

# **PDH** Academy

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# sUAS Aerial Data Acquisition for 3D Modeling

**4.0 PDH / 4 CE Hours / 4 AIA LU**

**AIAPDH188**

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# ANSWER SHEET

First Name: \_\_\_\_\_ Last Name: \_\_\_\_\_ Date: \_\_\_\_\_

Address: \_\_\_\_\_ City: \_\_\_\_\_ State: \_\_\_\_\_ ZIP: \_\_\_\_\_

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AIA#: \_\_\_\_\_

## SUAS Aerial Data Acquisition for 3D Modeling - AIAPDH188

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## Final Exam

1. What is the entry level cost for a sUAS used in land surveying?
  - a) \$2,000
  - b) \$10,000
  - c) \$40,000
  - d) \$400,000
  
2. In a region where proper cell technology is lacking, how is data delivered to the customer immediately after flying?
  - a) Using a quick stitching program
  - b) By transferring data to a laptop
  - c) By transferring data to a cell tower to upload
  - d) Using autonomous mission planning software
  
3. Regulations introduced in 2016 which govern the use of all sUAS for surveying are found on the FAA website under Title 14 CFR part
  - a) 61
  - b) 91
  - c) 107
  - d) 135
  
4. Primary benefits to hiring a data service provider, as opposed to buying your own sUAS, are that they have their own:
  - a) equipment, pilots and insurance.
  - b) equipment and pilots.
  - c) aircrafts and insurance.
  - d) remote pilots, flight controls and devices.
  
5. Using one or more VOs allows a remote PIC and person manipulating the controls to conduct other mission-critical duties while still ensuring situational awareness of the UA. The VO must be able to effectively communicate:
  - a) The small UA direction of flight
  - b) The position of hazards in the airspace
  - c) The determination that the UA does not endanger the life or property of another
  - d) All of the above

6. In addition to the standard FAA regulations for operating a sUAS it is necessary to obtain special written permission from which agency to legally fly a sUAS for surveying purposes within the airspace of class B, C, D, or E airspace as found on aeronautical charts.
- Local police
  - Governor of that state
  - FAA
  - TSA
7. Prior to flight, the remote PIC must conduct an assessment of the operating environment. This assessment must include:
- flight restrictions
  - ground hazards
  - location of persons and property on the surface
  - All of the above
8. Lidar and \_\_\_\_\_ cameras are the two most commonly used sensor types which are used in land surveying.
- Panoramic
  - Hyperspectral
  - Electro Optical
  - Multispectral
9. Combining GPS and GCPs with \_\_\_\_\_ greatly improves the precision of data acquired by a sUAS.
- Satellite imagery
  - RTK
  - INS
  - Ground survey data
10. Which type of sUAS is most commonly used today for land surveying due to their ease of use?
- Helicopter
  - Multirotor
  - Fixed Wing
  - Gyrocopter

11. There is no limit to the number of lithium polymer batteries that can be carried onto a commercial airline if they are each less than \_\_\_\_\_.
- a) 2" x 4" x 10"
  - b) 2.2 lbs.
  - c) 100Wh
  - d) 5,000 mAh
12. A "buddy box" is:
- a) when the PIC has another remote pilot working with him/her
  - b) a system that uses two control stations
  - c) when there are two people operating the sUAS and neither have a remote pilot certificate
  - d) when the remote PIC immediately engages an automation system
13. Mission planning software used to create a land survey can automatically determine the flight path, position to take imagery, altitude and flight speed once the user defines the boundary of the area and the \_\_\_\_\_
- a) Overlap
  - b) Sidelap
  - c) Ground Sampling Distance
  - d) Heading
14. Why is it challenging to keep up with camera technology on the market?
- a) There are very few reviews posted
  - b) Cameras are constantly evolving
  - c) Camera technology related to sUAS is rarely publicized
  - d) It is regulated by ISO and shutter speed
15. Why is shooting in JPEG suggested?
- a) Cameras process JPEG more quickly than RAW
  - b) RAW images tend to be compromised
  - c) JPEG is the only format available
  - d) They take longer to process, but the image is much clearer than RAW format
16. Mission planning for land surveying is more complicated for fixed wing compared to rotary wing aircraft due to \_\_\_\_\_
- a) GCP placement
  - b) Wind direction
  - c) GPS drift
  - d) RF interference

17. Which weather issue is least likely to cause issues with data collection from a sUAS for land surveying?
- a) Rain
  - b) Clouds
  - c) Fog
  - d) High wind speed
18. Most gas powered sUAS have \_\_\_\_\_ to supply power to the payloads and other operating systems.
- a) extra watts
  - b) engine rpm
  - c) battery backup systems
  - d) onboard generators
19. Low quality models are typically caused by:
- a) Vignetting images, unfocused cameras and motion blur
  - b) Vignetting images, unfocused cameras and including the horizon in the photo
  - c) Photos taken at a low altitude and insufficient overlap
  - d) All of the above
20. The key to obtaining proper imagery is to:
- a) Avoid getting the sky in the images and take turns slowly
  - b) Avoid getting the sky in the images and change altitude
  - c) Complete a tutorial on the Litchi app
  - d) Change speeds from one waypoint to another

## sUAS AERIAL DATA ACQUISITION FOR 3D MODELING

### CHAPTER 1

#### INTRODUCTION

##### **1-1 Purpose.**

This course presents guidance on the use of sUAS for aerial data acquisition for objects requiring 3D models during the various stages of civil and military projects. The focus is for architects and engineers. The course is intended to be a guide to obtaining consistent data using a sUAS following FAA regulations. Focus is on the consistency of data acquisition across sensor types, aircraft types, mission planning software, data processing, and targets.

##### **Learning Objectives:**

1. The student will be able to understand the limitations for small unmanned aircraft systems when gathering data for 3D modeling while also learning the new applications sUAS can bring to the design and building process to provide new levels of occupant comfort, site safety, and environmental concern.
2. The student will be able to summarize the FAA rules and regulations of small unmanned aircraft to ensure that risks from flying sUAS on site are identified and procedures are in place to ensure property occupant wellbeing and prevent accidental injury to people and property on that site.
3. Students will learn key skills needed to influence ideas for 3-D modeling by learning some of the aircraft types and sensor types available for use in 3-D Modeling to encourage and increase overall efficiency and improved quality of 3-D Modeling for better urban planning and building design that will benefit site users.
4. Students will review the role of flight planning software and systems for 3-D Modeling. They will discover ways to perform and make sUAS missions for 3-D Modeling for planning sites faster, increasing energy efficiency while decreasing the carbon footprint of the project and keeping workers and site occupants safer due to the accuracy of the 3-D modeling and the ability to reach destinations not possible by humans.

##### **1-2 Applicability.**

This course applies to general sUAS aerial operations under the regulations of the FAA 14 CFR Part 107.

##### **1-3 Background.**

Drones, or more accurately sUAS (the term coined by the FAA for small unmanned aircraft systems) have been in existence since WWII. They have just recently become more popular due to the advent of reliable, low cost autopilots. sUAS involves those systems which are guided at least part of the time with an “autopilot”. We refer to RPV (remotely piloted vehicles) as those which are stabilized and have sensors, but not operating with an autopilot which directs the plane to fly to waypoints. FPV (First Person View) allows the pilot to fly using a camera mounted on the aircraft but not necessarily using

an autopilot. RPV and FPV are complementary to sUAS because some sUAS require manned intervention, especially during takeoff and landing.

Critical to the autopilot is the use of a precise GPS and gyroscope technology. Once these sUAS were available inexpensively for modelers in the early 2000s, some of these worked their way into commercial applications. As they became more and more prevalent, the FAA put the hammer down and restricted flying to hobbyists only until rules could be passed regarding the operation of sUAS in the national airspace. The FAA passed regulations governing the use of sUAS in the USA on 8/29/2016. Since then there has been a huge influx of money into R&D from many major electronics companies as well as countless private investors. Millions of dollars have been invested into aircraft, sensors, navigation systems, collision avoidance, data processing, battery technology, data recording, integration into the national airspace and more. Investment will continue to grow at an exponential pace for decades. This can be compared to the beginning of other major industries like the automotive industry or the computer industry where dozens or hundreds of companies are all entering the market simultaneously.

Today, almost all 3D model type sUAS fly completely autonomously from takeoff to landing. They operate completely using waypoints generated by an easy to use mission planning system. All systems use similar hardware, the major differences are the formats and interfaces.

We can broadly classify 3D modeling into 2 classifications.

- 1) 3D modeling of geography for volumetric calculations such as piles of coal and sizes of open pit mines. In most cases a boundary is set up around the area to be 3D modeled by the pilot/engineer, and the actual flight path is determined by the software.
- 2) 3D modeling of manmade structures such as a bridges and buildings. The flight software for these structures is not as automatic as that for geography. At this time, it takes more pilot expertise to obtain the proper imagery for quality modeling.

Software development has been at a frantic pace. Companies are competing to make totally autonomous mission planning software which is universal across sUAS. They automatically decide the altitude to fly at to get the resolution required. They also decide the separation of the flight paths to be the most efficient that they can be. Who, what, when, where and how to gather data are being completely computerized. The human factors will be greatly reduced which will greatly enhance safety and productivity.

When large areas are modeled, many photos are taken. It takes time and high computing power to stitch the photos together into a usable format for 3D models. At the field, some companies offer a quick stitching program which takes only minutes. This program does not give a usable final result

(yet) but it does show if there is some bad data and if all or part of the mission needs to be flown again. This saves a lot of time because if the data is incomplete and it isn't discovered for days, then another trip must be made to the area to gather the missing data. This is a huge leap forward in the technology. Some companies can transmit the photos to a cell tower to upload as the sUAS is still flying. This cuts down on the time it takes to get a deliverable to a client. If the region lacks proper cell technology, the data can be transferred to a laptop in the field as it is flying, and the software on the laptop starts to process the data. The goal is that the data will be delivered to the customer immediately after flying.

#### **1-4 sUAS vs conventional methods for 3D modeling**

In the past it has been very difficult to put the sensor in the correct position to obtain the proper imagery. Scaffolding, camera booms, cranes, and a variety of cumbersome methods have been employed to obtain aerial shots. sUAS are becoming more prevalent due to their ability to obtain imagery of complex objects, or in difficult terrain. Collections can be made quickly and accurately. It's much easier to fly a sUAS to the correct position using higher speeds than using the old cumbersome conventional methods.

The sUAS is made possible to use thanks to innovative software which automatically puts the sUAS in the correct position to obtain the imagery. The time taken to determine where the imagery is taken and then putting the sensor in the proper position using a sUAS is very fast. Recent software improvements in the 3D modeling industry can utilize low cost (under \$2,000) sUAS. The software is a combination of mission planning software to obtain the imagery and then processing software to merge the imagery into the desired 3D model.

More time is saved in poor terrain. No need to worry about working over water or around cliffs or heavy foliage where it is difficult to set up ground based equipment. The sUAS can fly to the location.

#### **1-5 Manned aircraft vs unmanned aircraft for 3D modeling**

Unmanned aircraft have a lower cost barrier to entry for the hardware. An entry level sUAS can cost under \$2,000 which includes the aircraft, sensor, autopilot software, spare parts, and more to perform data collection. This does not include the cost of data processing software or cloud processing.

Data collection from a manned aircraft is typically performed with a helicopter. A low cost manned helicopter such as a Robinson R-22 costs \$100,000 to \$300,000. The hourly cost of operation is \$250. The R-22 is not widely used for commercial operations. Most times the expense is about 5 to 10 times greater. The cost of the camera may be in the \$60,000 range.

Software costs for unmanned aircraft are far less than manned aircraft. The cost of the software to navigate unmanned aircraft are often times free. Paid apps are usually under \$30. The software to actuate a camera mounted on a manned aircraft is thousands of dollars. The cost of the navigation software (and possible hardware upgrade) for manned aircraft again is several thousands of dollars.

The cost of a FAA remote pilot certificate is far less than the cost of a manned pilot certificate. Remote pilots often study using online materials which are available at no charge. Some pay nominal fees of \$150 for an at home study course. A manned pilot certificate will cost tens of thousands of dollars for training with an instructor and aircraft rental. Usually a sport license is not enough to fly commercially. While it is legal to fly and capture imagery from a manned helicopter with a sport license, usually an IFR rating is necessary for safety reasons. If the weather turns bad during a flight, without an IFR rating the results could be severe. The pilot may need to layover in a distant airport or worse. Maintaining a remote certificate costs \$150 every 2 years for an exam. Maintaining an IFR certificate requires an extensive flight exam, and the pilot must remain current.

Maintenance costs of sUAS are far less than on manned planes. The cost of a battery or cable or propeller might be a few hundred dollars while manned planes cost thousands of dollars to maintain. Maintenance entails 100 hr. and annual checks, and parts and labor are far more expensive for manned planes. Even if the helicopter is rented these costs must be covered in the rental fee.

Since manned systems cost more to operate the hourly expense is higher than with unmanned aircraft. A lower cost barrier to entry allows more companies to get into the data collection business. sUAS reduce airmen casualties because there are no airmen. Smaller jobs can be done economically. Manned helicopters have a higher minimum cost for a job, so smaller jobs are not economically feasible. In certain instances where there are nearby obstructions the helicopter cannot get in close enough to obtain the best data.

## **CHAPTER 2**

### **FAA REGULATIONS FOR sUAS 3D Modeling**

#### **2-1 Background**

The FAA rules the skies when it comes to data collection from a sUAS for 3D modeling. The key points are:

- 1) Remote pilot certificate from the FAA is required to operate a sUAS
- 2) sUAS aircraft must be registered with the FAA and the markings must be on the aircraft
- 3) sUAS must operate under FAA rules

The FAA has literally thousands of pages of information and tens of thousands of rules that must be followed when operating a sUAS in the National Airspace (NAS) of the USA.

All of the information is available (usually at no charge) on the FAA website. Below is a summary of information which is basic to sUAS operations. To fully understand all that is required to operate from an FAA standpoint is beyond the scope of this course. sUAS are allowed to operate under FAA 14 CFR Part 107. While this pertains to sUAS, many other parts of the FAA regulations are required knowledge. For someone new to FAA regulations it can take dozens of hours of studying to become familiar with all the information pertaining to the FAA.

This course is not to train you to become a sUAS pilot, but is to familiarize you with the general regulations of what the FAA will and will not allow (as of this writing in 2/2017).

#### **2-2 14 CFR PART 107**

Below are the basic things an operator must know for flying under the small UAS rule (14 CFR part 107):

Pilot Requirements:

- Must be at least 16 years old
- Must pass an initial aeronautical knowledge test at an FAA-approved knowledge testing center+
- Must be vetted by the Transportation Safety Administration (TSA)

A person who already holds a pilot certificate issued under 14 CFR part 61 and has successfully completed a flight review within the previous 24 months can complete a part 107 online training course at [www.faasafety.gov](http://www.faasafety.gov) to satisfy this requirement.

For more information, read about Remote Pilot Certification on the FAA website.

Below is a summary of the part 107 rule. This is to help decide whether your firm should purchase a sUAS and operate it themselves, or use a data service provider. Data service providers are becoming very prevalent and this trend will continue. These providers have their own equipment, pilots and insurance. They are an alternative for many companies. Typically smaller firms will hire out service providers while the larger firms will take on these duties themselves.

### 2-3 SUMMARY OF SMALL UNMANNED AIRCRAFT RULE (PART 107) (from <https://www.faa.gov/>)

Go to the FAA website to read this in its entirety.

<b>Operational Limitations</b>	<ul style="list-style-type: none"><li>• Unmanned aircraft must weigh less than 55 lbs. (25 kg).</li><li>• Visual line-of-sight (VLOS) only; the unmanned aircraft must remain within VLOS of the remote pilot in command and the person manipulating the flight controls of the small UAS. Alternatively, the unmanned aircraft must remain within VLOS of the visual observer.</li><li>• At all times the small unmanned aircraft must remain close enough to the remote pilot in command and the person manipulating the flight controls of the small UAS for those people to be capable of seeing the aircraft with vision unaided by any device other than corrective lenses.</li><li>• Small unmanned aircraft may not operate over any persons not directly participating in the operation, not under a covered structure, and not inside a covered stationary vehicle.</li><li>• Daylight-only operations, or civil twilight (30 minutes before official sunrise to 30 minutes after official sunset, local time) with appropriate anti-collision lighting.</li><li>• Must yield right of way to other aircraft.</li><li>• May use visual observer (VO) but not required.</li><li>• First-person view camera cannot satisfy “see-and-avoid” requirement but can be used as long as requirement is satisfied in other ways.</li></ul>
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- Maximum groundspeed of 100 mph (87 knots).
- Maximum altitude of 400 feet above ground level (AGL) or, if higher than 400 feet AGL, remain within 400 feet of a structure.
- Minimum weather visibility of 3 miles from control station.
- Operations in Class B, C, D and E airspace are allowed with the required ATC permission.
- Operations in Class G airspace are allowed without ATC permission.
- No person may act as a remote pilot in command or VO for more than one unmanned aircraft operation at one time.
- No operations from a moving aircraft.
- No operations from a moving vehicle unless the operation is over a sparsely populated area.
- No careless or reckless operations.
- No carriage of hazardous materials.

- Requires preflight inspection by the remote pilot in command.
- A person may not operate a small unmanned aircraft if he or she knows or has reason to know of any physical or mental condition that would interfere with the safe operation of a small UAS.
- Foreign-registered small unmanned aircraft are allowed to operate under part 107 if they satisfy the requirements of part 375.
- External load operations are allowed if the object being carried by the unmanned aircraft is securely attached and does not adversely affect the flight characteristics or controllability of the aircraft.

	<ul style="list-style-type: none"> <li>• Transportation of property for compensation or hire allowed provided that- <ul style="list-style-type: none"> <li>o The aircraft, including its attached systems, payload and cargo weigh less than 55 pounds total;</li> <li>o The flight is conducted within visual line of sight and not from a moving vehicle or aircraft; and</li> <li>o The flight occurs wholly within the bounds of a State and does not involve transport between (1) Hawaii and another place in Hawaii through airspace outside Hawaii; (2) the District of Columbia and another place in the District of Columbia; or (3) a territory or possession of the United States and another place in the same territory or possession.</li> </ul> </li> <li>• Most of the restrictions discussed above are waivable if the applicant demonstrates that his or her operation can safely be conducted under the terms of a certificate of waiver.</li> </ul>
<p><b>Remote Pilot in Command</b></p> <p><b>Certification and Responsibilities</b></p>	<ul style="list-style-type: none"> <li>• Establishes a remote pilot in command position.</li> </ul> <p>A person operating a small UAS must either hold a remote pilot airman certificate with a small UAS rating or be under the direct supervision of a person who does hold a remote pilot certificate (remote pilot in command).</p> <ul style="list-style-type: none"> <li>• To qualify for a remote pilot certificate, a person must: <ul style="list-style-type: none"> <li>o Demonstrate aeronautical knowledge by either: <ul style="list-style-type: none"> <li>▪ Passing an initial aeronautical knowledge test at an FAA-approved knowledge testing center; or</li> <li>▪ Hold a part 61 pilot certificate other than student pilot, complete a flight review within the previous 24 months, and complete a small UAS online training course provided by the FAA.</li> </ul> </li> </ul> </li> </ul>

- - Be vetted by the Transportation Security Administration.
  - Be at least 16 years old.

