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Tech Brief

USE OF SMALL UNMANNED AIRCRAFT – BASIC FUNDAMENTALS

INTRODUCTION

State Departments of Transportation (DOTs) have found that the adoption of small Unmanned Aircraft Systems (UAS) as a supplemental tool across various use cases can increase safety, cost savings, and efficiency in collecting data. Given this interest, the Federal Highway Administration (FHWA) has been working with State DOTs to incorporate UAS into their operations. FHWA has assisted transportation agencies in understanding UAS applications, limitations, and use cases.

This document provides foundational information on UAS utilization including regulations, aircraft platforms, remote sensors, and UAS data management.

FAA REGULATIONS

UAS operators in both the public and private sectors must also adhere to statutory and regulatory requirements. Public aircraft operations (including UAS operations) are governed under the statutory requirements for public aircraft established in 49 U.S.C. § 40102 and § 40125. Additionally, both public and civil UAS operators may operate under the regulations promulgated by the Federal Aviation Administration (FAA). The provisions of 14 CFR Part 107 apply to most operations of UAS weighing less than 55 lbs. Operators of UAS weighing greater than 55 lbs may request exemptions to the airworthiness requirements of 14 CFR part 91 pursuant to 49 USC §44807. UAS operators should also be aware of the requirements of the airspace in which they wish to fly as well as the requirements for the remote identification of unmanned aircraft. The FAA provides extensive resources and information to help guide UAS operators in determining which laws, rules, and regulations apply to a particular UAS operation. For more information, please see https://www.faa.gov/uas/.

Public aircraft operation is significantly limited in purpose under the statute and activities such as mapping, surveying, planning, or monitoring infrastructure construction and other generalized public works activities do not qualify for public aircraft authority. These small UAS activities must be carried out under the authority of 14 CFR Part 107 (Part 107). All government entities qualify for operation as a civil entity and may operate under the rules of Part 107. Unlike public aircraft operation, Part 107 has few restrictions on operational purpose. Operating in accordance with Part 107 requires the remote pilot in command to have a remote pilot certificate which is done on an individual pilot basis, while public aircraft operations require additional coordination with the FAA for approval for the organization, as well as determination that the function for which the operation would occur falls within the parameters of § 40125(a)(2). Public aircraft operations also require the organization to take on additional risk and liability. Table 1 provides a comparison of the requirements for Part 107 and public aircraft operations. As Part 107 has evolved, there are many advantages to flying under Part 107. It provides few restrictions on operational purpose, use of the Low Altitude Authorization and Notification Capability system (LAANC), fewer reporting requirements, and ongoing beneficial updates, which has made Part 107 a logical choice for many State DOTs.

Safety is a crucial element of each flight and is the responsibility of the Remote Pilot in Command (RPIC) (14 CFR § 107.19). The FAA regulations for the commercial use of small UAS help mitigate risk for operations. It is the duty of the RPIC to ensure that the small UAS is in a condition for safe operation (14 CFR § 107.15). Positive relationships with other agencies and the public to coordinate and notify

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those whom the operations may affect (e.g., medical helicopter flights operating in the vicinity, nearby airports, property owners) can help facilitate local awareness of recurring operations.

Table 1. Comparison of FAA Part 107 and Public Aircraft Operator

	Commercial Operations 14 CFR § 107	Public Aircraft Operator 49 U.S.C. § 40102 and § 40125
Aircraft Requirements	UAS <55 pounds	Self-certification by the public agency
Pilot Requirements	Part 107 remote pilot certificate with small UAS rating	Self-certification by the public agency
Airspace Requirements	Airspace waiver or authorization for Class B, C, D, E airspace.	Blanket Certificate of Authorization (COA) for Class G within the Continental United States or Jurisdictional COA for Specific Airspace in a specific operating area
Types of Operations	Visual Line of Sight, Class G Airspace, Below 400 ft above ground level (AGL)	Public Aircraft Operations (AC 00-1.1B)

Safety programs vary between agencies and involve an understanding of the nature of the work and the obstacles that are on-site within the operating area and airspace. It can be beneficial for State DOTs to develop risk management procedures that include the following topics:

