after sunset) operations may be approved with appropriate UAS lighting.
- UAS operations shall not be conducted over any persons not directly involved in the UAS project operations.
- All aircraft must use flight controllers that incorporate stabilization and autopilot systems with GPS "return to home" (RTH) capabilities.
- Once UAS crew members arrive on-site for a project they should be in an alert status, actively scanning the airspace and listening for aircraft and observing any other activities in the area which could affect or be affected by the UAS flight activities.
- UAS crew members should continuously monitor weather conditions, specifically wind velocity and the potential of a dust or sandstorm developing.
- An appropriate level launch area should be selected with sufficient space (preferably away from bystanders) to unpack and assemble the necessary equipment for the UAS project. Try to select an area where the UAS will not kick up a dust cloud on takeoff. UAS operations tend to attract local bystanders so be prepared to implement controls for safety.
- A first-aid kit with laceration supplies and a fire extinguisher shall be available on-site, and a cellphone shall be readily available on-site in the event of an emergency.

5.7.2. Minimum Flight Crew Requirements

At a minimum, all UAS operations must include both a PIC and a VO. Under no circumstances will an agency UAS Pilot conduct UAS activities alone.

5.7.3. Limits and Termination of UAS Activities

UAS projects shall not be conducted under the following conditions:

- When weather conditions or visibility are deemed unsafe by the UAS Coordinator or PIC
- When manned aircraft are observed within the immediate vicinity
- In any situation where local conditions have changed considerably prior to or during flight
- If significant risks to equipment, staff, or observers are identified that cannot be mitigated

The PIC has final authority regarding whether conditions are safe for flying. Should any UAS activity be terminated due to safety or changing conditions, the PIC will inform the UAS Coordinator of the decision.

6. EQUIPMENT, INSPECTIONS, AND MAINTENANCE

Although an airworthiness certification is not required, small UAS aircraft are exposed to high-frequency vibrations and should be well maintained to ensure they are always in a condition for safe flight. It is important to ensure the safety of the UAS crew by regular inspection and maintenance of all UAS aircraft, radio transmitters, and accessories.

Maintenance logs should be maintained for each aircraft and at a minimum, the following UAS components should be checked and replaced per manufacturer guidelines or if otherwise necessary:

- Motors
- Propellers (check for nicks and abrasions)
- Electronic speed controllers
- Electrical connections (plugs and solder connections)
- Antennae and GPS mounts
- Screws that secure the body of the UAS, its arms, motor mounts, landing gear, camera gimbal, etc.

The PIC is responsible for choosing the appropriate equipment.

6.1. Lithium-Polymer (LiPo) Battery Management

Batteries used for UAS operations are made from Lithium Polymer (LiPo) and are especially sensitive and potentially dangerous if not maintained and stored properly. As an example, if a LiPo battery is discharged to less than 20 percent of capacity it can potentially catch fire or explode during the next charging. Special battery chargers with cell balancing capabilities must be used and the batteries must be monitored and stored safely.

All batteries should be charged, maintained, and stored in accordance with the battery manufacturer's recommendations. Charging of the batteries must always be monitored closely. Never leave a charging battery unattended; it could catch fire!

LiPo batteries should also be drained to approximately 60 percent of capacity if stored for more than a few days. Some batteries have autodischarge capability, but not all. Storing LiPo batteries charged to 100 percent for long periods will cause the battery to begin to off-gas and start bulging. Bulging batteries must be properly discharged and disposed of immediately at an approved disposal site.

6.2. UAS Crew Equipment Requirements

Separate from the UAS aircraft, radio control transmitter, and tablet, each crew must have the necessary equipment, provided by the agency, to use for the UAS Project. This includes, but is not limited to, the following items:

- Spare propellers, spare batteries, field battery charger
- Launchpad (when needed)
- Handheld anemometer to measure wind velocity
- First aid kit
- Fire extinguisher

6.3. Maintenance Logging

All hardware and software updates will be logged into a central location for each UAS setup. This will include:

- Firmware updates to UAS, controller, and batteries
- Tablet application updates (DJI Go, Map Pilot, etc.)
- Tablet OS updates (iOS)
- Equipment repair or replacement (rotors, batteries, etc.)

6.4. Use of Personal UAS

Agency staff may not use their personal UAV for agency work.