Part 61 pilot certificate holders may obtain a temporary remote pilot certificate immediately upon submission of their application for a permanent certificate. Other applicants will obtain a temporary remote pilot certificate upon successful completion of TSA security vetting. The FAA anticipates that it will be able to issue a temporary remote pilot certificate within 10 business days after receiving a completed remote pilot certificate application.

- Until international standards are developed, foreign-

certificated UAS pilots will be required to obtain an FAA issued remote pilot certificate with a small UAS rating.

A remote pilot in command must:

- Make available to the FAA, upon request, the small UAS for inspection or testing, and any associated documents/records required to be kept under the rule.
- Report to the FAA within 10 days of any operation that results in at least serious injury, loss of consciousness, or property damage of at least \$500.
- Conduct a preflight inspection, to include specific aircraft and control station systems checks, to ensure the small UAS is in a condition for safe operation.
- Ensure that the small unmanned aircraft complies with the existing registration requirements specified in § 91.203(a)(2).

A remote pilot in command may deviate from the requirements of this rule in response to an in-flight emergency.

<b>Aircraft Requirements</b>	<ul style="list-style-type: none"> <li>• FAA airworthiness certification is not required. However, the remote pilot in command must conduct a preflight check of the small UAS to ensure that it is in a condition for safe operation.</li> </ul>
<b>Model Aircraft</b>	<ul style="list-style-type: none"> <li>• Part 107 does not apply to model aircraft that satisfy all of the criteria specified in section 336 of Public Law 112-95.</li> <li>• The rule codifies the FAA's enforcement authority in part 101 by prohibiting model aircraft operators from endangering the safety of the NAS.</li> </ul>

**2-4 PART 107 SUBPART B, OPERATING LIMITATIONS FOR SMALL UNMANNED AIRCRAFT SYSTEMS (sUAS)**

Below are important excerpts from the FAA regulations. The entire FAA part 107 is hundreds of pages in length if you are interested in reading additional information. These rules must be obeyed by sUAS pilots gathering data for 3D modeling. The full set of rules can be found on the FAA website. This is an FAA Advisory Circular. AC No: 107-2

**1. Applicability.** This chapter provides guidance regarding sUAS operating limitations and the responsibilities of the remote pilot in command (PIC), person manipulating the controls, visual observer (VO), and anyone else that may be directly participating in the sUAS operation. A person is also a direct participant in the sUAS operation if his or her involvement is necessary for the safe operation of the sUAS.

**2. Aircraft Operation.** Just like a manned-aircraft PIC, the remote PIC of an sUAS is directly responsible for, and is the final authority as to, the operation of that UAS. The remote PIC will have final authority over the flight. Additionally, a person manipulating the controls can participate in flight operations under certain conditions. It is important to note that a person may not operate or act as a remote PIC or VO in the operation of more than one UA at the same time. The following items describe the requirements for both a remote PIC and a person manipulating the controls:

*Remote PIC.* A person acting as a remote PIC of an sUAS in the National Airspace System (NAS) under part 107 must obtain a remote pilot certificate with an sUAS rating issued by the FAA prior to sUAS operation. The remote PIC must have this certificate easily accessible during flight operations. Guidance regarding remote pilot certification is

found in Chapter 6, Part 107 Subpart C, Remote Pilot Certification. Again, the remote PIC will have the final authority and responsibility for the operation and safety of an sUAS operation conducted under part 107.

*Additionally, part 107 permits transfer of control of an sUAS between certificated remote pilots.* Two or more certificated remote pilots transferring operational control (i.e., the remote PIC designation) to each other may do so only if they are both capable of maintaining Visual Line of Sight (VLOS) of the UA and without loss of control (LOC). For example, one remote pilot may be designated the remote PIC at the beginning of the operation, and then at some point in the operation another remote pilot may take over as remote PIC by positively communicating that he or she is doing so. As the person responsible for the safe operation of the UAS, any remote pilot who will assume remote PIC duties should meet all of the requirements of part 107, including awareness of factors that could affect the flight.

*Person Manipulating the Flight Controls.* A person who does not hold a remote pilot certificate or a remote pilot that has not met the recurrent testing/training requirements of part 107 may operate the sUAS under part 107, as long as he or she is directly supervised by a remote PIC and the remote PIC has the ability to immediately take direct control of the sUAS. This ability is necessary to ensure that the remote PIC can quickly address any hazardous situation before an accident occurs. The ability for the remote PIC to immediately take over the flight controls could be achieved by using a number of different methods. For example, the operation could involve a “buddy box” type system that uses two control stations (CS): one for the person manipulating the flight controls and one for the remote PIC that allows the remote PIC to override the other CS and immediately take direct control of the small UA. Another method could involve the remote PIC standing close enough to the person manipulating the flight controls so as to be able to physically take over the CS from the other person. A third method could employ the use of an automation system whereby the remote PIC could immediately engage that system to put the small UA in a pre-programmed “safe” mode (such as in a hover, in a holding pattern, or “return home”).

*Autonomous Operations.* An autonomous operation is generally considered an operation in which the remote pilot inputs a flight plan into the CS, which sends it to the autopilot onboard the small UA. During automated flight, flight control inputs are made by components onboard the aircraft, not from a CS. Thus, the remote PIC could lose the control link to the small UA and the aircraft would still continue to fly the programmed

mission/return home to land. During automated flight, the remote PIC also must have the ability to change routing/altitude or command the aircraft to land immediately. The ability to direct the small UA may be through manual manipulation of the flight controls or through commands using automation.

*The remote PIC must retain the ability to direct the small UA to ensure compliance with the requirements of part 107.* There are a number of different methods that a remote PIC may utilize to direct the small UA to ensure compliance with part 107. For example, the remote pilot may transmit a command for the autonomous aircraft to climb, descend, land now, proceed to a new waypoint, enter an orbit pattern, or return to home. Any of these methods may be used to satisfactorily avoid a hazard or give right of way.

*Use of automation does not allow a person to simultaneously operate more than one small UA.*

### **3. Aeronautical Decision-Making (ADM) and Crew Resource Management (CRM).**

ADM is a systematic approach to the mental process used by pilots to consistently determine the best course of action in response to a given set of circumstances. A remote PIC uses many different resources to safely operate an sUAS and needs to be able to manage these resources effectively. CRM is a component of ADM, where the pilot of sUAS makes effective use of all available resources: human resources, hardware, and information. Many remote pilots operating under part 107 may use a VO, oversee other persons manipulating the controls of the small UA, or any other person who the remote PIC may interact with to ensure safe operations. Therefore, a remote PIC must be able to function in a team environment and maximize team performance. This skill set includes situational awareness, proper allocation of tasks to individuals, avoidance of work overloads in self and in others, and effectively communicating with other members of the crew, such as VOs and persons manipulating the controls of an sUAS.

**4. Aircraft Registration.** A small UA must be registered, as provided for in 14 CFR part 47 or part 48 prior to operating under part 107. Part 48 is the regulation that establishes the streamlined online registration option for sUAS that will be operated only within the territorial limits of the United States. The online registration Web address is <http://www.faa.gov/uas/registration/>. Guidance regarding sUAS registration and marking may be found at [http://www.faa.gov/licenses\\_certificates/aircraft\\_certification/aircraft\\_registry/](http://www.faa.gov/licenses_certificates/aircraft_certification/aircraft_registry/). Alternatively, sUAS can elect to register under part 47 in the same manner as manned aircraft.

**5. sUAS Maintenance, Inspections, and Condition for Safe Operation.** An sUAS must be maintained in a condition for safe operation. Prior to flight, the remote PIC is responsible for conducting a check of the sUAS and verifying that it is actually in a condition for safe operation. Guidance regarding how to determine that an sUAS is in a condition for safe operation is found in Chapter 7, sUAS Maintenance and Inspection.

**6. Medical Condition.** Being able to safely operate the sUAS relies on, among other things, the physical and mental capabilities of the remote PIC, person manipulating the controls, VO, and any other direct participant in the sUAS operation. Though the person manipulating the controls of an sUAS and VO are not required to obtain an airman medical certificate, they may not participate in the operation of an sUAS if they know or have reason to know that they have a physical or mental condition that could interfere with the safe operation of the sUAS.

**7. VLOS Aircraft Operation.** The remote PIC and person manipulating the controls must be able to see the small UA at all times during flight. Therefore, the small UA must be operated closely enough to the CS to ensure visibility requirements are met during small UA operations. This requirement also applies to the VO, if used during the aircraft operation. However, the person maintaining VLOS may have brief moments in which he or she is not looking directly at or cannot see the small UA, but still retains the capability to see the UA or quickly maneuver it back to VLOS. These moments can be for the safety of the operation (e.g., looking at the controller to see battery life remaining) or for operational necessity. For operational necessity, the remote PIC or person manipulating the controls may intentionally maneuver the UA so that he or she loses sight of it for brief periods of time. Should the remote PIC or person manipulating the controls lose VLOS of the small UA, he or she must regain VLOS as soon as practicable. For example, a remote PIC stationed on the ground utilizing a small UA to inspect a rooftop may lose sight of the aircraft for brief periods while inspecting the farthest point of the roof. As another example, a remote PIC conducting a search operation around a fire scene with a small UA may briefly lose sight of the aircraft while it is temporarily behind a dense column of smoke. However, it must be emphasized that even though the remote PIC may briefly lose sight of the small UA, he or she always has the see-and-avoid responsibilities set out in part 107, §§ 107.31 and 107.37. The circumstances of what would prevent a remote PIC from fulfilling those responsibilities will vary, depending on factors such as the type of UAS, the operational environment, and distance between the remote PIC and the UA. For this reason, there is no specific time interval that interruption of VLOS is permissible, as it would have the effect of potentially allowing a hazardous interruption

or prohibiting a reasonable one. If VLOS cannot be regained, the remote PIC or person manipulating the controls should follow pre-determined procedures for a loss of VLOS. These procedures are determined by the capabilities of the sUAS and may include immediately landing the UA, entering hover mode, or returning to home sequence. Thus, the VLOS requirement would not prohibit actions such as scanning the airspace or briefly looking down at the small UA CS.

*Unaided Vision.* VLOS must be accomplished and maintained by unaided vision, except vision that is corrected by the use of eyeglasses (spectacles) or contact lenses. Vision aids, such as binoculars, may be used only momentarily to enhance situational awareness. For example, the remote PIC, person manipulating the controls, or VO may use vision aids to avoid flying over persons or conflicting with other aircraft. Similarly, first person view devices may be used during operations, but do not satisfy the VLOS requirement. While the rule does not set specific vision standards, the FAA recommends that remote PICs, persons manipulating the controls, and VOs maintain 20/20 distant vision acuity (corrected) and normal field of vision.

*The use of a VO is optional.* The remote PIC may choose to use a VO to supplement situational awareness and VLOS. Although the remote PIC and person manipulating the controls must maintain the capability to see the UA, using one or more VOs allows the remote PIC and person manipulating the controls to conduct other mission-critical duties (such as checking displays) while still ensuring situational awareness of the UA. The VO must be able to effectively communicate:

- The small UA location, attitude, altitude, and direction of flight;
- The position of other aircraft or hazards in the airspace; and
- The determination that the UA does not endanger the life or property of another.

*To ensure that the VO can carry out his or her duties, the remote PIC must ensure that the VO is positioned in a location where he or she is able to see the small UA sufficiently to maintain VLOS.* The remote PIC can do this by specifying the location of the VO.

The FAA also requires that the remote PIC and VO coordinate to:

- 1) scan the airspace where the small UA is operating for any potential collision hazard, and
- 2) maintain awareness of the position of the small UA through direct visual observation.

This would be accomplished by the VO maintaining visual contact with the small UA and the surrounding air space, and then communicating to the remote PIC and person manipulating the controls the flight status of the small UA and any hazards which may enter

the area of operation, so that the remote PIC or person manipulating the controls can take appropriate action.

*To make this communication possible, the remote PIC, person manipulating the controls, and VO must work out a method of effective communication, which does not create a distraction and allows them to understand each other.*

The communication method must be determined prior to operation. This effective communication requirement would permit the use of communication-assisting devices, such as a hand-held radio, to facilitate communication from a distance.

**8. Operation Near Airports;** in Certain Airspace; in Prohibited or Restricted Areas; or in the Proximity of Certain Areas Designated by a Notice to Airmen (NOTAM).

Though many sUAS operations will occur in uncontrolled airspace, there are some that may need to operate in controlled airspace. Operations in Class B, Class C, or Class D airspace, or within the lateral boundaries of the surface area of Class E airspace designated for an airport, are not allowed unless that person has prior authorization from air traffic control (ATC). The link to the current authorization process can be found at [www.faa.gov/uas/](http://www.faa.gov/uas/). The sUAS remote PIC must understand airspace classifications and requirements. Failure to do so would be in violation of the part 107 regulations and may potentially have an adverse safety effect. Although sUAS will not be subject to part 91, the equipment and communications requirements outlined in part 91 were designed to provide safety and efficiency in controlled airspace. Accordingly, while sUAS operating under part 107 are not subject to part 91, as a practical matter, ATC authorization or clearance may depend on operational parameters similar to those found in part 91. The FAA has the authority to approve or deny aircraft operations based on traffic density, controller workload, communication issues, or any other type of operations that could potentially impact the safe and expeditious flow of air traffic in that airspace. Those planning sUAS operations in controlled airspace are encouraged to contact the FAA as early as possible.

*Small UA Operations Near an Airport—Notification and Permissions.* Unless the flight is conducted within controlled airspace, no notification or authorization is necessary to operate at or near an airport. When operating in the vicinity of an airport, the remote PIC must be aware of all traffic patterns and approach corridors to runways and landing areas. The remote PIC must avoid operating anywhere that the presence of the sUAS may interfere with operations at the airport, such as approach corridors, taxiways, runways, or helipads. Furthermore, the remote PIC must yield right-of-way to all other aircraft,

including aircraft operating on the surface of the airport.

*Remote PICs are prohibited from operating their small UA in a manner that interferes with operations and traffic patterns at airports, heliports, and seaplane bases.* While a small UA must always yield right-of-way to a manned aircraft, a manned aircraft may alter its flightpath, delay its landing, or take off in order to avoid an sUAS that may present a potential conflict or otherwise affect the safe outcome of the flight. For example, a UA hovering 200 feet above a runway may cause a manned aircraft holding short of the runway to delay takeoff, or a manned aircraft on the downwind leg of the pattern to delay landing. While the UA in this scenario would not pose an immediate traffic conflict to the aircraft on the downwind leg of the traffic pattern or to the aircraft intending to take off, nor would it violate the right-of-way provision of § 107.37(a), the small UA would have interfered with the operations of the traffic pattern at an airport.

*Temporary Flight Restrictions.* Certain temporary flight restrictions (<http://tfr.faa.gov/tfr2/list.html>) may be imposed by way of a NOTAM (<https://pilotweb.nas.faa.gov/PilotWeb/>). Therefore, it is necessary for the sUAS remote PIC to check for NOTAMs before each flight to determine if there are any applicable airspace restrictions.

*Type of Airspace.* It is important that sUAS remote PICs also be aware of the type of airspace in which they will be operating their small UA. Referring to the B4UFLy app or a current aeronautical chart (<http://faacharts.faa.gov/>) of the intended operating area will aid the sUAS remote PIC's decision making regarding operations in the NAS.

**9. Preflight Familiarization, Inspection, and Actions for Aircraft Operation. The remote PIC must complete a preflight familiarization, inspection, and other actions, such as crewmember briefings, prior to beginning flight operations.** The FAA has produced many publications providing in-depth information on topics such as aviation weather, aircraft loading and performance, emergency procedures, ADM, and airspace, which should all be considered prior to operations (see paragraph 5.20). Additionally, all remote pilots are encouraged to review FAA publications.

*Prior to Flight.* The remote PIC must:

A.) Conduct an assessment of the operating environment. The assessment must include at least the following:

- Local weather conditions,
- Local airspace and any flight restrictions,
- The location of persons and property on the surface, and
- Other ground hazards.

B.) Ensure that all persons directly participating in the small UA operation are informed about the following:

- Operating conditions,
- Emergency procedures,
- Contingency procedures,
- Roles and responsibilities of each person involved in the operation, and
- Potential hazards.

C.) Ensure that all control links between the CS and the small UA are working properly. For example, before each flight, the remote PIC must determine that the small UA flight control surfaces necessary for the safety of flight are moving correctly through the manipulation of the small UA CS. If the remote PIC observes that one or more of the control surfaces are not responding correctly to CS inputs, then the remote PIC may not conduct flight operations until correct movement of all flight control surface(s) is established.

D.) Ensure there is sufficient power to continue controlled flight operations to a normal landing. One of the ways that this could be done is by following the sUAS manufacturer's operating manual power consumption tables. Another method would be to include a system on the sUAS that detects power levels and alerts the remote pilot when remaining aircraft power is diminishing to a level that is inadequate for continued flight operation.

E.) Ensure that any object attached or carried by the small UA is secure and does not adversely affect the flight characteristics or controllability of the aircraft.

F.) Ensure that all necessary documentation is available for inspection, including the remote PIC's remote pilot certificate, aircraft registration (if required), and Certificate of Waiver (CoW) (if applicable).

*Safety Risk Assessment.* These preflight familiarizations, inspections, and actions can be accomplished as part of an overall safety risk assessment. The FAA encourages the remote PIC to conduct the overall safety risk assessment as a method of compliance with the prohibition on operations over certain persons and the requirement to remain clear of other aircraft, which are discussed in paragraphs 5.11 and 5.12. Appendix A provides additional guidance on how to conduct an overall safety risk assessment.

**10. Operating Limitations for Small UA.** The small UA must be operated in accordance with the following limitations:

- Cannot be flown faster than a groundspeed of 87 knots (100 miles per hour);
- Cannot be flown higher than 400 feet above ground level (AGL), unless flown within a 400-foot radius of a structure and does not fly higher than 400 feet above the structure's immediate uppermost limit;
- Minimum visibility, as observed from the location of the CS, may not be less than 3 statute miles (sm); and
- Minimum distance from clouds being no less than 500 feet below a cloud and no less than 2000 feet horizontally from the cloud.

Note: These operating limitations are intended, among other things, to support the remote pilot's ability to identify hazardous conditions relating to encroaching aircraft or persons on the ground, and to take the appropriate actions to maintain safety.