- Part 107 Operating Rules - (14 CFR § 107.11-107.51)
- Airspace - (14 CFR § 107.41)
- Weather - (14 CFR § 107.49, 107.73, 107.74)
- Proximity to traffic and people - (14 CFR § 107 Subpart D)
- Radio interference - (14 CFR § 107.73)
- Emergency procedures - (14 CFR § 107.49, 107.73, 107.74)
- Identification and understanding of potential site hazards before flying - (14 CFR § 107.19, 107.49)
- Pilot experience and proficiency - (14 CFR § 107.65, 107.73)

RPIC of small UAS must be cognizant of the requirements of the airspace in which they wish to fly. When flying in controlled airspace, FAA uses the LAANC system to provide near-real time approval from Air Traffic Control (ATC). The above consideration for the development of risk management procedures is not comprehensive, States DOTs which are operating UAS should seek additional and substantive resources to assist with this process. The FAA offers extensive resources and information to help RPICs determine which laws, rules, and regulations apply to a particular small UAS operation. For more information, see https://www.faa.gov/uas/.

Types of UAS Aircraft

State DOTs may consider a variety of factors when investing in UAS to integrate across its operations. Two major types of UAS are available, based on the type of aircraft: multi-rotor and fixed-wing. There is an emerging third type of UAS that is a vertical take-off and landing aircraft that combines the utility of a traditional rotorcraft and a traditional fixed-wing. Each type is suited for different applications (see Table 2). Fixed-wing is the most advantageous when it is necessary to cover large areas efficiently. This is especially true if a waiver can be obtained for beyond visual line of sight operations. If large areas do not need to be covered, multi-rotor aircraft are typically preferred because they can take off and land vertically, maneuver under challenging environments, and hover in place. Multi-rotor aircraft are generally limited to 25-60 minutes of flight time. Depending on the site of interest and data collection mission goals, multiple batteries may be required. The hybrid fixed-wing UAS can take-off and land vertically and hover as a rotorcraft but can also transition into forward flight relying more on its wings to provide lift.

Table 2. UAS Aircraft Platforms Strengths and Weaknesses

Multi-Rotor UAS	
Strengths	**Weaknesses**
Vertical take-off and landing and flexibility on take-off and landing sites	Battery life
Hover in place	Generally lower payload capacity
Easy to fly	Lower endurance than fixed-wing
Maneuverable	More complex to maintain, due to more moving parts
Lower cost	Typically, higher noise level
Ability to change camera angles	
Precision maneuvering	
Fixed-Wing	
Long endurance	Cannot hover unless VTOL
Aerodynamically efficient	Higher vulnerability to turbulence
Cover large areas more efficiently	Need large take-off and landing zones
Vertical Take-off and Landing	
Long endurance	Not as versatile for complex maneuvers as rotorcraft
Vertical take-off and landing	Less efficient than multi-rotor while hovering, or while in take-off and landing configurations
Cover large areas efficiently due to airfoil/wing while in flight	Limited close range inspection capabilities
Aerodynamically efficient	Can be target for birds-of-prey
Reduced take-off and landing size zones than traditional fixed-wing	Higher maintenance costs

REMOTE-SENSING DATA

UAS aircraft can be equipped with different types of sensors for remote sensing, including high-resolution Red, Green, Blue (RGB) cameras, Light Detection and Ranging (LiDAR), hyperspectral, thermal/infrared cameras, and ultrasonic sensors. Selection of the UAS sensor depends on analysis and monitoring uses, the preference for images or LiDAR data depends on the project goals and budget, site characteristics, and accuracy or resolution requirements.

High-resolution RGB visual camera sensors come in a wide variety of configurations and specifications, which provide options when choosing a UAS for varying missions. Data collection using RGB cameras often benefits from basic photography knowledge, particularly given the rapidly changing lighting and weather conditions that can occur. Understanding the tradeoffs between ISO (the standard industry scale for measuring sensitivity of an image sensor to light), aperture (the size of opening; given by f-stop [as aperture increases, f-numbers decrease]), and shutter speed (controls how long the image sensor is exposed to light) is helpful for ensuring proper exposure and other aspects of image quality, such as noise and amount of motion blur. In turn, image quality may directly affect the accuracy of deformation estimates generated using photogrammetric techniques.

Structure from Motion (SfM) combined with Multi-view Stereo (MVS) is a photogrammetric range imaging technique for estimating 3D structures from two-dimensional image sequences to create multiple data outputs such as ortho-imagery, 3D meshes, Digital Elevation Models (DEMs), or point clouds. SfM software enables projects to be processed with or without geo-locations; however, accurate and well-distributed Ground Control Points (GCPs) may improve the global accuracy of the project.