7. EMERGENCY PROCEDURES

UAS accidents or incidents are defined as an injury or illness occurring during or as a result of a UAS activity. An incident is further defined as any adverse consequence that caused or could have caused injury to personnel and/or damage to equipment, properties, or biological resources.

Biological resource incidents are more than just collisions and include but are not limited to displacement of wildlife, nest or den abandonment, aggressive behavior towards the UAS by wildlife, and out-of-ordinary vocalization or alarm calling by wildlife.

Accidents resulting from UAS activities can range from minor injuries and mishaps to life-threatening injuries or even death. All accidents and incidents, regardless of the severity or whether the employee is injured, must be reported to the UAS Coordinator.

All accidents requiring medical treatment or resulting in a serious injury or death must be reported immediately after taking necessary actions to preserve life or respond to injuries. In an emergency, dial 911 to reach local authorities and medical aid as soon as possible.

7.1. Incident Reports

If an incident or accident resulting from UAS activities occurs, the PIC must complete and submit an agency UAS Incident Report.

Incidents from operation of a UAS that result in serious injury or property damage of more than $500 must also be reported to the FAA within 10 days. The PIC must coordinate with the UAS Coordinator to file this report. The PIC will report all near misses involving UAS activities to the UAS Coordinator.

7.2. Reporting and Investigation Responsibilities

A key element of any successful accident prevention program is the timely reporting and investigation of all accidents and incidents. Determining the root cause of an incident and implementing corrective actions will lead to a continual improvement in UAS safety. All crew members involved in the UAS activity (PIC, VO, UAS Coordinator, and any support personnel) must freely discuss and document any incident or near miss to determine what went wrong and develop ways to prevent recurrence.

7.2.1. UAS Coordinator

The UAS Coordinator has the following responsibilities to investigate and report incidents and accidents:

- Review the incident report submitted by the PIC
- Ensure the submission of the incident to the FAA within 10 days of any operation that results in serious injury or property damage more than $500
- Immediately investigate each employee-reported incident
- Notify their respective supervisor of any work-related incident
- Submit to their respective health and safety official the timely documentation of elements necessary for job-related injuries or illness requiring medical treatment or first aid provided by a medical professional

8. UAS ACTIVITIES CONDUCTED BY NON-AGENCY PERSONNEL

Any agency or contractor personnel on an agency UAS Project must agree to abide by the procedures established in this manual. Those meeting the standards of this manual may be allowed to conduct UAS Projects for the agency after proper certification and documentation has been approved by the UAS Coordinator.

8.1. Contracting for UAS Services

When the agency contracts out for services that include UAS technology, specific requirements must be met and documented.

8.1.1. UAS Submittal Package

The contractor shall provide appropriate UAS equipment for the job being contracted. This includes the most suitable aerial vehicle and payload (camera/sensors) equipment for the job, ground station equipment, and data post-processing capabilities.

The contractor must be certified by the FAA for UAS operations as applicable to the work being contracted. The contractor is responsible for obtaining the appropriate authorization as may be required by the FAA for any UAS projects under this contract. Proof of the certification/exemption and authorization must be provided to the agency prior to any flights.

The contractor shall obtain general liability insurance per agency standards specifically covering the UAS operations and shall name the agency as additional insureds for any UAS use.

Proof of liability insurance must be provided to the agency prior to any flights. The contractor must also comply with all safety procedures as set out in the FAA regulations and the agency's UAS policy.

MODEL OPERATIONS MANUAL APPENDICES

APPENDIX 1. UAS IN-FLIGHT CONTINGENCY PROCEDURES

The UAS In-Flight Contingency Procedures cover several potential unplanned in-flight situations. The procedures listed below provide the basic steps for each situation. These procedures may be modified to the capabilities of a UAV as needed.

Loss of visual line of sight: Defined as when neither the PIC nor the VO has a visual on the UAV.
Procedure: If the UAV is visually reacquired promptly, the mission may continue. Otherwise, the mission shall be aborted, and the PIC shall attempt to assess the location of the drone. Prior to piloting the drone in any direction, the PIC will utilize the map and data readouts on the controller and the camera on the drone to determine its position. If still unclear, the PIC will direct the UAV to ascend to gain more clearance from ground objects and will then try to assess the location again. If visual line of sight is not then reacquired, a Return-to-Home command shall be executed. If the UAV is on an autonomous mission, Return-to-Home com-

mand shall be executed if the UAV is not visually reacquired promptly. Once visual line of sight is reacquired, the Return-to-Home command may be canceled, and the mission may be continued.