*Determining Groundspeed.* There are many different types of sUAS and different ways to determine groundspeed. Therefore, this guidance will only touch on some of the possible ways for the remote PIC to ensure that the small UA does not exceed a groundspeed of 87 knots during flight operations. Some of the possible ways to ensure that 87 knots is not exceeded are as follows:

- Installing a Global Positioning System (GPS) device on the small UA that reports groundspeed information to the remote pilot, wherein the remote pilot takes into account the wind direction and speed and calculates the small UA airspeed for a given direction of flight, or
- Timing the groundspeed of the small UA when it is flown between two or more fixed points, taking into account wind speed and direction between each point, then noting the power settings of the small UA to operate at or less than 87 knots groundspeed, or
- Using the small UA's manufacturer design limitations (e.g., installed groundspeed limiters)

*Determining Altitude.* In order to comply with the maximum altitude requirements of part 107, as with determining groundspeed, there are multiple ways to determine a small UA's altitude above the ground or structure. Some possible ways for a remote pilot to determine altitude are as follows:

- Installing a calibrated altitude reporting device on the small UA that reports the small UA altitude above mean sea level (MSL) to the remote pilot, wherein the remote pilot subtracts the MSL elevation of the CS from the small UA reported MSL altitude to determine the small UA AGL altitude above the terrain or structure;

- Installing a GPS device on the small UA that also has the capability of reporting MSL altitude to the remote pilot;
- With the small UA on the ground, have the remote pilot and VO pace off 400 feet from the small UA to get a visual perspective of the small UA at that distance, wherein the remote pilot and VO maintain that visual perspective or closer while the small UA is in flight; or
- Using the known height of local rising terrain and/or structures as a reference.

*Visibility and Distance from Clouds.* Once the remote PIC and VO have been able to reliably establish the small UA AGL altitude, it is incumbent on the remote PIC to determine that visibility from the CS is at least 3 sm and that the small UA is kept at least 500 feet below a cloud and at least 2,000 feet horizontally from a cloud. One of the ways to ensure adherence to the minimum visibility and cloud clearance requirements is to obtain local aviation weather reports that include current and forecast weather conditions. If there is more than one local aviation reporting station near the operating area, the remote PIC should choose the closest one that is also the most representative of the terrain surrounding the operating area. If local aviation weather reports are not available, then the remote PIC may not operate the small UA if he or she is not able to determine the required visibility and cloud clearances by other reliable means. It is imperative that the UA not be operated above any cloud, and that there are no obstructions to visibility, such as smoke or a cloud, between the UA and the remote PIC.

**11. Prohibited Operation Over Persons.** Part 107 prohibits a person from flying a small UA directly over a person who is not under a safe cover, such as a protective structure or a stationary vehicle. However, a small UA may be flown over a person who is directly participating in the operation of the sUAS, such as the remote PIC, other person manipulating the controls, a VO, or crewmembers necessary for the safety of the sUAS operation, as assigned and briefed by the remote PIC. There are several ways that the sUAS remote PIC can comply with these requirements, such as:

- Selecting an operational area (site) that is clearly unpopulated/uninhabited. If selecting a site that is populated/inhabited, have a plan of action which ensures persons remain clear of the operating area, remain indoors, or remain under safe cover until such time that the small UA flight has ended. Safe cover is a structure or stationary vehicle that would protect a person from harm if the small UA were to crash into that structure or vehicle;
- Establishing an operational area in which the remote PIC has taken reasonable precautions to keep free of persons not directly participating in the operation of the sUAS;
- Choosing an operating area that is sparsely populated, or, ideally, clear of persons if operating a small UA from a moving vehicle;

- Having a plan of action that ensures the small UA remains clear of persons who may enter the operating area.
- Adopt an appropriate operating distance from persons not directly participating in the operation of the sUAS.

**12. Remaining Clear of Other Aircraft.** A remote PIC has a responsibility to operate the small UA so it remains clear of and yields to all other aircraft. This is traditionally referred to as “see and avoid.” To satisfy this responsibility, the remote PIC must know the location and flight path of his or her small UA at all times. The remote PIC must be aware of other aircraft, persons, and property in the vicinity of the operating area, and maneuver the small UA to avoid a collision, as well as prevent other aircraft from having to take action to avoid the small UA.

**13. Operations from Moving Vehicles.** Part 107 permits operation of an sUAS from a moving land or water-borne vehicle over a sparsely-populated area. However, operation from a moving aircraft is prohibited. Additionally, small UA transporting another person’s property for compensation or hire may not be operated from any moving vehicle.

*Waiving the Sparsely-Populated Area Provision.* Although the regulation states that operations from a moving vehicle may only be conducted over a sparsely-populated area, this provision may be waived (see paragraph 5.19). The operation is subject to the same restrictions that apply to all other part 107 operations. For instance, the remote PIC operating from a moving vehicle is still required to maintain VLOS and operations are still prohibited over persons not directly involved in the operation of the sUAS unless under safe cover. The remote PIC is also responsible for ensuring that no person is subject to undue risk as a result of LOC of the small UA for any reason. If a VO is not located in the same vehicle as the remote PIC, the VO and remote PIC must still maintain effective communication.

*Careless or Reckless Operation of sUAS.* Part 107 also prohibits careless or reckless operation of an sUAS. Flying an sUAS while driving a moving vehicle is considered to be careless or reckless because the person’s attention would be hazardously divided. Therefore, the remote PIC or person manipulating the flight controls cannot operate an sUAS and drive a moving vehicle in a safe manner and remain in compliance with part 107.

*Applicable Laws.* Other laws, such as state and local traffic laws, may also apply to the

conduct of a person driving a vehicle. Many states currently prohibit distracted driving and state or local laws may also be amended in the future to impose restrictions on how cars and public roads may be used with regard to a sUAS operation. The FAA emphasizes that people involved in an sUAS operation are responsible for complying with all applicable laws and not just the FAA's regulations.

**14. Transportation of Property.** Part 107 permits transportation of property by sUAS for compensation or hire. These operations must be conducted within a confined area and in compliance with the operating restrictions of part 107. When conducting the transportation of property, the transport must occur wholly within the bounds of a state. It may not involve transport between, 1) Hawaii and another place in Hawaii through airspace outside Hawaii, 2) the District of Columbia (DC) and another place in DC, or 3) a territory or possession of the United States and another place in the same territory or possession, as this is defined by statute as interstate air transportation.

*Limitations.* As with other operations in part 107, sUAS operations involving the transport of property must be conducted within VLOS of the remote pilot. While the VLOS limitation can be waived for some operations under the rule, it cannot for transportation of property. Additionally, part 107 does not allow the operation of an sUAS from a moving vehicle or aircraft if the small UA is being used to transport property for compensation or hire. This limitation cannot be waived. The maximum total weight of the small UA (including any property being transported) is limited to under 55 pounds. Additionally, other provisions of part 107 require the remote pilot to know the UA's location; to determine the UA's attitude, altitude, and direction; to yield the right-of-way to other aircraft; and to maintain the ability to see and avoid other aircraft.

**15. Operations while Impaired.** Part 107 does not allow operation of an sUAS if the remote PIC, person manipulating the controls, or VO is unable to safely carry out his or her responsibilities. It is the remote PIC's responsibility to ensure all crewmembers are not participating in the operation while impaired. While drug and alcohol use are known to impair judgment, certain over-the-counter medications and medical conditions could also affect the ability to safely operate a small UA. For example, certain antihistamines and decongestants may cause drowsiness. We also emphasize that part 107 prohibits a person from serving as a remote PIC, person manipulating the controls, VO, or other crewmember if he or she:

- Consumed any alcoholic beverage within the preceding 8 hours;
- Is under the influence of alcohol;
- Has a blood alcohol concentration of .04 percent or greater; and/or

- Is using a drug that affects the person's mental or physical capabilities.

*Medical Conditions.* Certain medical conditions, such as epilepsy, may also create a risk to operations. It is the remote PIC's responsibility to determine that their medical condition is under control and they can safely conduct a UAS operation.

**16. Daylight Operations.** Part 107 prohibits operation of an sUAS at night, which is defined in part 1 as the time between the end of evening civil twilight and the beginning of morning civil twilight, as published in The Air Almanac, converted to local time. In the continental United States (CONUS), evening civil twilight is the period of sunset until 30 minutes after sunset and morning civil twilight is the period of 30 minutes prior to sunrise until sunrise. In Alaska, the definition of civil twilight differs and is described in The Air Almanac. The Air Almanac provides tables which are used to determine sunrise and sunset at various latitudes. These tables can also be downloaded from the Naval Observatory and customized for your location. The link for the Naval Observatory is <http://aa.usno.navy.mil/publications/docs/aira.php>.

**17. Applying for a CoW.** To apply for a CoW under § 107.200, an applicant must go to [www.faa.gov/uas/](http://www.faa.gov/uas/) and follow the instructions.

*Application Process.* The application must contain a complete description of the proposed operation and a justification, including supporting data and documentation (as necessary), that establishes that the proposed operation can safely be conducted under the terms of a CoW. Although not required by part 107, the FAA encourages applicants to submit their application at least 90 days prior to the start of the proposed operation. The FAA will strive to complete review and adjudication of waivers within 90 days; however, the time required for the FAA to make a determination regarding waiver requests will vary based on the complexity of the request. The amount of data and analysis required as part of the application will be proportional to the specific relief that is requested. For example, a request to waive several sections of part 107 for an operation that takes place in a congested metropolitan area with heavy air traffic will likely require significantly more data and analysis than a request to waive a single section for an operation that takes place in a sparsely-populated area with minimal air traffic. If a CoW is granted, that certificate may include specific special provisions designed to ensure that the sUAS operation may be conducted as safely as one conducted under the provisions of part 107. A listing of standard special provisions for part 107 waivers will be available on the FAA's Web site at <http://www.faa.gov/uas/>.

**18. Supplemental Operational Information.** Appendix B, Supplemental Operational Information, contains expanded information regarding operational topics that should be considered prior to operations.

## **2.5 PART 107 SUBPART C, REMOTE PILOT CERTIFICATION**

**1. Applicability.** This chapter provides guidance regarding the airman certification requirements and procedures for persons acting as remote pilot in command (PIC) of a small UA operated in the National Airspace System (NAS). In the aviation context, the FAA typically refers to “licensing” as “certification.”

**2. Remote Pilot Certification.** A person exercising the authority of PIC in compliance with part 107 is considered a “remote pilot in command” (remote PIC). As such, prior to acting as remote PIC, he or she must obtain a remote pilot certificate with an sUAS rating.

**3. Eligibility.** A person applying for a remote pilot certificate with an sUAS rating must meet and maintain the following eligibility requirements, as applicable:

- Be at least 16 years of age.
- Be able to read, speak, write, and understand the English language. However, the FAA may make an exception if the person is unable to meet one of these requirements due to medical reasons, such as a hearing impairment.
- Be in a physical and mental condition that would not interfere with the safe operation of an sUAS.
- Pass the initial aeronautical knowledge test at an FAA-approved knowledge testing center (KTC). However, a person who already holds a pilot certificate issued under 14 CFR part 61, except a student pilot certificate, and has successfully completed a flight review in accordance with part 61 within the previous 24 calendar-months is only required to successfully complete a part 107 online training course, found at [www.faasafety.gov](http://www.faasafety.gov). For more information concerning aeronautical knowledge tests and training, see paragraph 6.6.

**4. Application Process.** This paragraph provides guidance on how a person can apply for a remote pilot certificate.

*Applicants Without Part 61 Certificates.* A person who does not have a part 61 pilot certificate or a part 61 certificate holder who has not completed a part 61 flight review in the previous 24 calendar-months must use the following process. A part 61 pilot who has completed a flight review within the previous 24 calendar-months may elect to use this

process.

A. Pass an initial aeronautical knowledge test administered at a KTC (see paragraph 6.6).

B. Complete the Remote Pilot Certificate and/or Rating Application for a remote pilot certificate (FAA Form 8710-13).

- Option 1 (Online Form): This is the fastest and simplest method. The FAA Form 8710-13 application should be completed online using the electronic FAA Integrated Airmen Certificate and/or Rating Application (IACRA) system

**5. Aeronautical Knowledge Tests (Initial and Recurrent).** It is important to have and retain the knowledge necessary to operate a small UA in the NAS. This aeronautical knowledge can be obtained through self-study, taking an online training course, taking an in-person training course, or any combination thereof. The FAA has published the Small Unmanned Aircraft Systems Airman Certification Standard ([https://www.faa.gov/training\\_testing/testing/acs/](https://www.faa.gov/training_testing/testing/acs/)) that provides the necessary reference material.

Note: The below information regarding initial and recurrent knowledge tests apply to persons who do not hold a current part 61 airman certificate.

*Initial Test.* As described in paragraph 6.4, a person applying for remote pilot certificate with an sUAS rating must pass an initial aeronautical knowledge test given by an FAA-approved KTC. The initial knowledge test will cover the aeronautical knowledge areas listed below:

1. Applicable regulations relating to sUAS rating privileges, limitations, and flight operation;
2. Airspace classification and operating requirements, and flight restrictions affecting small UA operation;
3. Aviation weather sources and effects of weather on small UA performance;
4. Small UA loading and performance;
5. Emergency procedures;
6. Crew Resource Management (CRM);
7. Radio communication procedures;
8. Determining the performance of small UA;
9. Physiological effects of drugs and alcohol;
10. Aeronautical decision-making (ADM) and judgment;
11. Airport operations; and
12. Maintenance and preflight inspection procedures.

*A part 61 certificate holder who has completed a flight review within the previous 24 calendar-months may complete an initial online training course instead of taking the knowledge test.*

*Recurrent Test.* After a person receives a remote pilot certificate with an sUAS rating, that person must retain and periodically update the required aeronautical knowledge to continue to operate a small UA in the NAS. To continue exercising the privileges of a remote pilot certificate, the certificate holder must pass a recurrent aeronautical knowledge test within 24 calendar-months of passing either an initial or recurrent aeronautical knowledge test. A part 61 pilot certificate holder who has completed a flight review within the previous 24 calendar-months may complete a recurrent online training course instead of taking the knowledge test.

## **2.6 Part 107.15 Subpart B sUAS MAINTENANCE AND INSPECTION**

**1. Applicability.** Section 107.15 requires the remote PIC to perform checks of the UA prior to each flight to determine if the sUAS is in a condition for safe operation. This chapter provides guidance on how to inspect and maintain an sUAS. Additionally, Appendix C, sUAS Maintenance and Inspection Best Practices, contains expanded information and best practices for sUAS maintenance and inspection.

*If there are no scheduled maintenance instructions provided by the sUAS manufacturer or component manufacturer, the operator should establish a scheduled maintenance protocol.* This could be done by documenting any repair, modification, overhaul, or replacement of a system component resulting from normal flight operations, and recording the time-in-service for that component at the time of the maintenance procedure. Over time, the operator should then be able to establish a reliable maintenance schedule for the sUAS and its components.

**2. Preflight Inspection.** Before each flight, the remote PIC must inspect the sUAS to ensure that it is in a condition for safe operation, such as inspecting for equipment damage or malfunction(s). The preflight inspection should be conducted in accordance with the sUAS manufacturer's inspection procedures when available (usually found in the manufacturer's owner or maintenance manual) and/or an inspection procedure developed by the sUAS owner or operator.

*Creating an Inspection Program.* As an option, the sUAS owner or operator may wish to create an inspection program for their UAS. The person creating an inspection program

for a specific sUAS may find sufficient details to assist in the development of a suitable inspection program tailored to a specific sUAS in a variety of industry programs.

*Scalable Preflight Inspection.* The preflight check as part of the inspection program should include an appropriate UAS preflight inspection that is scalable to the UAS, program, and operation to be performed prior to each flight. An appropriate preflight inspection should encompass the entire system in order to determine a continued condition for safe operation prior to flight.

*Title 14 CFR Part 43 Appendix D Guidelines.* Another option and best practice may include the applicable portions of part 43 appendix D as an inspection guideline correlating to the UA only. System-related equipment, such as, but not limited to, the CS, data link, payload, or support equipment, are not included in the list in appendix D. Therefore, these items should be included in a comprehensive inspection program for the UAS.

*Preflight Inspection Items.* Even if the sUAS manufacturer has a written preflight inspection procedure, it is recommended that the remote PIC ensure that the following inspection items are incorporated into the preflight inspection procedure required by part 107 to help the remote PIC determine that the sUAS is in a condition for safe operation.

*Benefits of Recordkeeping.* sUAS owners and operators may find recordkeeping to be beneficial. This could be done by documenting any repair, modification, overhaul, or replacement of a system component resulting from normal flight operations, and recording the time-in-service for that component at the time of the maintenance procedure. Over time, the operator should then be able to establish a reliable maintenance schedule for the sUAS and its components. Recordkeeping that includes a record of all periodic inspections, maintenance, preventative maintenance, repairs, and alterations performed on the sUAS could be retrievable from either hardcopy and/or electronic logbook format for future reference. This includes all components of the sUAS, including: small UA, CS, launch and recovery equipment, C2 link equipment, payload, and any other components required to safely operate the sUAS. Recordkeeping of documented maintenance and inspection events reinforces owner/operator responsibilities for airworthiness through systematic condition for safe flight determinations. Maintenance and inspection recordkeeping provides retrievable empirical evidence of vital safety assessment data defining the condition of safety-critical systems and components supporting the decision to launch. Recordkeeping of an sUAS may provide

essential safety support for commercial operators that may experience rapidly accumulated flight operational hours/cycles. Methodical maintenance and inspection data collection can prove to be very helpful in the tracking of sUAS component service life, as well as systemic component, equipage, and structural failure events.

The document FAA-G-8082-22 is the study guide for the sUAS Remote Pilot test. The information in this 87 page document is very important to the safe operation of a sUAS. You can view the study guide at the following link:

[https://www.faa.gov/regulaions\\_policies/handbooks\\_manuals/aviation/media/remote\\_pilot\\_study\\_guide.pdf](https://www.faa.gov/regulaions_policies/handbooks_manuals/aviation/media/remote_pilot_study_guide.pdf)

## Chapters 1 and 2: Review Questions

1. One of the two broad classifications of 3D modeling is the modeling of geography for \_\_\_\_\_ calculations.
  - a) Boundary
  - b) Volumetric
  - c) Structural
  - d) Automatic
  
2. Currently, almost all 3D model type sUAS operate completely using \_\_\_\_\_ generated by a mission planning system.
  - a) Formats
  - b) Interfaces
  - c) Waypoints
  - d) Imagery
  
3. Daylight-only operations, or civil twilight, refers to:
  - a) 45 minutes before official sunrise to 45 minutes after official sunset
  - b) Anytime, provided you use appropriate anti-collision lighting
  - c) 30 minutes before official sunrise to 30 minutes after official sunset
  - d) At sunrise and sunset
  
4. The maximum groundspeed for an sUAS, according to FAA rules, is \_\_\_\_\_.
  - a) 100 mph (87 knots)
  - b) 85 mph (74 knots)
  - c) 110 mph (96 knots)
  - d) 45 mph (39 knots)
  
5. To qualify for a remote pilot's certificate, a person must:
  - a) Pass an aeronautical knowledge test at an independent testing center.
  - b) Complete a sUAS online training course provided by the FAA.
  - c) Be at least 18 years old.
  - d) Be vetted by the FAA.