LiDAR is an active remote-sensing technique where laser pulses are transmitted by the LiDAR system. These pulses travel down toward the earth's surface, reflect off a surface, and return to a sensor on the UAS platform where the roundtrip travel time and angle of the emitted pulse are measured. LiDAR scanners emit pulses of light (at speeds ranging from thousands to millions of points per second) to acquire X, Y, Z (3D) coordinates of points in an area of interest, producing a point cloud. Unlike photographs, because LiDAR is an active sensor, solar illumination (e.g., clouds, low sun angle) has minimal impact on the data quality. This may also help in highly vegetated areas. A LiDAR sensor for a UAS can be survey grade (5-10 millimeter accuracy) or mapping grade (1-3 centimeter accuracy), and as such, may be selected based on the magnitude of deformations anticipated and monitoring accuracy needed to meet data acquisition goals. Some UAS systems have bathymetric LiDAR capabilities, which may be important for mapping anything that is underwater.

Custom designed, small hyperspectral imaging systems are available for UAS. These systems are capable of imaging at multiple wavelengths within specific ranges such as Ultraviolet-Visible (UV-VIS) (UV-VIS; 250–500 nanometers [nm]), Visible and Near-Infrared (VNIR; 400–1000 nm), extended VNIR (600–1700 nm), Near-Infrared (NIR; 900–1700 nm), Short-wave Infrared (SWIR; 900–2500 nm), and Medium-wave Infrared (MWIR 3000–5000 nm). VNIR, extended VNIR, NIR, and SWIR tend to be the most common systems used in geologic applications such as mineralogy analysis and quantifying surficial moisture content. However, it is important to note that the imaging results could be sensitive to lighting conditions (i.e., the shadows and hot spots), which may introduce noise into the 3D point cloud.

Although UAS-SfM and UAS LiDAR techniques typically provide comparable data accuracies (with some differences, as a function of terrain and ground cover type), the application of UAS-SfM is generally less expensive, may impose less stringent requirements for the remote aircraft, may require less expert knowledge and training to operate, and could yield higher data densities. Therefore, SfM processing may be beneficial for small scale, less than 1.5 square miles, high-density topographic mapping applications based on its low cost, attainable accuracy, and usability. Nevertheless, moving objects, dense foliage and blurry imagery could be disadvantages if using SfM. UAS LiDAR may be an alternative when any of the following conditions apply:

- The area of interest (AOI) has homogeneous surface texture over a large area.
- Data acquisition through thick canopy is critical to characterize the terrain surface.
- Poor lighting conditions (e.g., extreme amounts of shadowing throughout the AOI, data collection at night) are anticipated.
- Surface characteristics derived from intensity returns are desired.
- Substantial vertical gradients exist throughout the AOI.
- Significant vertical (relative to flying height) obstructions are located throughout the AOI.

DATA MANAGEMENT

Utilizing UAS across operations could create large amounts of data. Collaborating with the agency's Information Technology (IT) department and developing a data management plan for UAS data may be helpful. The agency may also have policies and procedures related to data security, data sharing and storage that could apply to UAS data. Industry best practices for UAS data management are still being refined, but the following considerations may be helpful to State DOTs developing a UAS data governance plan:

- Where the UAS data will be stored, for example, cloud, network, or local server storage
- Access and permissions to manage the UAS data
- Whether all raw data be saved or only final deliverable data
- Data organization and shareability
- Life cycle of the UAS data

CONCLUSION

As State DOTs continue to discover ways in which UAS may be employed as a supplemental tool the agencies may find a variety of resources to be useful. Various publications, webinars, and other resources specific to State DOT use of UAS can be found at: https://www.fhwa.dot.gov/uas/. Several State DOTs have robust UAS programs and are willing to assist their peers. A basic understanding of UAS regulations, UAS platforms and remote sensors may be helpful in selecting equipment to meet data-collection goals of various use cases while also meeting overall goals related to increasing safety and efficiency.

ONLINE RESOURCES

Federal Highway Administration Unmanned Aircraft Systems Resources: https://www.fhwa.dot.gov/uas/

REGULATORY RESOURCES

Federal Aviation Administration Unmanned Aircraft Systems Resources: https://www.faa.gov/uas/

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Distribution and Availability—This Tech Brief can be found at http://www.fhwa.dot.gov/uas.

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