Lost link: Defined as when the Controller and the UAV are no longer connected, and the PIC no longer has control of the UAV.
Procedure: The UAS will be programmed to issue the Return-to-Home command to the UAV in which the UAV climbs to a preset altitude, returns to the Home Point, and lands.

Flyaway: Defined as a lost link condition where the Return-to-Home command is not being issued or not being executed by the UAV.
Procedure: This is an emergency and all attempts should be made to regain control of the UAV by moving closer to the UAV. If this situation occurs while operating in controlled airspace, or if there is a chance of the UAV entering controlled airspace, the PIC must notify the ATC as soon as possible.

Evasive maneuvers: Defined as unplanned manual maneuvering of the UAV to avoid wildlife interaction.
Procedure: To avoid an aggressive bird, the first option is to ascend rapidly. Birds cannot ascend as fast as a drone. If the drone is already at max altitude, move laterally away from the bird. Once clear of the bird, move laterally until enough distance has been created to safely descend and land the drone. Do not resume operations until the bird has left the area. See Figure E.1.

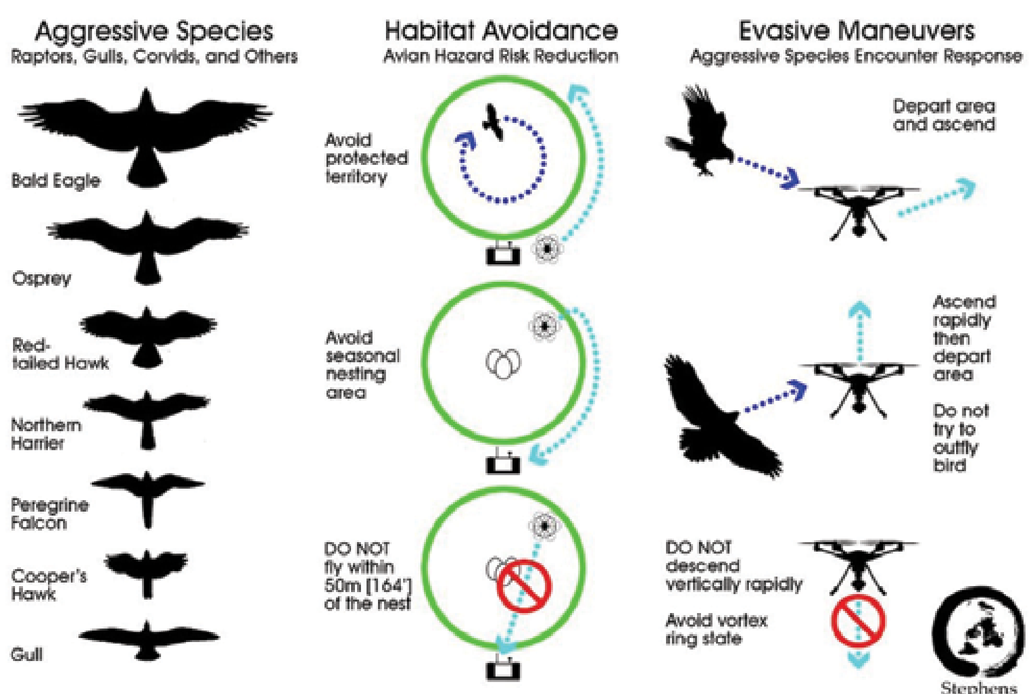
APPENDIX 2. UAS INCIDENT PROCEDURES

Near-Miss Incidents

A near miss is an event in which personal injury or damage to equipment, property, or the environment nearly occurred, but was averted. If a near-miss incident occurs, submit a completed copy of the agency UAS Incident Report with a description of the incident to the agency UAS Coordinator within 48 hours of the incident.

In a near miss the list of persons injured and environmental, property, and equipment damaged should be entered as "None" or equivalent. The description should include distance details of the near miss and what actions were taken to avoid injury or damages.

Figure E.1. Bird strike avoidance guidance (Ric Stephens)



UAS Crashes

A crash includes any incident that results in damage to the UAS, persons, property, equipment, or the environment resulting from a collision with people, wildlife, trees, structures, wires, terrain, other obstructions, or mechanical failures.

Following a crash, agency staff should immediately take appropriate actions to protect people and property from further damage and administer appropriate first aid or seek medical assistance for injured persons.