## **CHAPTER 3**

### **sUAS REMOTE SENSORS FOR 3D MODELING**

#### **3-1 Background**

Choosing an aerial platform to carry a sensor starts with choosing the sensor. The form factor, weight, power consumption and other attributes of the camera will determine the aircraft needed to carry it. So the sensor is the place to start. It is possible to purchase an all in one package, but again, it is the camera which is the primary component for a 3D modeler to be concerned with. Some aerial platforms have the ability to swap out cameras very quickly and easily. Some aerial platforms can carry 2 sensors simultaneously to get different angles at the same time under the same lighting conditions and to save time. In the 3D modeling industry there are really only 2 types of sensors that are prevalent, those are the common RGB cameras (known as EO or Electro Optical), and Lidar. There are platforms which carry both Lidar and an EO camera simultaneously. These aerial platforms are a bit larger than the usual ones which carry Lidar.

#### **3-2 Red Green Blue RGB/ELECTRO OPTICAL (EO)**

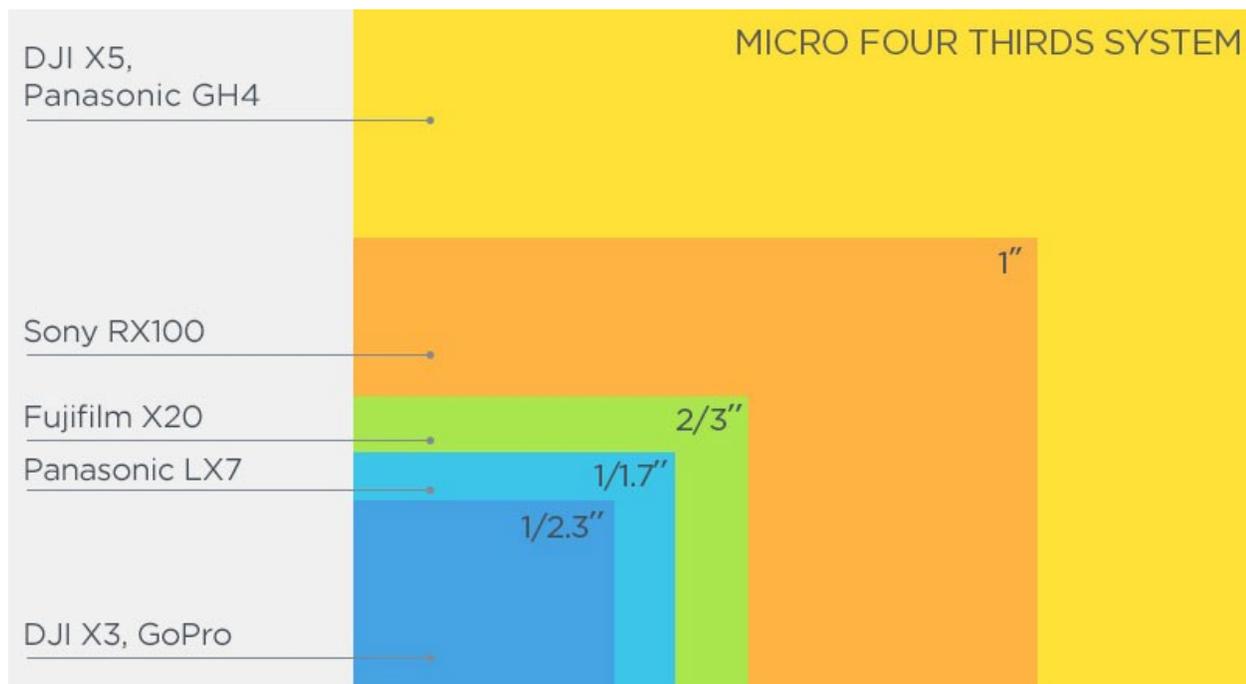
EO cameras cost a few hundred to a few thousand dollars and weigh a few ounces. Lidar costs between tens of thousands of dollars and hundreds of thousands of dollars and weighs a few pounds to 15 pounds (for the lightweight aerial versions). With the relatively recent advent of installing cameras on drones, camera technology on sUAS is on a rapid rate for technological advancement. The Go Pro type camera was one of the first used. Then variations of this camera were produced at lower cost. One of the key issues with the “action” cameras let’s call them – is that they have no aperture, so the amount of light that is let into the sensor is regulated by ISO and shutter speed. With most photogrammetry operations, they are done at close range for high resolution. This necessitates the need for a fairly high shutter speed to avoid blur due to motion. DSLR cameras were installed early on using complex and fragile gimbal systems for improved resolution. Then DSLR camera were bashed and combined with gimbal systems eliminating the viewing screen on the back of the camera to save weight and complexity not needed in a UAV. Cameras are continuing to evolve such that it is very difficult to keep up with technology as every few months a newer, better camera is on the market. For this reason it is not possible to offer a recommendation to a specific brand or camera. However, there are some key points to keep in mind when shopping for a camera to perform 3D modeling.

A key component of an EO camera is the lens. Some with large FOV (field of view) have very high distortions. Some software companies have come out with algorithms to reduce the effects of lens distortion, however, it’s best to avoid the distortion in the first place where possible. If you look at the imagery taken from many “action” cameras it is very obvious that the horizon is quite bowed. This distortion is not the best when trying to achieve high accuracy modeling. Most of the cameras coming

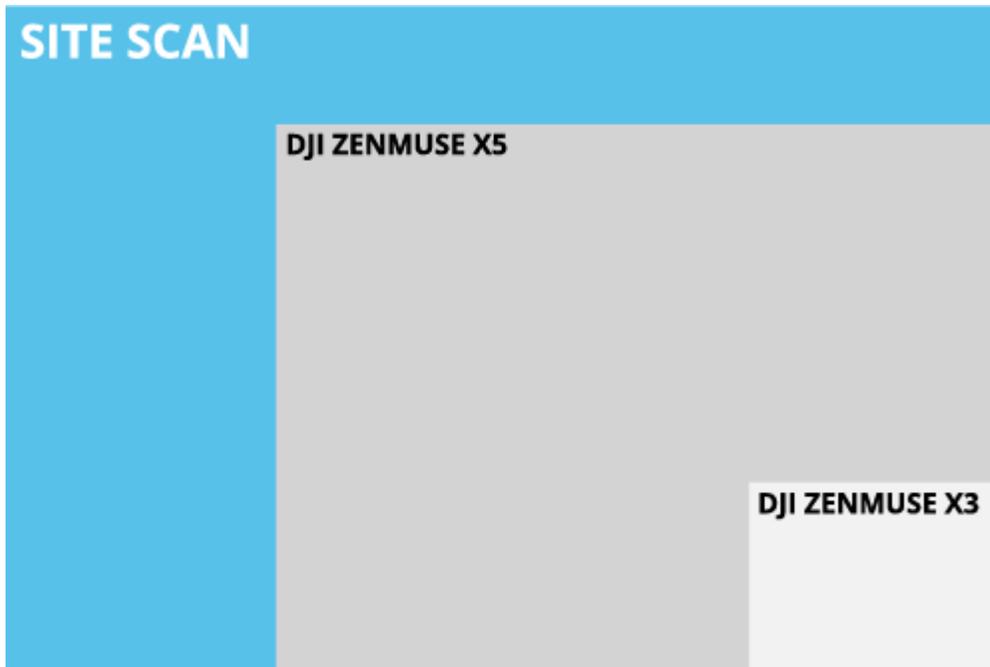
out today have corrected this issue by not using a wide angle (fisheye) lens.

3D models consist of many overlapping photos per object. Each photo is compared for key points by the computer to match the photos to one another. A common amount of key points is 20,000 per photo. It helps if the imagery is as good as possible to assist the computer to match up these points as quickly and easily as possible. It is the pilot's job to obtain the best possible imagery for the computer to do its job. A better camera assists in this area.

Some off the shelf cameras which work well and are relatively inexpensive are the DJI X3, DJI X5, some point and shoot cameras, any DSLR, and 3DR Sony R10C. These are recommended primarily because they fit onto common sUAS. It is recommended that you do not use "action" type cameras with huge wide angle fisheye lenses even though they are available. Keep in mind that it is not all about megapixels (MP). It is more about pixel size and the relative "noise" associated with the sensor. The sensor is the part inside the camera that the light activates. If the sensor is small, it typically is not as good for 3D modeling as a camera with a large sensor. Cameras in manned helicopters use medium and larger format cameras which cost \$50,000 or a lot more. Size does matter when it comes to sensors! A small sensor may be 12 mp, and a sensor which is ten or twenty times larger may also be 12mp, but which one do you think is better? Always go with the bigger sensor. As you can see below the DJI X5 sensor is about 9X larger than the DJI X3 sensor.



Site scan from 3DR has a sensor for their aircraft which is larger than the DJI X5. See below. Expect that better camera systems will be coming out quickly. The 3DR Sony 20MP APS-C sensor offers a 0.5 cm/pixel ground sampling distance at 200 feet AGL.



Sensor size comparison

Cameras which are wide angle can be flown closer to the object to increase the resolution, however wide angle lenses gather more oblique imagery which is difficult for the computer programs to process so errors are more apparent.

A key aspect to cameras is how fast they can take (process) a photo. Many are about 1 per second at maximum resolution. This is fast enough for most applications. Use the SD card that is the biggest and can be written to the fastest. This will allow a higher speed that the sUAS can operate which may significantly reduce the flight time.

It is usually not beneficial to shoot in RAW format. JPEG is usually appropriate. RAW images might be 25mb while jpeg are about 5mp. It takes far less time for the camera to process jpg images which increases the number of photos that can be taken per minute which increases the speed at which the aircraft might fly. Jpg images also upload to the data processing software much faster as well. The

format used will be dependent upon the software used, so you need to follow the manufacturer's directions.

### **3-3 Lidar**

When is Lidar used vs photogrammetry for 3D modeling? - Lidar will be used in circumstances where high measurement precision is required, but not a photo quality image. The image from Lidar is dots without color. False colors can be added but at a high cost. There are lots of variables but you can think that Lidar is about 10 times more precise than high precision photogrammetry. Another advantage is that Lidar can see through most foliage, so it can find the ground through trees where photogrammetry does not. If one is looking for the remnants of an ancient fort buried under trees for instance, only Lidar can offer a possible solution. Lidar can accurately measure the topography, so even small undulations in the earth's surface can be detected. Another use is to check the catenary sag of power wires under load or the amount of lean of towers or poles.

Several companies produce small, lightweight Lidar units for sUAS. They are usually at a lower price point as well. The disadvantage of the sUAS Lidar units is that they have shorter range than those in manned planes. Lidar in manned planes can operate at high altitudes which is necessary to be safe with pilots on board. The sUAS versions of Lidar are typically flown as close to the ground and object as possible. This works out to be 50 – 200 feet away. No manned aircraft, be it a plane or a helicopter, would like to operate at this altitude long term for safety reasons. Of course manned aircraft does fly low where necessary though the costs are high due to the risk involved. The Lidar systems installed in manned aircraft are very sophisticated and cost upwards of \$1,000,000. Of course in many instances the Lidar system in a manned plane is justifiable. However Lidar in a sUAS is less expensive, can fly low to the ground and close to the object and not endanger the pilot, and get a dense point cloud. Point cloud density can be precisely tuned while using an unmanned helicopter or multirotor. These can fly as low and as slow as necessary to obtain the point cloud which is required by the customer. Installation onto a fixed wing aircraft will extend the endurance, but the higher minimum speed required to avoid stalling a fixed wing doesn't allow as high a density of the point cloud as a rotary wing. One sUAS data collection company uses fixed wing for forestry and for power lines because the lower point cloud density is adequate for its needs. For 3D modeling, depending on the vegetation of the area to be 3D modeled, a fixed wing aircraft may provide adequate cloud density. There are several companies providing Lidar today. A couple of the more popular today which mount onto sUAS are Velodyne and Riegl. The Velodyne being less expensive it sells more units annually than the Riegl into the sUAS market. However there are advantages to the more expensive Riegl Vux-1 which justifies its higher price point.

The laser has 3 distinct components, often times they come from different manufacturers. The laser scanner works together with an INS and an on-board computer. The INS is the inertial navigation

system which is made up of an IMU (inertial measurement unit) and a GPS. This is often a very high portion of the cost. It is also a very critical piece of the component which provides location to the points in the cloud. Accuracy of the data is highly dependent on the accuracy of the INS. The aircraft is flying along, bobbing and weaving to stay on course, and if the requested accuracy of the data is 2 cm, then the INS has to know where it is within 2cm at all times. This is not an easy feat with traditional GPS which is accurate only to a couple of meters.

The prices of Lidar are coming down, and companies like Lidar USA are putting together packages which make getting into the Lidar business easier and more affordable. Lidar has a lot of advantages over EO photogrammetry, and with the cost coming down, it is becoming much more prevalent. At this time most of the Lidar airborne units are put onto rotary wing aircraft. The Pulse Aerospace Vapor 55 helicopter or the Gryphon Dynamics GD-1000 multicopter and a couple of the dozens of available aircraft suitable to carry Lidar. These can also carry small EO cameras to get RGB info simultaneously.

This technology, though it has been available for many years, is changing rapidly. With the advent of drones capable of lifting more weight and being very reliable a lot of money is going into R&D to miniaturize Lidar and the associated components. Again, it is difficult to recommend a particular system because different Lidar have different specific purposes, and new entries to the market happen regularly. For instance a LIDAR system for mapping roadways only is not the same LIDAR system used to map roadways if signs and railings are included.

## **CHAPTER 4**

### **sUAS ACCURACY & PRECISION FOR 3D Modeling**

#### **4-1 Background**

This chapter discusses the accuracy of the data file. How close are the measurements to being accurately placed. Resolution is discussed in another chapter. Resolution is the size of the pixels for an EO camera or the density of the point cloud of Lidar.

#### **4-2 GPS**

GPS has increased accuracy as the sampling rate increases. Systems on some cameras sample only once per second (1Hz). Most sample at 10 Hz. Some sample faster. In between samples the latitude and longitude are estimated. This is fine for slow moving sUAS but not as accurate for faster moving sUAS. This is a very important figure, so all sUAS manufacturers and data processors will quote this figure.

GPS is accurate to about 2-4 meters. Accuracy is dependent on atmospheric effects and receiver quality. There are a few methods to improve accuracy. Two common methods are RTK (Real Time Kinematics) and GCP (Ground Control Points). They both depend on hardware locating positions on the ground with high accuracy and adding this to the data.

#### **4-3 RTK (Real Time Kinematics)**

Devices on the ground will discover where they are located to 1 cm of accuracy given enough time to receive GPS + GLONASS satellite data. This device then communicates with the sUAS to give the sUAS more accurate positioning data. This data is used to geolocate imagery.

DJI offers a system for some models of their sUAS: <http://www.dji.com/d-rtk/info> This system costs several thousand dollars.

Some RTK systems eliminate the need for GCPs, some are used in conjunction with GCPs. It depends on the system.

#### **4-4 GCP (Ground control points)**

GCP greatly increase the accuracy of the dataset. They are used in conjunction with GPS or RTK data during the sUAS flight.

Higher accuracy is available when the GCP is located using RTK.

A minimum of 3 and a maximum of 10 GCPs are required per dataset.

GCPs need to be spread out randomly throughout the area of concern. Follow the manufacturer's recommendations. More information on how DroneDeploy uses GCPs and RTK can be found here: <http://support.dronedeploy.com/docs/ground-control-points-gcps> Pix4D info can be found here: <https://support.pix4d.com/hc/en-us/articles/202558699-Using-GCPs#gsc.tab=0>



Photo © Drone Deploy

## CHAPTER 5

### sUAS AIRCRAFT FOR 3D MODELING - BACKGROUND

#### 5-1 Multirotor

Multirotors are the most common sUAS aircraft due to their ease of use.

- They take off and land in tight spaces. No runway is required. A reasonably flat surface about 10 feet in diameter is adequate for auto landing. A skilled pilot can manually land in a 3 foot diameter landing zone.
- They are lightweight so they do little damage in the case of an accident.
- They are small, thus easy to travel with. Many can fit into the overhead bins on commercial aircraft.
- Battery size can be small. The maximum battery size which can be transported onto a commercial airplane is 100 Watt Hours. This is found printed on each battery. It is found by multiplying battery voltage by capacity. The smaller drones pictured below use batteries which are just under 100Wh. It is legal to carry on as many batteries as you can put into your carry-on luggage.
- Multirotors fly very easily if they operate under GPS control. Simply let go of the control sticks and the copter will stay in position. The wind will not move it.
- They are quite durable. They can survive many imperfect landings often without even breaking a propeller.

Common multirotor sUAS for mapping:



## *DJI Phantom 4 with X3 Photo © DJI*

This drone was released in the spring of 2016. At the time of the writing it is the most advanced quad copter in its class. It has GPS position hold, a low distortion camera, free advanced autopilot options, indoor position hold, obstacle avoidance (note the two cameras in the front), 28 minute flight time (very high for a quad copter), and top speed of about 45 mph. At \$1,200 (at this time), it provides adequate imagery for many smaller 3D models. It will map about 160 acres in one flight if modeling mines, pits, piles of aggregate materials, mountains, volcanoes, and similar other larger areas. Factors which determine the number of acres are wind, flight speed, photo overlap, altitude, ground resolution, battery age, and more. To understand better what the deliverable is from this drone it is necessary to understand the software which controls its flight path and performs data processing.

### **CAMERA**

Sensor	1/2.3" (CMOS), Effective pixels:12.4 M
Lens	FOV 94° 20 mm (35 mm format equivalent) f/2.8, focus at ∞
ISO Range	100-3200 (video) 100-1600 (photo)
Shutter Speed	8s -1/8000s
Image Max Size	4000×3000
Still Photography Modes	Single shot Burst shooting: 3 / 5 / 7 frames Auto Exposure Bracketing ( AEB ): 3 / 5 bracketed frames at 0.7 EV Bias Timelapse HDR
Video Recording Modes	UHD: 4096×2160 (4K) 24 / 25p 3840×2160 (4K) 24 / 25 / 30p 2704×1520 (2.7K) 24 / 25 / 30p FHD: 1920×1080 24 / 25 / 30 / 48 / 50 / 60 / 120p HD: 1280×720 24 / 25 / 30 / 48 / 50 / 60p
Max Video Bitrate	60 Mbps

Supported File Formats	FAT32 ( ≤ 32 GB ); exFAT ( > 32 GB )
Photo	JPEG, DNG ( RAW )
Video	MP4, MOV (MPEG-4 AVC/H.264)
Supported SD Card Types	Micro SD Max capacity: 64 GB. Class 10 or UHS-1 rating required
Operating Temperature	32° to 104° F ( 0° to 40° C )



*DJI Inspire 1 with X5 camera photo © DJI*

The DJI Inspire 1 is in a different class from the DJI Phantom 4 class. While still a quad copter, the key difference is that the sensor is interchangeable. There are dozens of sensors available, one of which is a DSLR version with improved sensor over the “action camera” of the Phantom 4. Note the difference in the camera and the camera specifications. A RAW version is also available but not needed for 3D model work. Go here for more information on the X5 camera: [http://www.dji.com/zenmuse-x5?site=brandsite&from=insite\\_search](http://www.dji.com/zenmuse-x5?site=brandsite&from=insite_search) (The X5 has a 9X greater sensor size than the X3 camera for improved resolution.)



*DJI Matrice 600 with Velodyne Lidar photo © LidarUSA*

The DJI Matrice introduced in mid 2016 is a heavy lift multirotor. It can carry a variety of the smaller Lidars such as the Velodyne models. Flight times are about 15 minutes. This is the first larger DJI multirotor which uses the proprietary DJI flight batteries. The advantage of DJI batteries is that they keep track of the number of charges, automatically discharge when sitting around unused, it's easy to check their charge state, are easy and safe to charge, and are small enough to be legally carried onto a commercial air carrier. The disadvantage is that it used 6 batteries at once. To keep the usual 4 sets of batteries on hand translates to 24 batteries which is problematic to charge, heavy and bulky to transport – and a bit expensive. A portable generator and several high powered chargers are required to keep 3 sets of batteries on charge in order to maintain constant operations. The charging issue for larger electrics is a major one. Traveling with a large electric compounds the issues of bringing a generator, and lots of charging equipment when operating in the field.

## **5-2 Helicopter**

There are advantages and disadvantages of a helicopter vs a multirotor. The main advantages of a helicopter vs a multirotor is that the helicopter is more efficient, inherently more stable in gusting wind conditions, and lends itself to gas operation. The four smaller blades on a multirotor are safer than the one large main rotor on a helicopter. The main rotor of a helicopter is large and heavy thus it has a lot of inertia and can do more damage than several small props. A helicopter is more prone to mechanical failure than multirotors or airplanes due to the lower frequency and higher amplitude vibration induced by the heavy main rotor blade if it is not perfectly balanced. The vibration tends to loosen the vast number of screws fastening the various components together. All the screws must use

thread locking compound and must be marked so if they start to loosen it is easily noticeable. These screws must be checked before each flight. Also the vibration may affect the sensor itself, so the sensor must be shock mounted. And all loose wires must be held such that they don't vibrate and break loose from the plugs and fittings.

The Pulse Aerospace Vapor 55 is capable of carrying the Riegl Vux-1 Lidar as shown below. This is a popular set up. It is well proven with the proper fasteners and vibration mounts. It weighs under the 55 lb FAA maximum weight limit for a sUAS as of today. The cost is several hundred thousand dollars. The price might sound steep but it has been a very sound investment for many companies. The daily rate for the operation of one of these by a data acquisition service company can be thousands of dollars depending on the circumstances.

It would be more efficient to put the Riegl Vux-1 Lidar onto a larger copter than the Vapor 55. Pulse Aerospace has larger copters waiting in the wings for the time that the FAA allows heavier sUAS to operate on a regular basis. Gas powered copters are even more efficient and thus can fly for hours at a time. As discussed below there are advantages and disadvantages of gas power. Gas power can greatly increase the flight times, but maintenance is higher and the exhaust is messy and needs to be kept well away from the sensor. Gas engines are usually 2-stroke which expel oil which will cloud the sensor and ruin the data.



## SPECIFICATIONS

Gross Weight	55 lbs
Useful Load - (Battery + Payload)	34 lbs

Allowable Payload - With Full Endurance*	< 11 lbs
Max Cruise Endurance - With Full Payload	60 Minutes
Max Hover Endurance - With Full Payload	45 Minutes

### 5-3 Fixed Wing

The only advantages of a fixed wing plane vs a multicopter is that of longer endurance and thus range. This is true for electric planes but also gas powered planes are available which can fly for days. No economical gas powered multicopters are available yet. The reason for the improved efficiency of a fixed wing is that an airplane floats along on its wing. The propeller provides just enough thrust to push it forward to create lift to avoid stalling. A helicopter or multicopter uses motor power/thrust for lift and to fly forward as well. This uses a lot more energy. There are literally dozens of planes available for the 3D modeling industry.

There are a few key *disadvantages* to airplanes compared to rotary aircraft. However it is true that you should use the correct tool for the job. One platform is not best for all types of data acquisition. A fixed wing plane does work best in some situations.

- Airplanes need more room to take off and land. Airplanes cannot ascend or descend rapidly. Clearing vegetation like trees is an issue. Also even without trees, the landing zone is much larger whether they slide, roll or parachute in for a landing.
- Takeoffs and landings are directional. They should takeoff and land into the wind. This is often a problem due to the environment. An urban area usually does not have the room for takeoffs, landings, ascents and descents. There are fixes to these issues. Catapult launches, parachute recoveries, stall techniques, tight spirals, plane & rotary wing combos which take off like a rotary wing then transition to horizontal flight on a wing, etc.
- Many fixed wing planes cannot be hand launched. They are often pushed to their maximum weight so as to extend their range and wind penetration. These must have an assisted launch. Smaller and lower wing loading planes can be hand launched though they can have issues operating in high winds or carrying heavy cameras.
- Fixed wing must operate at a very narrow speed range. The power used increases by the third power vs speed. Just a small increase in flight speed of 20%, for example from 40 knots to 48 knots will use 73% more energy due to parasitic drag. Thus fixed wing usually flow a few knots over their stall speed, a little faster with gusting wind. The higher the wind speeds and the higher the gusts the higher the cruise speed needs to be to avoid stalling and porpoising.
- Fixed wing will crab into a crosswind. The direction that the nose is pointed will change as the aircraft flies around an object. This may affect the data collection.

- Data collection at tight corners requires very high overlap, like 90% or more. A photo should be taken every 15 degrees so in a 90 degree turn, 6 shots need to be taken in rapid succession. This usually means that the aircraft must move quite slowly, which is more easily done with a multicopter.

Therefore airplanes (at the time of writing) are seldom used for 3D data acquisition on smaller areas such as buildings and is used more for larger mines and mountainous areas.

A common mapping plane is the eBee which uses a point and shoot camera. It is small and light weight. It costs tens of thousands of dollars. It is very refined and has logged many hours of 3D modeling. It is hand launched. Wingspan is under 4'. Weight is under 3 lbs. They have partnered with Pix4D software to provide a complete solution.



The RF-70 is another common 3D modeling plane. It weighs about 10 lbs, is bungee launched, and can carry multiple sensors.



While the more traditional looking aircraft with the propeller in the front is more efficient, a rear facing motor is quite common. Having the motor in the rear decreases the chance of damage to the propeller and motor during normal and hard landings.

Most do not use a landing gear. Landing gear are easily damaged in unimproved landing zones. They also add drag and weight which reduces efficiency. Most aircraft belly land.

Some aircraft use parachutes for landing. Problems with parachutes:

- Drift in the wind. Can land on a rock or tree stump which will cause damage.
- Must replace the parachute often due to wear
- Must pack the parachute carefully to deploy properly
- Extra weight
- Extra complexity to open the hatch
- Can get caught in a powerline or top of a tree

Advantage is that if there is a mechanical failure of the aircraft such as loss of power, or a wing breaks off the parachute can be deployed to lessen the impact. If it lands on a car or other personal property, damage will be less.

#### **5-4 Control System Range**

All aircraft of any type use communications systems between the aircraft and the ground using radio frequency (RF). Some use cell phone connections, some direct RF. Most use one or more RF links (not cellular at this time). Those RF links are very susceptible to interference. The FCC limits their power to 1 watt, but most use far less than this amount of power. The transmission range in perfect conditions is about 3 miles. That is over water or flat land with little vegetation. It is very easy to lose communications (coms) as soon as the aircraft goes out of the line of sight. Going to the other side of

a row of trees or tall buildings can cause loss of coms at just 100 yards.

There are long range systems available which have much longer range, up to 100 miles. These also are susceptible to the terrain, vegetation and buildings, but they are much improved. These are typically not used today because the FAA regs state that the aircraft must stay within line of sight (LOS).

These long range systems employ 3 methods to increase range:

- Lower frequency – usually on 433 MHz instead of 2.4 GHz. Not only is 433 MHz lower which allows it to bend more easily around obstacles but it is less crowded than 2.4 GHz. 2.4 GHz is used for cell phones, cordless phones, garage door openers, laptops, tablets, baby monitors and much more.
- More power – The FCC allows up to 1 watt for this type of use. Most drones use less than this to conserve battery power.
- Better antennas – The lower freq. 433 MHz uses an antenna which is much longer than the 2.4 GHz. High gain antennas such as Zagi, Helical, and Patch are used. These are directional antennas so they must be pointed at the drone, if not, the signal is gone. So, most times they also combine the directional antenna with an antenna tracker which points the antenna to the direction of the drone automatically using the data from the ground station to identify where the drone is and relay that to the tracker.

### **5-5 Gas vs Electric**

Gasoline has a far higher energy density than that of a lithium polymer battery. One pound of gasoline has 50 times more energy than a pound of lithium polymer batteries. In 2002 Maynard Hill flew an RC plane weighing 11 lbs. 1,882 miles across the Atlantic in 39 hours on 3 quarts of gasoline.

So why aren't all sUAS gasoline power?

- High maintenance – spark plugs, fuel lines, carburetors and gasoline engines require lots of maintenance. Spark plugs are changed every 25 – 50 hours for instance.
- High vibration – takes its toll on all components. Servos wear out quickly. Autopilots and other sensitive electronic components cannot tolerate vibration.
- Noisy – 4-stroke engines are used more due to the lower noise, though they are much more complicated having a camshaft and valves. 2-stroke engines cannot be effectively silenced because the back pressure from the muffler creates inefficient operation. 2-stroke engines are far less fuel efficient than 4-stroke engines, though 2 stroke are more reliable and lighter due to fewer moving parts. Most gas drones in the 50 to 250 lb range are 2-stroke.
- The FAA has a limit of 55 lbs. all up weight including fuel. There are no efficient, reliable gasoline engines which are small and inexpensive. Most gas engines are in the string trimmer size of 25 to 30cc which weigh a couple lbs. and are used on aircraft around 55 lbs. Most

drones like the Phantom or eBee weigh 2 or 3 pounds. Tiny gas engines to operate 3 pound aircraft have not been developed. Glow engines are used for these type models which operate on alcohol instead of gasoline. They are messy, high vibration, high maintenance, unreliable, and not particularly user friendly.

- Throttle response is poor and power is nonlinear. These traits are especially bad for synchronizing multiple engines on one aircraft.
- Altitude changes the air density, and air density changes on a daily basis, both of which cause engine issues due to changing fuel air mixture.
- Temperature changes affect the usability of gasoline engines.
- Fuel injection resolves many of these issues of gasoline engines. The power is more consistent, fuel economy is greatly enhanced, reliability goes up, air density and temperature have less effect and more. This works great though it adds complexity and is very expensive. A fuel injection system (today) for a 30cc engine can cost over \$15,000. The engine itself might cost less than \$1,000 normally. It's a large premium to pay for extended flight times.
- Electric motors can operate maintenance free for up to 100,000 hours. They are quiet, reliable, low maintenance, and very user friendly.
- Drones (today) cannot fly out of the line of sight. While a drone can be made to fly for many days on gas power there is little point to it because it's easy enough to land, swap batteries and go back up again. The aircraft can't be very far away. Once we start flying beyond line of sight and are many miles away where it must fly for several hours then gas will be a viable option.

## **5-6 sUAS Batteries**

All sUAS use lithium polymer batteries, even MOST gas powered aircraft have backup batteries. As of today these are the highest energy density batteries at a reasonable price. Lithium is one of the lightest metals, so it is perfect for sUAS.

- It is very important that lithium polymer batteries obtain the proper care. These batteries are considered hazardous materials. There are restrictions to shipping them and carrying them onto airplanes. They cannot be shipped in the cargo hold of an airplane as checked baggage!
- Higher capacity batteries will give longer endurance up to the crossover point when the battery weight pushes the airframes power system over the limit.
- Batteries wear out. They lose a small percentage of their total capacity after each use. The amount lost depends on how the battery was used. Using up more than 85% of the battery's storage capacity is detrimental. Leaving the battery fully charged between uses is detrimental.
- Keep in mind that your home's circuit breakers are 15 amps at 110v. Lipo batteries can put out 228 amps at 24v, so it can really kick out the amps. This is why they are so tightly controlled. They are very dangerous at full charge. Do not leave the battery at full charge unless it will be used soon, and do not charge the battery unattended.

Keeping batteries at the correct state of charge at all times is quite the task. Some sUAS will have a multitude of batteries that need to be maintained simultaneously, many requiring different chargers, and most requiring 110v to perform the charging. Some systems may have:

- Multiple flight batteries
- Camera battery
- Remote control battery
- Monitor battery
- Laptop battery
- Tablet battery
- Smartphone battery

A checklist is imperative to avoid forgetting to turn off one of the batteries between flights. The camera battery if separate is most common to be left on.

The DJI Inspire 1 for example is one of the best thought out battery and charging systems today. Most sUAS manufacturers will adapt these features.

- It has an integral battery for the camera and airframe.
- The transmitter can be charged while it is in use (not true with many others).
- The transmitter will charge the battery in the tablet or smartphone it is connected to when the transmitter is on except for Apple products such as iPhones and iPads.
- Batteries will self-discharge if they are stored to increase storage life.
- Battery level is easy to check. Just touch the button and the charge state is revealed.

Battery labels – the labels have a few designations which are important. For example, below is the Inspire 1 battery. All batteries have similar labels. There are 2 versions of the DJI Inspire 1 battery, the TB47 and the TB48. As shown below the TB48 is:

- 5,700 mAh This is the storage capacity when the battery is new. The TB47 is 4,500 mah.
- 129.96Wh Wh is watt hours. This is found by multiplying the voltage by the amperage. The maximum allowed to be carried onto most airliners is 100Wh, so this battery cannot be legally transported on a commercial airline. Some will allow up to two batteries over 100Wh but not exceeding 160Wh with special permission. See the FAA website for complete information: [https://www.faa.gov/about/initiatives/hazmat\\_safety/more\\_info/?hazmat=7](https://www.faa.gov/about/initiatives/hazmat_safety/more_info/?hazmat=7) The TB47 is conveniently 99.9Wh. This is the one to choose if you plan on traveling on commercial airlines.
- 22.8v This is the nominal voltage which is 3.8 volts per cell. Some batteries will state 22.2v for a 6 cell battery which is 3.7 volts per cell. This allows a lower stated number of Wh. The actual fully charged voltage is 4.2 volts per cell, or 25.2 volts. The minimum recommended voltage for a LiPo cell is about 3.7v.

- A couple of designations which are missing here are the number of cells. In this case it is 6 cells in series which is usually designated 6S. Another missing designation is the nominal and maximum discharge rate of the battery. This is expressed in terms of the capacity of the battery. This is not disclosed by the manufacturer. It is probably about 40C which means it can continuously discharge at 40 times its capacity – in this case 5.7 amps for the TB48 which calculates to 228 amps at 24 volts.



### 5-7 sUAS Charging Systems

- Manual charging systems must be operated with great care to reduce the risk of explosion or fire. The automatic systems such as those found on the DJI Phantom and Inspire are safer because it is less likely to charge them improperly.
- The DJI system also estimates the amount the battery has degraded and shows its current maximum storage capacity. Each battery has its own memory of number of charges and various other values.



Photo © DJI

- The optimum charging rate of a LiPo battery of any size takes about an hour. This translates to charging at one time its capacity or 1C. Charging slower is OK, but charging faster will decrease the life of the battery. Charging at 2-3C is fine and sometimes it is necessary.
- Field charging today is problematic. Flight batteries are generally quite large and thus require a lot of current to charge them. Batteries found on the Gryphon 1400 for instance are 22,000mAh 6S. Four batteries are used at once. After a 15 minute flight all four batteries need to be charged. Charging the batteries at 2C or 45 amps (1,100 watts) is necessary to get them charged quickly. This is a ton of current which requires a large portable gas generator capable of about 6,000 watts to operate the four chargers. Multiple generators are required if multiple sets of batteries are available. For 100Wh batteries a large inverter connected directly to a car battery can charge one battery at a time which will not allow continuous flight. Be sure to keep the car running when charging. A 6,500watt generator, is a good-sized generator for this. The biggest problem with this sized generator is that it cannot be used when driving from place to place until it is mounted into a trailer or truck bed so it can run continuously.
- For continuous operation of the sUAS typically 4-6 sets of batteries are required. Three or more are charging while one is being used. This can get expensive and cumbersome. Typically, you should keep 6-8 sets to be on the safe side.
- Even charging the 100Wh batteries in the field takes planning. For example, you would need a truck with two deep cycle marine batteries, an alternator which is upgraded to 200 amps from the stock 90 amps and 6 gauge wire run into the engine compartment to supply enough current. The truck engine must idle continuously at 1,000 rpm instead of the stock 600 rpm to

put out adequate current.

- Charging at night at home or in a hotel room requires special equipment. Checking into a hotel at 11pm and leaving by 7am doesn't make one want to wake up every hour to take one battery off the charger and put another one on the charger. There are multiple output chargers available or simple purchasing of several single output chargers is an option.

### **5-8 Onboard Generators**

- Most gas powered sUAS are fixed wing. There are a few large rotary wing sUAS.
- Most gas powered sUAS have onboard generators to supply power to the payloads and other operating systems.
- Onboard generators supply a few hundred to a few thousand watts. They are very reliable and use little fuel.
- Current output varies with engine rpm so this is monitored closely to avoid running below minimum requirements
- Battery backup systems, usually LiPo, are on board in case of generator failure. They provide enough battery power to return to home with the payload turned off.

### **5-9 Camera Gimbals**

- Many fixed wing sUAS airplanes have no camera gimbal. The aircraft is stable enough to provide good imagery. The wind limits for low wing loading and smaller sUAS is lower than that of higher wing loading and larger sUAS. The manufacturer and the data processor will determine the limits. Testing of your set up will be required.
- Most rotary wing sUAS do have gimbals, but often times a gimbal is not required for 3D modeling.

## Chapters 3, 4 and 5: Review Questions

1. 3D models consist of many overlapping photos per object. A common amount of key points is \_\_\_\_\_ per photo.
  - a) 20,000
  - b) 8,000
  - c) 30,000
  - d) 10,000
2. Some off the shelf cameras which work well for 3D modeling are the:
  - a) DJI X3
  - b) DJI X5
  - c) 3DR Sony R10C
  - d) All of the above
3. GPS is accurate to about 2-4 meters. There are a few methods to improve accuracy. One common method is:
  - a) RTK (Remote Tested Kinematics)
  - b) GCP (Ground Control Points)
  - c) Receiver quality
  - d) Atmospheric effects
4. Which is **not** an advantage of using a helicopter over a multirotor?
  - a) A helicopter is more efficient than a multirotor
  - b) A helicopter is more stable in gusting wind conditions than a multirotor
  - c) A helicopter is safer than a multirotor
  - d) A helicopter can be gas operated

## **CHAPTER 6**

### **sUAS FLIGHT PLANNING SYSTEMS FOR 3D MODELING**

#### **6-1 Background**

Today, in just a few short years software development has improved significantly, and more and more software companies are jumping into the fray. This is great for consumers because the prices are reasonable – some being free. Also, the software is more reliable and easier to use.

The key difference between 2D mapping and 3D modeling is that mapping data is acquired with nadir (straight down) shots only, whereas 3D modeling data uses nadir in addition to oblique angle shots at various angles and in sharp turns, the overlap needs to increase dramatically. Therefore there are many times more photos required for 3D vs 2D.