If the UAS contains LiPo batteries, they may be crushed or punctured in a crash. Acting to mitigate fire risk is a critical secondary consideration to treating injured persons.

If a crash occurs, the PIC must submit a completed agency UAS Incident Report to the agency UAS Coordinator within 48 hours of the incident. The incident report must include a clear description of the incident, any injuries to persons, and all damage to equipment, property, or the environment, including estimates of costs to repair or replace any property or equipment.

Should damage or injury occur to non-agency persons or property, provide contact information for the PIC and the agency UAS Coordinator to any involved parties and collect contact information from them for inclusion in the incident report and follow-up.

Agency staff should recover the UA involved in a crash if the recovery can be accomplished without placing staff or other equipment at risk of injury or damage. During recovery, a fire extinguisher should be carried by the recovering staff. Photo documentation of the crash site should be made for inclusion with the incident report.

APPENDIX 3. UAS MISSION PLANNING TEMPLATE

See p. 106.

APPENDIX 3. UAS MISSION PLANNING TEMPLATE

UAS Mission Planning Form

Mission Name	✓	
Pilot-in-Command Name, Certificate No., Mobile Phone No.		
Organization / Client		
Property Owner Approval		
Flight Crew: Remote Pilot(s), Visual Observer(s), others		
Mission Description, Standard Operating Procedures, Important Considerations		
UAV Make(s)/Model(s), Registration Number(s)		
Payload		
Mission Map (attached)		
Location Address		
Latitude & Longitude		☐ Lat ☐ Long
Airspace		☐ A ☐ B ☐ C ☐ D ☐ E ☐ Special
Nearest Airport, Distance, RF		
Airspace Authorization (attached)		☐ FAA "DroneZone" Airspace Waiver No. ☐ LAANC No.
Waivers (attached)		☐ Night ☐ Over People ☐ From Moving Vehicle ☐ Multiple Aircraft ☐ BVLOS ☐ +400'AGL
Radius / Area		
Maximum Altitude (≤400' AGL)		
Flight Mode/Path		
Date(s)		
Time(s)		☐ Launch/Land ☐ Sunrise/Sunset
Solar Angle(s)		
GPS & EMI		☐ Satellites ☐ EMI
Visibility & Weather		☐ ≥3SM ☐ Wind ☐ Precipitation ☐ Density Altitude
Pre-flight Checklist		☐ Manufacturer's Manual ☐ Operator's Checklist
Post-flight Checklist		☐ Manufacturer's Manual ☐ Operator's Checklist
Flight Log		☐ FAA Report (if required)
Data Management		

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ACKNOWLEDGMENTS

This PAS Report has benefited from the support and expertise of many individuals: Kraig Blim, Daniel Boultinghouse, Dawn Davis, Lawrence Dennis, Jason Gibson, Spencer Karel, Rich Margerum, Tom Mynes, Byron Will-Noel, Jeff Pricher, Mike Stys, Tristan Sundsted, Rich Thurau, Dean Walton, and Bob Watrel. In addition, many organizations provided teaching and aerial project opportunities: Big Bend Community College, NV5, Portland Community College, South Dakota State University, University of Oregon, and WHPacific.

Thank you to Rob Dannenberg for drawing on his extensive UAS mission experience in fleshing out Chapters 2, 3, and 4, and to Wendie Kellington and Patrick Sherman for sharing their extensive legal and regulatory expertise in writing Chapter 5. The report was further improved through the thoughtful review and comments provided by Petra Hurtado, PHD, APA; Patrick Sherman; Alice Pence, Port of Portland; and Jordan Petersen, ColeJenest & Stone. Thanks also to the practitioners who contributed sidebars to the report: Alice Pence; Emily McCoy, Sara Egan, AICP, and Maddie Clark, Design Workshop; Adam Cohen and Susan Shaheen, Transportation Sustainability Research Center, University of California, Berkeley; and Kathleen Schwind, MIT Special Interest Group in Urban Settlement. And special thanks to Ann Dillemuth, AICP, who deserves credit for herding cats, juggling balls, and many other analogies that apply to the complexity of producing a PAS Report.

Finally, I am deeply indebted to my wife, June—a talented wildlife artist, extraordinary ornithologist, and skilled drone operator—for her support and guidance with UAS projects, teaching, and the occasional avian encounter.

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