It is necessary to use different collection methods based on the target being modeled. With 2D mapping the flights are always pretty much the same – simply fly at a particular altitude and take shots with a particular overlap. With 3D modeling the shape and size of the object makes a huge difference in the flight plan. A tall TV tower in an open area, a small building in a congested downtown area, the side of a mountain with a bridge, an open pit mine, several piles of gravel or coal, or a skyscraper are all flown vastly differently.

There is no software today which automatically performs flight planning for 3D structures. Auto flight planning software is used for the nadir portion while manual flight planning is required for the oblique portion of the data acquisition.

There are many teaching aids for those do it yourselfers, or there are academies, universities, and other learning institutes ready to assist however the software stitching companies are the best source for flying techniques. Typically a few trials are required to gain the required experience.

To create a 2D mission, you simply draw a box around the area on Google maps, set the resolution/altitude, and the software creates the rest. Press a button, the aircraft takes off, runs its mission, and returns to home for landing. If the battery runs low during the flight, the aircraft knows how far away from home it is, leaves in plenty of time and lands. You change the battery and send it off again.

There are a few tweaks that you can perform to make the mission a little faster or a little safer, but as long as you follow the instructions from the data processing company or through experience, it will be pretty quick to get into the air.

There are many softwares on the market today which perform flight planning. Some, like

DroneDeploy, Pix4D, SenseFly, and PrecisionHawk for instance all have flight planning systems which work seamlessly with their data processing software. It is possible to use flight planning software from one company and data processing software from another company. For instance some aircraft use Pixhawk as an autopilot but instead of using Site Scan they may opt for Dronifi, Data Mapper or AgPixel. If you do this then you need to perform several test plots to make sure that it works well in all conditions.

Shadows can be especially problematic if there is more than one flight, and the flights are spaced apart in different times of the day. When the stitching software looks for tie points and the shadows are in different locations in similar images it causes serious problems. Manual tie points is an alternative. Manual tie points require the stitching engineer to go to areas which are not stitched properly by the software, and locate the exact same point in 10 or more photos so as to help the stitching software. This is time consuming and can lead to inaccuracies so it should be avoided where possible.

## **6-2 Boundary Identification for nadir imagery**

When marking the boundary, it is possible for your customer to provide you with a .kml or .kmz file. Some mission planning software programs allow the input of this file directly. If it can't be input directly it takes a bit of time to transfer the boundary of the area of interest over to the mission planning software and mistakes can happen. If you are planning the mission from the office it will take a little longer to find the correct spot than if you go out to the area of interest and plan from there. When you are at the site the location program on your phone or tablet will take you directly to the spot on the map as long as your mobile device has a hot spot or cell service to connect to the internet. If you did not download the maps ahead of time it will be necessary to get to the nearest Wi-Fi or use cell service if available.

Don't use this as the border, but use it to plan where to put the border. You usually want to extend the border of the mission planner 20-50 meters beyond the hard border that the customer is requesting. This will get photos from slightly beyond the area of interest which greatly assists in the stitching process at the edges of the area of interest. This extra distance does not take a lot of extra flight time. It may also gather in extra features to assist in stitching such as roads or other unusual features. It also gets some obliques of the edges of the area of interest. As softwares improve the amount of area needed to fly past the area of interest will decrease. Your data processing software will give guidelines on this. If not, experience with your software will have to do.

Save the work for future use. Before each flight save the flight plan. Once the program is run and it does the job correctly then be sure that it is marked in such a way that you can find it again. You may be asked to photograph the area again in the future especially if you want to have construction

progress photos. This will take photos the exact same way time and time again so the stitching will be done the exact same way as well. This is great for the managers to monitor the progress. This is true for multirotors but not true for airplanes. Typically the flight paths of airplanes are contingent on wind conditions so you will be able to retain the border but not the flight path. Multirotors don't care at all about wind direction. They will fly the same direction no matter what.

If your mission planning computer does not have a hot spot or any way of connecting to the internet then you will not see Google Maps at the field unless you cache the maps from a wifi connection beforehand. You need to plan a mission before you go to the field so that the maps are cached in all the resolutions that you will need in the field. Some programs have the ability to cache maps at the press of a button. Some must cache maps by having you actually go to the area of interest in Google on your laptop, then zooming in and out. These maps are usually cached indefinitely until you physically clear the cache yourself.

For the oblique portion of the imagery, follow the manufacturer's guidelines. In the example of an office building, you may take photos with the camera pointed straight ahead. If the building is high, and you cannot get very far from the building due to trees, towers, parking lot lights, etc. then you may need to make multiple passes at various altitudes. You may find that you need to take photos at 0 degrees (straight ahead), -30, -45, -60 and -90 (nadir). It depends on the resolution and accuracy that your client is requesting.

When taking photos at 0 degrees, do not get a lot of sky in the photograph because sky is not easily stitched. If you find that there is a lot of sky in the shot, then omit the 0 degree shots, and start with -15 degrees or other angle to avoid the sky.

### **6-3 Ground Sample Distance (GSD) (also known as Resolution)**

This is the distance between the centers of the pixels measured at the ground. Manned aircraft generally obtain GSDs in the range of 25 – 50 cm/pixel. sUAS being restricted to an altitude of 400' have much higher GSD in the range of 1 – 3 cm/pixel. The GSD required will depend on the requirements of the job. A data acquisition firm must obtain this parameter prior to flight. It is best to operate the drone at the maximum altitude allowable which is 400' which provides about 3 cm/pixel GSD (camera dependent). This is usually more than adequate for most jobs. A better GSD may be required for estimation of piles of materials or open mines. In these cases altitudes of 150' may be required.

### **6-4 Overlap and Sidelap Definition**

The aircraft is moving forward. The overlap of the photos in the direction of travel is termed overlap. Increasing the overlap is as simple as having the camera take photos at a faster rate. With the Inspire

using DroneDeploy and other similar set ups the aircraft will fly as fast as possible and the photos will be taken at the correct spacing. If a higher overlap is requested and the camera cannot cycle fast enough some mission planners will automatically slow down its forward speed to accommodate the camera.

Fixed wing aircraft have a lot less flexibility to fly slowly because they cannot fly near their stall speed. Fixed wing sUAS usually fly about 5 – 10 knots faster than their stall speed. This is so that if they are flying into a headwind (gust) at stall speed (the slowest speed they can fly to maintain flight) and the gust stops, the airplane doesn't stall. Most airplanes are set up so that if they do stall the nose falls and the plane quickly picks speed up again and begins flying. However it is better to avoid stalls because the aircraft will likely be blown off course and will definitely lose altitude. Once the autopilot recognizes this it will throttle up and bank to get back on course. These changes in attitude and pitch result in inconsistent imagery.

Overlap cannot be changed during the flight. The entire flight is at one overlap. Higher overlap is required in turns. The sharper the turn the higher the required overlap. For this reason it may be necessary to have more than one flight breaking the flights up into different regions of overlap. Run the entire mission as usual, then re-fly only the sharp corners to obtain additional images.

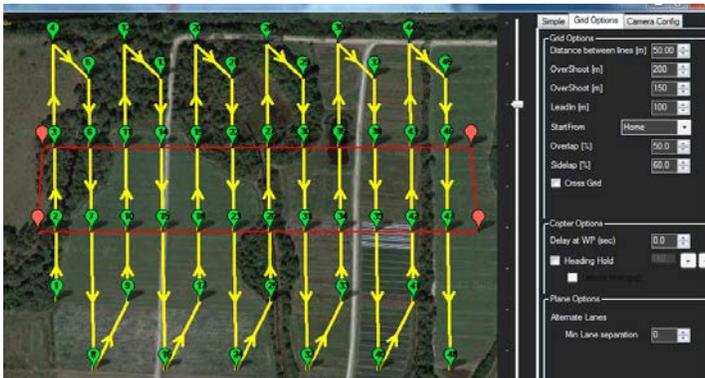
#### **6-5 Overshoot and lead-in**

Rotary aircraft can make 90 degree turns. When they get close to the end of each flightpath the aircraft slows to a stop, turns 90 degrees and heads to the next waypoint. This is quite efficient. Fixed wing aircraft do not do this. They typically throttle up in the turns to avoid losing altitude. Depending on the aircraft it may need to fly 50 to 200 meters past the end of the waypoint to have time to turn 180 degrees around and come down the next row. Lead-in is a term for a waypoint outside of the boundary which the plane tries to hit in order to get lined up for the next pass. As shown below, overshoot to the north of the red boundary is set at 150m as shown in waypoint 3 to waypoint 4. To the south of the boundary overshoot is set at 200m as shown in waypoint 7 to waypoint 8. The Lead In is 100m as shown in waypoint 9 to 10 and 13 to 14. The amount of overshoot and lead-in change with the wind speed and wind direction. Turns are very sharp when heading into high wind. Turning downwind with a high wind speed is usually very problematic for fixed wing planes. They get blown way off course and have a hard time recovering. Always avoid turning a fixed wing plane downwind.

#### **6-6 Skip a lane (row)**

A plane will turn much more sharply when it turns into the wind and will take a very long time to turn around when going downwind. The pilot must decide through experience with their aircraft what the proper settings are. If the rows are too tight for the airplane to turn consistently it is possible to skip one or more rows. At the bottom of the screenshot you see "Alternate Lanes" where the pilot can vary

the amount. The lower to the ground that the plane flies the closer together the rows are which may require skipping lanes. Avoid skipping lanes if at all possible because the resulting flightpath will have some downwind turns which causes problems.



Mission Planner Flight planning demonstrating overshoot and lead in photo © Gene Payson

## 6-7 Flying with and against the wind or flying perpendicular to the wind

There are various ways of flying in relation to the wind direction. The two extremes are:

**Flying with and against the wind.** In the example above if the wind is at 360 degrees meaning it is blowing out of the north to the south, then the aircraft is flying into the wind from waypoint 8 to 9 to 10 to 11 to 12. If the plane normally flies at 35 knots and the wind is at 15 knots the ground speed is only 20 knots. The camera must slow down the rate at which it takes photos. What usually happens is that the plane speeds up to full throttle to try to achieve 35 knots groundspeed. This keeps the photo rate the same. This greatly shortens the endurance of the airplane because the power to increase propeller rpm is cubed! Yes, to double propeller rpm it requires 2 to the third power or 8 times the power. In addition, drag increases to the square of the speed of the aircraft. In our example of increasing airspeed to 50 knots from 35 knots going into the wind to maintain a groundspeed of 35 knots increases parasitic drag by double. For these reasons aircraft fly just over their stall speed. Speeding up to fly into the wind is very detrimental to the endurance. Some stitching software highly prefers that the photos are perfectly in line with one another and are not skewed. The only way to achieve this is to fly with and against the wind. Otherwise the aircraft would have to crab into the wind to maintain its line. Another problem is that photos may not be able to be taken fast enough by the camera to be able to obtain all the necessary photos as the plane speeds downwind. In this example the plane will be flying 50 knots when heading south. This may exceed the capabilities of the camera to write to the SD card.

**Flying crosswind** – In the example above if the wind is at 090 degrees, meaning it is blowing from east to west (right to left) the plane would be crabbing into the wind (to the east). When

it travels from waypoint 8 to waypoint 12 the aircraft would crab to the right. The amount it crabbed to the right would be dependent on the wind speed and the aircraft speed. The slower the plane is flying and the higher the wind speed the more it must crab. Crabbing leads to skewed photos. Most stitching software can handle skewed photos so it's not a problem. In our example the aircraft will maintain its 35 knot speed throughout the flight which is best for endurance. The actual ground speed will be less depending on the wind speed, but it will be consistent in groundspeed and airspeed whether it is traveling north to south or south to north.

### **6-8 Speed vs flight time**

Parasitic drag and other factors have an exponential effect on the speed of a sUAS versus flight time. My testing of multicopters and helicopters is that the amount of energy required to hover, and the amount of energy required for a decent rate of forward flight are roughly the same. Rotary wing use a lot of energy to hover, and tilting forward to increase speed does not use much more energy until the aircraft reaches a critical point. In the multicopters that I tested this is about 80% of their maximum speed. The last 20% of the speed envelope requires that the aircraft tilt quite far forward which causes a loss in lift which is made up through an increase in power level. Each aircraft is different based upon a lot of factors. It is unlikely that a "cruise" speed has been determined for your sUAS. You can determine this fairly quickly with a few tests of your own. Fly a pattern which is larger than the copter can complete on one battery. Fly the pattern at various speeds. When the copter gets to its minimum battery level it will return to home automatically. Note that spot. Within a few flight you will determine the best speed for routine operations. It is the speed that offers the furthest distance of flight.

With fixed wing airplanes there is not a critical speed where the energy spikes up. It increases exponentially (to the third power not the second power) starting at its stall speed. The best endurance for a fixed wing sUAS will always be found to be slightly above the stall speed. It is imperative to fly high enough above the stall speed to take into account wind gusts. The higher the gusts the higher the flight speed. Fixed wing planes always have a recommended cruise speed. This accounts for the gusts. A difference of a 3 knots will have a noticeable effect on the aircraft's endurance.

### **6-9 Camera facing forward**

EO cameras have round lenses but rectangular images... The images are cropped to fit onto the sensor. If the camera is held such that the photos are taken in landscape mode, meaning the top of the camera is facing in the direction of flight, then it will cover more area side to side than if the camera was held in portrait mode, meaning the side of the camera is facing in the direction of flight. Some small fixed wing aircraft are so small that they must put the camera in sideways. This will increase the

number of rows that the aircraft needs to fly to obtain the proper overlap. This will significantly increase flight times.

## **6-10 Making successful 3D models**

3D models will be made up of a series of stitched photographs. Proper overlap, sidelap and other factors are required to avoid errors such as holes in the data (unstitched regions) or inaccuracies. Typical issues are: motion blur, unfocused cameras, vignetting on images, insufficient image overlap, photos taken during turns, photos taken at low altitude, homogenous imagery, etc.

Stitching Defined - each photo taken from the drone contains 'features' such as crop rows, trees, buildings, trails left by equipment, or anything that is distinctly recognizable in the visual space. As the aircraft takes continuous photos during the mission, it captures multiple photos of each distinct feature, from multiple angles. These features are identified and matched by a mathematical process, and aligned on top of each other. This is not simple. You must adjust your aircraft and camera settings to take images that make the stitching process as simple as possible.

Some methods to assist the stitching process are:

### **a) Flying higher**

Flying higher gives the camera lens (with a given field of view) more land area to cover in a single image. This grants the drone more chances to cover common unique features in multiple images, which can help mapping in areas with homogeneous imagery (such as tree canopies or agricultural areas). It also enables higher frontlap to be achieved for a given camera. **Flying higher is the single most powerful way to improve data quality.**

### **b) Modifying flight path to fly down the longest lines**

The Flight Direction feature allows you to change the direction that your drone flies. Changing the flight path can assist when you are mapping a narrow shape so that the drone conserves battery life. Adjust the flight path to make the longest straight lines as possible.

### **c) Increase side overlap (sidelap)**

Flying with more sidelap between each leg of the flight is the easiest way to get more matched features in the imagery, but it does come at the expense of reducing the area that your drone can cover in one flight, and adding more photos to be stitched.

### **d) Increasing front overlap (frontlap)**

This will increase the number of photos taken during each leg by simply making your camera take photos more quickly. Your camera will have a hard limit on how fast it can operate, so after you hit that point you will not see any further improvements. At this time the limit is about 1 photo per second. With rotary wing aircraft the aircraft will slow its

forward flight speed as required to obtain the requested frontlap. With fixed wing aircraft, it cannot slow below its stall speed. Most fixed wing 3D model planes cannot fly slower than about 30 knots.

**e) Starting Waypoint**

With a rotary wing sUAS it is not critical to start the mission at a certain point on the map. For a fixed wing sUAS it is critical to set up the flight path knowing the wind direction. Most fixed wing sUAS conserve energy and fly longer if they fly perpendicular to the wind. Start downwind so that the sUAS is always turning into the wind. Turning downwind makes for very large turns which are very difficult for the autopilot to overcome. Turning into the wind makes for tighter turns and shorter overshoot. Overshoot is the distance beyond the border that the plane needs to turn around and get back onto the proper flight path again.

**f) Check your camera settings and quality of individual photos**

Mission planning software typically attempt to make your camera capture imagery at its absolute best quality. However, ultimately image quality is governed by so many other parameters (some of them listed above), that it is useful for users to check the quality of the individual photos captured as the drone is performing the mission flight. By clicking the Automatic Camera Settings toggle button off you can manually adjust your camera settings. Set the focus (if there is one) to infinity. Set the f-stop, shutter speed and ISO so that the exposure is just a little dark. Images can be lightened but an over exposed pixel is worthless. Since you are taking photos of the ground only, and not the sky, it is much easier to set the exposure without over exposing some areas.

**g) Don't fly when it is too windy. Usually about 10 knots is the maximum.** While the aircraft can typically fly in much higher wind conditions the vegetation on the ground will be swaying back and forth and cause issues with stitching. If there is no vegetation or other things that can blow around, then it's OK to fly at higher speeds. However, high winds usually indicates high gusts. Gusts are a problem because this causes the copter to constantly correct its flight path which moves the camera more which causes blur.

## **Examples of Common Issues**

There are a few common issues that cause low quality models. Learn how to recognize and prevent these issues here:

### **Motion Blur**

This is caused by fast-moving drones or vibration- this either means the shutter speed isn't fast enough, or that you are flying too fast. The best way to solve this is to improve shutter speed, but flying slower or higher will help as well. Here is an example of what motion blur looks like:



*Normal image*



*Motion blur*

*Photo © DroneDeploy*

*Notice the distortion in the bottom right corner of the field.*

### **Unfocused Cameras**

Similar looking to motion blur, poor imagery may be due to an unfocused camera. Most cameras operate better if they are set to manual and focused to infinity before takeoff. Some autofocus programs take too long to adjust the setting and the photo is delayed.

### **Vignetting Images**

Vignetting is caused by a lack of light. Re-flying the mission with less cloud cover can help with this. Check the lens for dust or particles that may be causing the dark images.



*Normal image*



*Vignetting on image*

*The dark corners of this picture are evidence of vignetting. Photo © DroneDeploy*

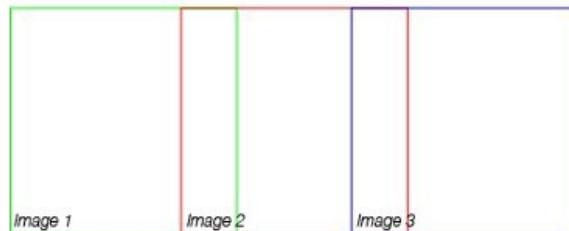
### **Insufficient image overlap**

The higher the image overlap, the easier it is for our software to process your image. High overlap gives you greater map detail over a smaller total space.

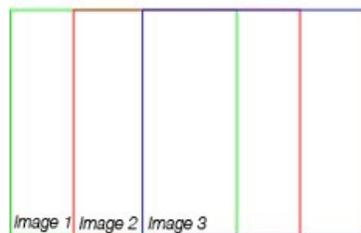
0% overlap



20% overlap



70% overlap



*The amount of overlap between photos will affect the map quality and size. Photo © DroneDeploy*

### **Photos which include the sky**

By including the horizon, the internal distance of the map will be distorted. The software will try to include the areas far away in stitching rather than the area of interest immediately below. Don't use any photos which have sky in the photos.

### **Photos taken at low altitude**

Taking photos at a low altitude lowers the surface area per image, which will make them difficult to stitch together. This can result in blurry maps. It is difficult to cover as much ground in one flight as you could from a higher altitude. However, this needs to be balanced with the resolution required. Usually in modeling (as opposed to mapping) very high resolution is preferable. Therefore flying low and close is necessary. A higher overlap can improve the stitching.

Make sure to always obey your local/national altitude restriction regulations.

## 6-11 3D Modeling Large Areas

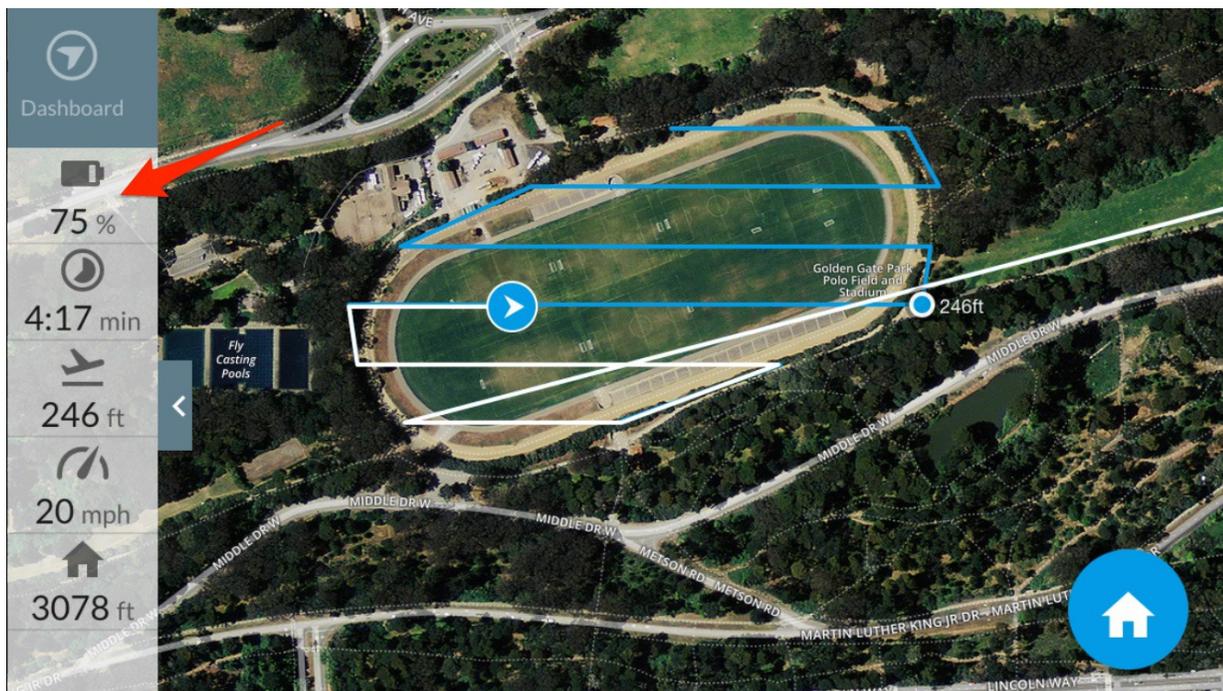
If you are 3D modeling an area which is larger than your sUAS will be able to cover in one flight there usually is a provision to split up the flight into sections. Many aircraft with return to launch (RTL) (also referred to as Return to Land (RTL), return to base (RTB), or return to home (RTH)) when the low battery level is reached. The flight is interrupted and the aircraft returns. The autopilot programs usually recognize this, and will remember the last waypoint reached and will begin with the next waypoint. However, depending on the mission planner, it may be necessary to reprogram to the prior waypoint to be sure that the images between the last waypoint of the last mission and first waypoint of the next mission are taken properly. Here is a visual example of how to map large areas using the DroneDeploy mission planning software.

### 1. Create a plan of the entire area you wish to map.

When planning - there's no need to create lots of small plans to join up at a later stage. You should create the plan as you normally would - but make the boundary large enough that it covers the entire area you are planning to map.

### 2. Begin your flight as usual.

Start your flight as usual, but make sure to monitor the battery level. You can see the current battery level in the graphic below.



Battery icon in the top left sidebar showing the current battery level. Photo © DroneDeploy

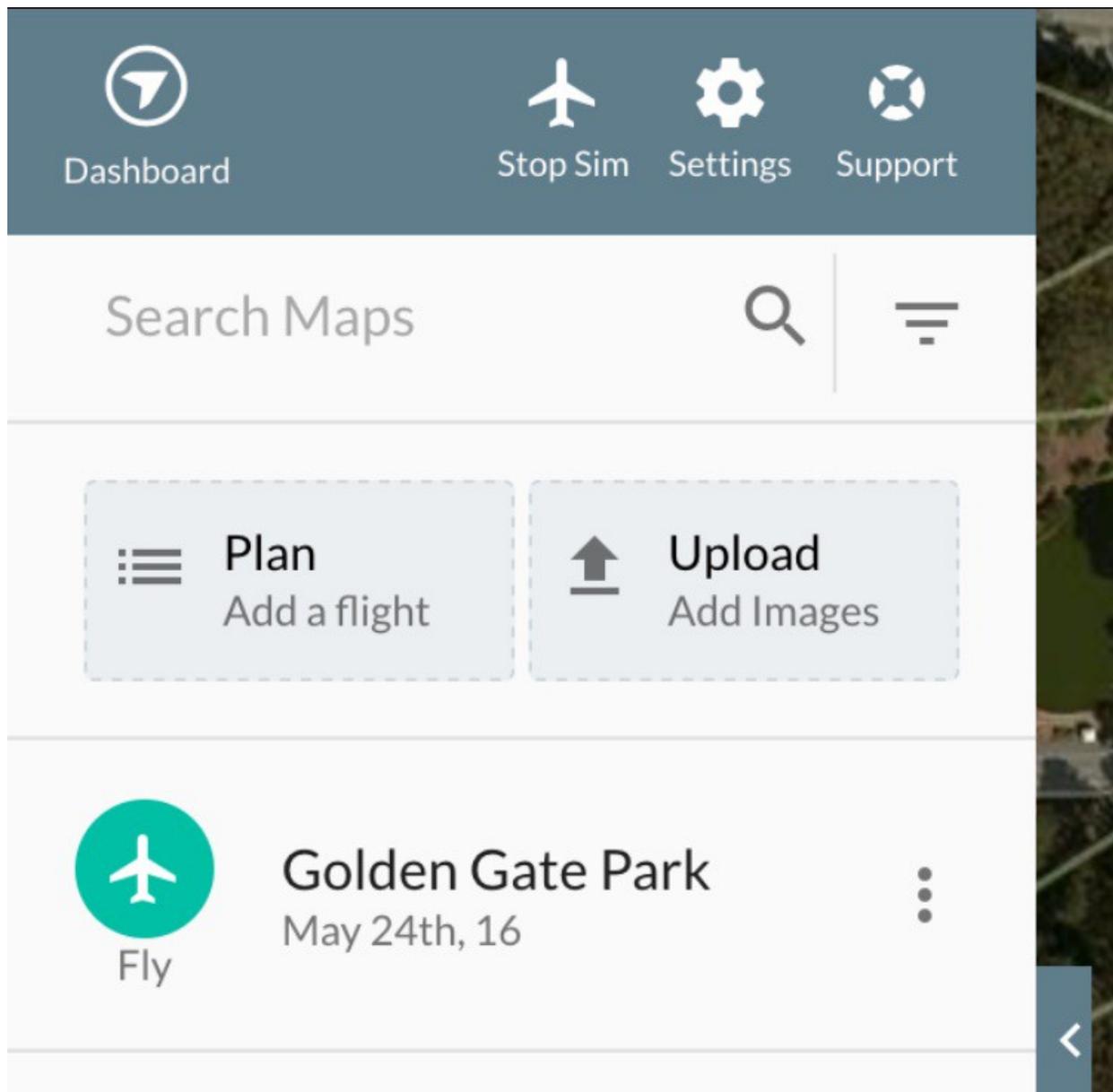
When the battery begins to get low, the remote control will start to beep to warn you, and the battery icon will turn red. You can press/click the red "Home" button in the bottom right of the screen, or press and hold the Home button on the remote control to bring the drone back to its takeoff location.

### 3. Switch out the batteries.

Turn off your battery. Swap the flat battery with a fresh one to carry on mapping.

### 4. Continue the mission by selecting the same plan

Open up your flight plans and select the one that you need to complete.



*Click 'Fly' to open up your incomplete plan. Photo © DroneDeploy*

## **5. Review Your Remaining Flight Plan**

A dotted line represents the part of the plan you have previously flown, and a solid line is the section you still need to fly. Your restart point is indicated by the 'start' point. Press the airplane icon button in the bottom right to start the checklist and then continue the flight.

## **6. Once the checklist passes, takeoff as normal.**

Once you start your unfinished flight, your drone will head back to the last completed waypoint and continue the mission from there. Repeat until the entire area is mapped! All of the flight data should be saved to the plan you were working on previously. The upload process will not change for these types of mission

## **6-12 Best Practices for Obtaining NADIR Imagery for Stitching**

### **1. Include unique objects in the photos**

Stitching software likes to see odd things in your photo pile. Those unique inconsistencies can mean the difference between a good stitch and leaving your pickup with an empty tank of gas at the end of the day with nothing to show for it. Be it cloud-based or desktop, stitching software picks up on those unique things in your photo pile.

Stitches tend to fall like a house of cards if variability isn't dotted across a field (bet you never thought all those red ant hills at the site could be a good thing, huh?). Is your field bounded by a road? Include it in the flight. Don't really need the corners around the center pivot? Capture them anyway as that variation could make all difference toward a successful stitch.

### **2. Fly Higher**

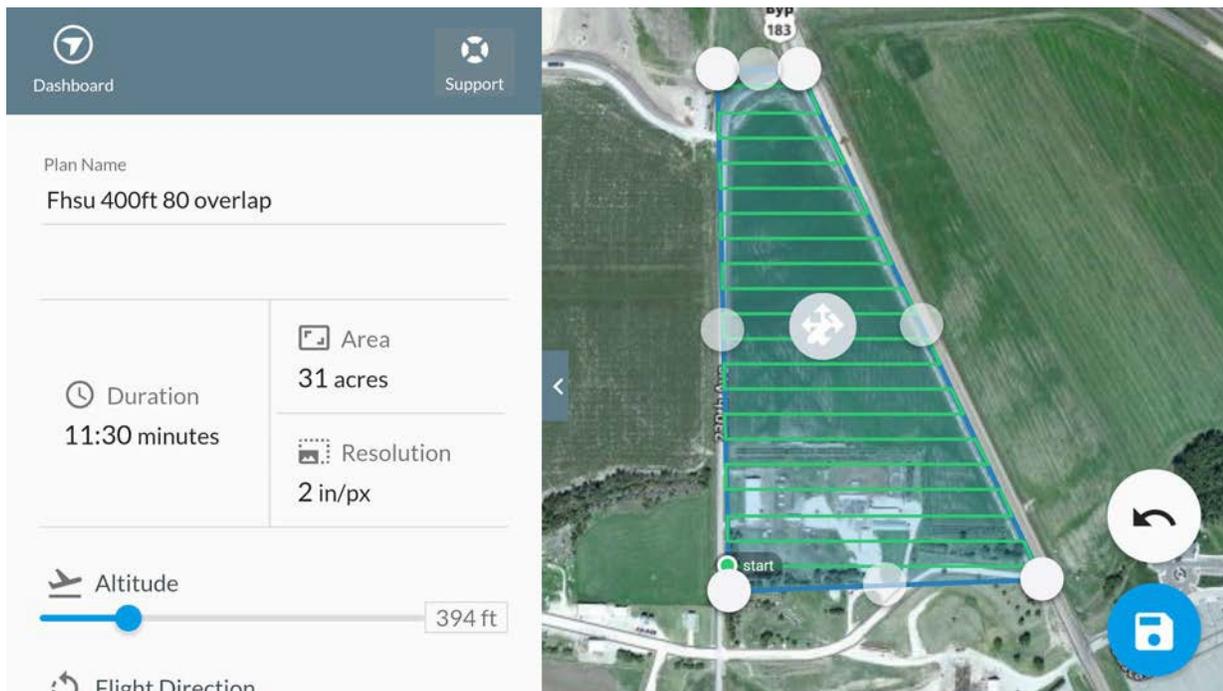
Fly as high as the law allows and get as much area as you can into every shot. The more tie points stitching software can find between overlapping images, the more likely it is you'll have a useable product. Flying higher will lower the resolution. Offer the lowest resolution that is required to do the job. Again this is more difficult to do when creating models instead of maps.

### **3. Fly Smart**

There comes a point of diminishing returns with respect to acquiring too much data. The goal is to maximize the efficacy of flights. Flying higher also gives us the added bonus of being able to cover more ground (a lot) faster; but short of the regulations changing, what we can do is dial in image overlap. Most mission planning software has options to modify both sidelap (cross-track) and frontlap

(along-track). In the context of a typical multirotor aircraft equipped with a stock camera, shutter frequency (and in turn frontlap density) ultimately falls back to ground speed. Flying slow really chews through battery on a multirotors; and it goes without saying that where sidelap is concerned, less rows means less flight time. Multirotors typically draw similar current when hovering or flying forward at about 60% of max or about 30 knots.

Take for example, two flights on the same field: Front and sidelap both at 80% gives us a successful stitch to be sure, but tweaking the side and frontlap to 65% and 75% respectively gives us almost four and a half additional minutes of flight time that could be better put to use elsewhere.



*More than sufficient coverage comes at a cost of battery life. This field can be covered with about 1/3 less overlap and still offer similar results. Extra photos don't help after a certain point. You and your processor need to work out these finer points. Photo © DroneDeploy*

#### 4. Everybody Freeze

Stitching software has a love/hate relationship with change. Point cloud works because of difference, but when those differences are temporal and not spatial, “GIGO” rears its ugly head. Stitching software can get quite confused if the similarity isn't there between images that should be; and in our experience unexpected temporal change is the number-one cause of failed image stitch when nothing seems wrong with a flight.

Temporal change offenders include:

- A shift in wind direction mid-flight that blows vegetation canopy in another direction.
- Vehicles or livestock on the move.
- And, the no. 1 bane of aerial image mosaics: Slowly moving, dense, spotty cloud cover.



*One well-placed moving ATV “twisted” this stitch. Photo © DroneDeploy*

## **5. No Two Models Are the Same**

The longer a drone is in the air, the larger the dataset. Larger datasets are inherently more difficult to process, so it goes to figure that those big acreage flights open yourself up to error. It may take more time, but smaller acreage missions may make more sense to cordon-off problem areas so that the rest of your data isn’t “poisoned” by a handful of bad images.

### **6-13 Best Practices for Obtaining OBLIQUE Imagery for Stitching**

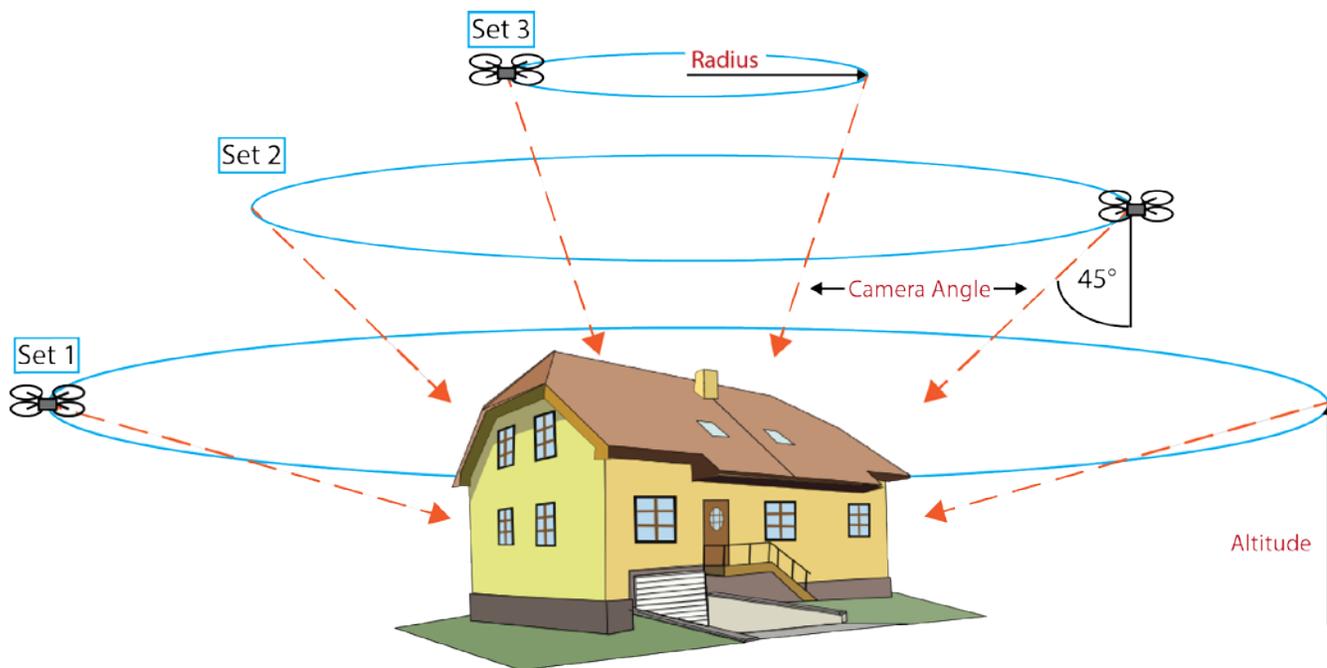
1. Below is an example where oblique images are used and are not used to create the 3D image. You will see that the vertical sides of buildings are distorted or missing, and that the details of tree trunks are missing entirely. Even so, most stitching programs have a difficult time recreating an exact 3D model. AS you can see in the better model the details are less than perfect. Some software works better than others. You will need to do some research when it’s time for you to make your purchase because software is upgrading so rapidly.



*No low-level obliques added Photo © DroneDeploy*



*Low-level obliques added Photo © DroneDeploy*



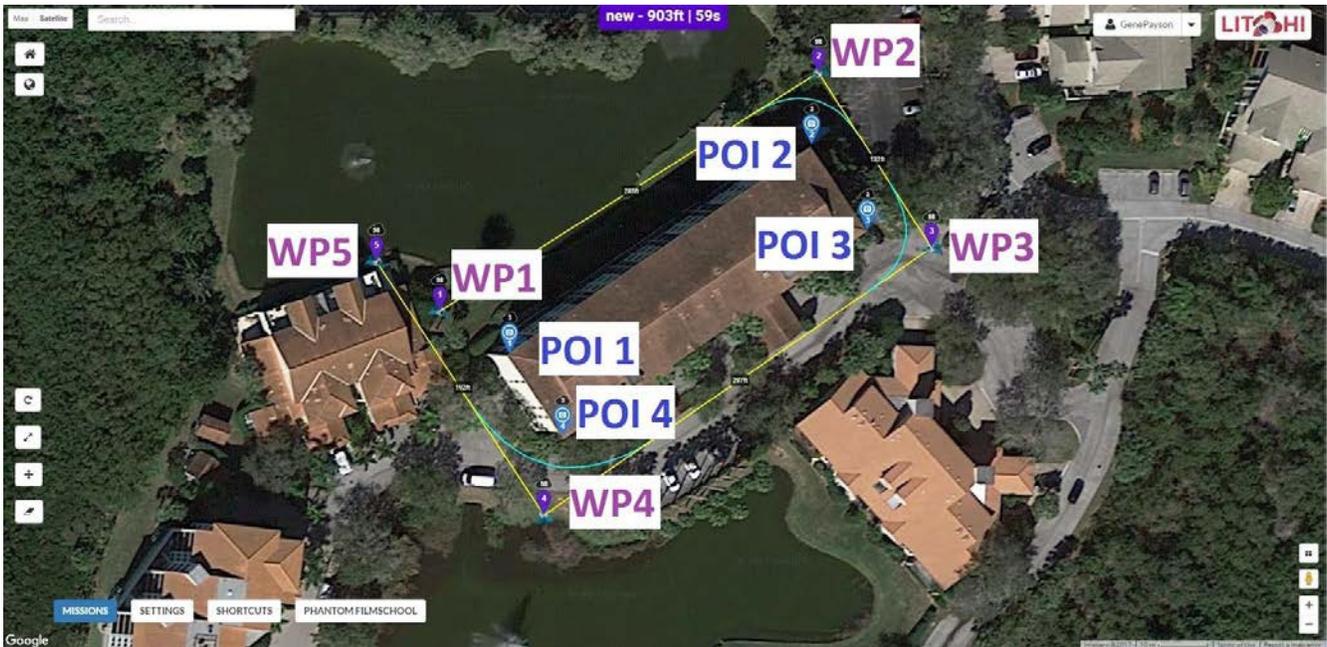
*Three oblique angles which will be added to the nadir shots. Photo © DroneDeploy*

2. So you need obliques, how do you get them? If the object is in a wide open area it is easier to use a flight planning program than to fly manually for most pilots. The program must have a “point of interest” (POI) function. The more advanced the POI function the better. Again, not to say that one is better than another because of the rapid changes in the upgrades, but currently DJI has a primitive POI function, and Litchi a very advanced POI function.

Below is a flight plan using Litchi. The boxes with WP1 thru WP5 are the waypoints. The boxes with POI 1 thru POI 4 are the POIs. With the Litchi program it is easy to program the multicopter to fly from waypoint to waypoint and as it changes waypoints the camera will slowly transition from focusing on one POI to another POI. It is also possible to change speeds from one waypoint to another waypoint. Changing the altitude of the waypoint and changing the altitude of the POI is just a click of a button, therefore having multiple angles is very quick, easy, and precise. You can create this flight plan in under a minute.

If you decide to use the Litchi app there are wonderful tutorials which are updated constantly. Watching tutorial videos on YouTube is a great way to learn.

The key to obtaining proper imagery is to be sure to go slow in the turns, and avoid getting the sky in the images as much as possible.



Litchi app for UAVs

Photo © Gene Payson

- 3.** Autopilot flights – if there are obstacles such as in the example above, an automatic flight will be dangerous – especially if the UAV goes out of your line of sight (LOS). Remember that the FAA requires that the UAV remain in your LOS at all times. As you can imagine, at a low camera angle such as -30 degrees on the SE side of the building there are a lot of obstacles. Should you hit a tree you not only risk your drone but the drone could land on a car and it would be quite an expensive crash. For this reason you may choose to do the flight in 2 (or more) parts. In the example above, for instance, standing at waypoint 2 while flying from waypoint 1 to 3 and then landing would be a good mission. Then standing at waypoint 4 while flying from waypoint 3 to waypoint 5 would be another good mission. Keep your finger on the terminate flight switch in case you are going to crash. However, once you complete the course once, you can be sure that you can repeat the mission again and again without an issue IF you keep in mind that the drone may wander 1-2 meters side to side. Keep at least 3 meters from any obstacle to be on the safe side.
- 4.** Manual flights – in the example above, for the low angle shots where the drone is near tree top level it may be prudent to manually fly instead of using an autopiloted mission. For instance flying from waypoint 3 to waypoint 5 is pretty dangerous looking. However, you must be a good pilot to do this because you need to angle the camera as well as fly the drone. This is going to take some skill, so you will need some extensive training. However, again there is a trick. While you are flying manually you can mark waypoints for a future

autopiloted flight. You can set a button on your transmitter to mark the waypoints. Then you can automatically fly from waypoint to waypoint and you can either tilt the camera manually or you can then program the camera to look at the appropriate POIs.



DJI Inspire 1 transmitter showing programmable buttons on rear. *Photo © Gene Payson*

Programming of these buttons to perform various functions are typically outlined in the app that you are using.

5. Failsafe & choosing a starting point – It is critical to program the failsafe to avoid all obstacles should the UAV have an issue and need to return to home. Usually an altitude of about 50' higher than any of the surrounding trees, buildings, towers or other obstacles. Usually 150' is high enough, but double check your area. One method to find the highest

structure in the area is to point the camera horizontal, then ascend to about 100' directly above where you are standing and look out while rotating the drone 360 degrees. If there is blue sky everywhere then 100' is safe and adding on another 50' is a good idea just to be sure. In the event that the failsafe is triggered it will ascend to the selected altitude, then head straight towards the take off point, staying at that altitude until it reaches the take off point, then pause a few seconds, then descend, land and shut off the motors. You can take back control of the drone at any time by flipping the correct switch. The drone will land within 2 meters of where it took off, so keep this in mind when choosing a starting point. Be sure there is plenty of room between trees before taking off.

## **CHAPTER 7**

### **sUAS WEATHER MINIMUMS FOR 3D MODELING**

#### **7-1 Background**

There are weather minimums for data collection for conventional methods, sUAS, and manned aircraft. They are similar for EO or Lidar collects. Rain is a problem for all methods. Clouds, fog, temperature, altitude, and wind have varying levels of effect.

#### **7-2 Rain**

For the most part data is not taken in the rain. Rain can get onto the sensor and this will cause collect problems or permanent damage due to corrosion. Some of the sensors are not weatherproof. Many of the sUAS are not weatherproof. A waterproofing product called CorrosionX and similar products are used by many companies to protect their electrical equipment from moisture.

#### **7-3 Clouds**

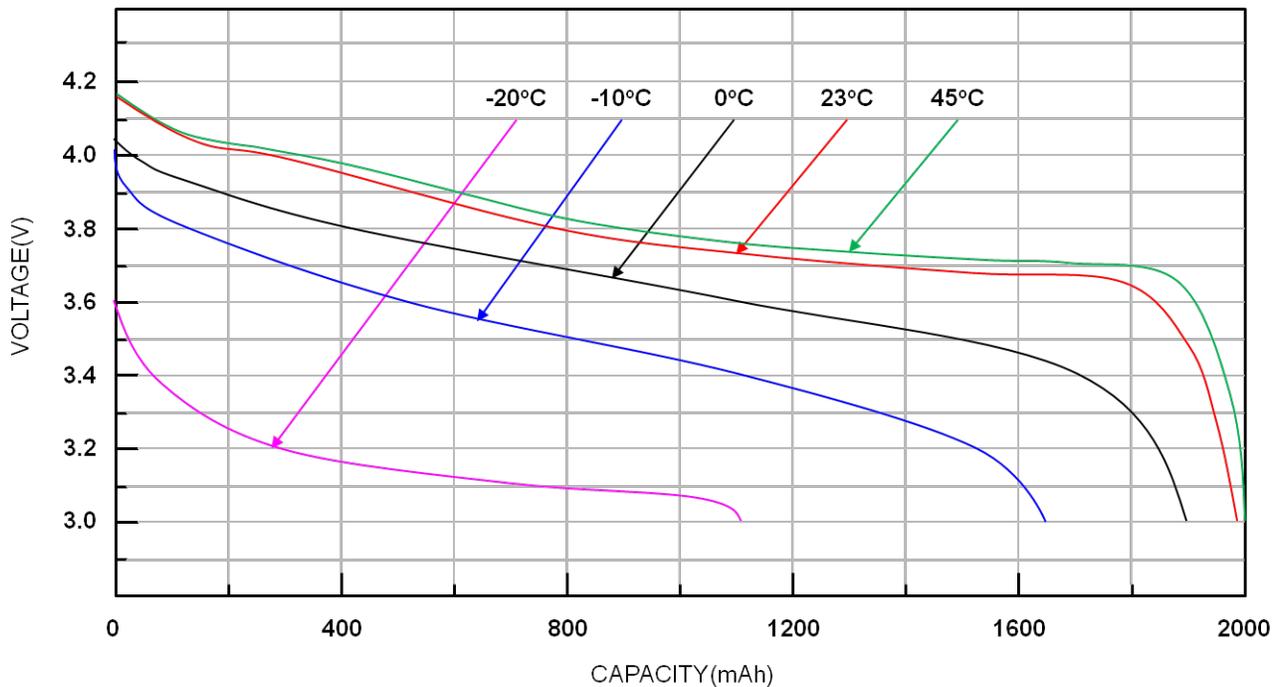
Clouds have no effect on Lidar data collects from the ground or a low flying sUAS. Lidar can be used for data collects using manned planes only if the manned plane is under the cloud cover at all times during the collect. When under the cloud cover, the laser provides its own light source, so there is no issue. Lidar collects can occur at night. Using EO sensors clouds are an issue, but can be corrected using different camera settings to let in more light (ISA, shutter speed, or F-stop). The contrast and the saturation of the data will be lower with less light, but there are no issues with data collects. While precision agriculture needs very consistent lighting throughout the data capturing phase, spotty clouds and thus spotty shadows do not cause major issues with 3D modeling data collects.

#### **7-4 Fog**

Neither Lidar or EO data can be collected when it is foggy. At some times of the year fog may not clear until well into the later morning hours. Data collects in these areas should be scheduled appropriately (after 10am in some cases).

#### **7-5 Temperature**

The most important relationship between temperature and data collection is that sUAS flight batteries are severely affected by temperature. There is a significant decrease in the amount of current available for takeoff, and the capacity of the battery for endurance. It is important to keep the batteries warm, hopefully around room temperature, before using in a sUAS when temperatures are below room temperature.



Reference: <http://www.richtek.com/en/Design%20Support/Technical%20Document/AN023>

Temperature can affect the sensors should water vapor condense inside the sensor to fog up the lens when used in a high humidity environment and the temperature of the sensor is low. This can happen when a sensor is used at high altitudes. The temperature drops at a rate of 2.5 deg F per 1,000 feet in altitude. At 7,000 feet where some manned planes might operate the temperature is cooler. This is not a typical problem because the sensors are sealed to avoid this issue but there are some instances of this.

### 7-6 Altitude

This only comes into play only on the sUAS. The propellers and the wings are severely affected by altitude. There is not a problem of being up to 400' AGL (above ground level). The problem is the altitude above MSL (mean sea level). The thin air is very detrimental to the performance. A fixed wing drone can lose about half of its flying time when flown at 10,000 feet versus flying at sea level. There is a bit of a double whammy on the fixed wing because it has 2 problem areas, the propeller and the wing. For multirotors and fixed wing it is helpful to put on a propeller which is bigger in diameter or larger in pitch or both in order to grab more of the less dense air.

### 7-7 Wind

Wind conditions only have much effect on the fixed wing sUAS. sUAS fly at much lower ground speeds than manned planes so that the wind has a much greater effect. The sUAS gets blown around and which affects the camera angle because most fixed wing sUAS have no gimbal to keep the camera

vertical. For sUAS which are flying into the wind they will use power to a much greater extent. There is a max wind component for most sUAS of 10 – 25 knots. Some of this is due to the flying characteristics of the sUAS, and some is due to the vegetation on the ground which is moving and difficult to stitch because the vegetation is changing its look. Each airframe will have a specific maximum wind speed associated with it. If there is no vegetation in the area of concern the aircraft can be flown to its maximum wind speed. If there is vegetation, the max wind speed may be reduced to 10 knots.

## **CHAPTER 8**

### **sUAS DATA PROCESSING SOFTWARE FOR 3D MODELING**

#### **8-1 Background**

This is an important area to understand before companies purchase a sUAS. The output of the data processing software must integrate with the system being used by the company at this time. Companies can request data files from the data processor, and companies can use free trial offers for evaluation purposes. This course does not cover the methods of using data processing software. The intent of the course is to describe the operation of the sUAS, though the type of sUAS and the software which operates it is dependent upon the software required to process the data because they are intertwined.

#### **8-2 Possible solutions**

There are several black box solutions to create point clouds, meshes, maps, etc. using the data collected from a sUAS. You can purchase the software and have it reside on your computer, or you upload the images to the cloud. There are advantages and disadvantages of each method. You may choose to have both. There are many software companies to choose from and more are becoming available each day. Here are a few of the more popular ones : Drone Deploy, Pix4D, Data mapper, Identified technologies, Agisoft, AgPixel, AgerPoint, Site scan, and Dronifi. Some of the data processors also provide software to operate the autopilot of the sUAS. Having both from one source simplifies troubleshooting of data so that there is no finger pointing from one company to the other. When there is a problem the data processor can blame the way the data was obtained and vice versa. These companies usually offer free trial packages. The packages are for most all the features for a limited time or a limited amount of features for a long period of time.

Software – pay once or pay monthly – your choice. You can pay once and purchase the software and have it reside on your computer or you can pay monthly and have the software reside in the cloud. The issue today is that the data crunching is very power intensive for large jobs, is time consuming, requires an expensive computer system (and maintenance), and requires a large amount of storage capacity. Some companies spend \$20,000 for a computer system. Then you need a way to get this information to the customer. Will the customer keep the information on their computer or do you need to keep it forever? These are large data sets, so be prepared and have a lot of storage space. What if a new technology comes out in 2 years and you want to crunch all the old data with the new software? Will you be keeping all the raw data on file as well? Will your customer? In some cases it is easier to simply upload the data to a cloud processor. Your client pays the monthly fee, you upload to their account. If you are using the data internally, then you pay the fee. Check to see if they also keep the raw data in case a new technology comes out and you want to run the data again.

Security is a big issue. Highly sensitive data may not be able to be stored on a remote server not under the companies complete control. This is a big decision that companies make early on in the process. It may not be possible to use online processors for all your needs.

**ABOUT THE AUTHOR** – Gene Payson is a contract sUAS pilot for the USAF, chief pilot for Unmanned Vehicle University and chief pilot for AngelEyesUAV. He has been operating remotely pilot vehicles since 1968 and has accumulated over 20,000 hours of flight time. He has designed, developed and flown dozens of aircraft. He has trained hundreds of sUAS pilots. He has a manned pilot certificate and flies airplanes and helicopters, as well as a remote pilot in command (FAA part 107) certificate flying both rotary and fixed wing aircraft. He offers a variety of hands on sUAS training courses on many types of sUAS and is available as a freelance pilot to acquire aerial data. Gene has dozens of instructional videos available at no charge on the Gene Payson YouTube channel.



## Chapters 6, 7 and 8: Review Questions

1. It is best to operate the drone at the maximum altitude allowable which is\_\_\_\_\_.
  - a) 600'
  - b) 200'
  - c) 300'
  - d) 400'
2. There are many methods to improve the stitching process. Which is **not** a method to improve stitching?
  - a) Modifying the flight path
  - b) Increasing sidelap
  - c) Flying lower
  - d) Increasing frontlap
3. In 3D modeling, what does RTB stand for?
  - a) Rove to base
  - b) Return the base
  - c) Return to base
  - d) Remote to base
4. The propellers and the wings on an sUAS can be severely affected by\_\_\_\_\_.
  - a) Fog
  - b) Altitude
  - c) Temperature
  - d) Rain
5. Currently, data crunching is very power intensive for large jobs. Which of the following is **not** a data crunching challenge?
  - a) It requires a large amount of storage capacity
  - b) It is time consuming
  - c) It requires multiple software programs
  - d) It requires an expensive computer system

## Review Questions: Answers and Evaluative Feedback

### Chapter 1

1. One of the two broad classifications of 3D modeling is the modeling of geography for \_\_\_\_\_ calculations.
  - a) Boundary; Incorrect. Boundary is not a broad classification of 3D modeling.
  - b) Volumetric; Correct. One of the two broad classifications of 3D modeling is the modeling of geography for volumetric calculations such as piles of coal and sizes of open pit mines.
  - c) Structural; Incorrect. Structural is not a broad classification of 3D modeling.
  - d) Automatic; Incorrect. Automatic is not a broad classification of 3D modeling.
  
2. Currently, almost all 3D model type sUAS operate completely using \_\_\_\_\_ generated by a mission planning system.
  - a) Formats; Incorrect. Formats are not generated by mission planning systems, and they can vary from system to system.
  - b) Interfaces; Incorrect. Interfaces are not generated by mission planning systems, and they can vary from system to system.
  - c) Waypoints; Correct. Almost all 3D model type sUAS fly completely autonomously from takeoff to landing. They operate completely using waypoints generated by an easy to use mission planning system.
  - d) Imagery; Incorrect. Imagery is not an inherent part of a mission planning system.

### Chapter 2

3. Daylight-only operations, or civil twilight, refers to:
  - a) 45 minutes before official sunrise to 45 minutes after official sunset; Incorrect. Daylight-only operations, or civil twilight is 30 minutes before official sunrise to 30 minutes after official sunset, local time, with appropriate anti-collision lighting.
  - b) Anytime, provided you use appropriate anti-collision lighting; Incorrect. Anti-collision lighting is required, but in addition, daylight-only operations refers to 30 minutes before official sunrise to 30 minutes after official sunset, local time.
  - c) 30 minutes before official sunrise to 30 minutes after official sunset; Correct. Daylight-only operations, or civil twilight refers to 30 minutes before official sunrise to 30 minutes after official sunset, local time, with appropriate anti-collision lighting.
  - d) At sunrise and sunset; Incorrect. Daylight-only operations, or civil twilight refers to 30 minutes before official sunrise to 30 minutes after official sunset, local time, with appropriate anti-collision lighting.

4. The maximum groundspeed for an sUAS, according to FAA rules, is \_\_\_\_\_.
- a) 100 mph (87 knots); Correct. Operational limitations include a maximum groundspeed of 100 mph (87 knots).
  - b) 85 mph (74 knots); Incorrect. Operational limitations include a maximum groundspeed of 100 mph (87 knots).
  - c) 110 mph (96 knots); Incorrect. Operational limitations include a maximum groundspeed of 100 mph (87 knots).
  - d) 45 mph (39 knots); Incorrect. Operational limitations include a maximum groundspeed of 100 mph (87 knots).
5. To qualify for a remote pilot's certificate, a person must:
- a) Pass an aeronautical knowledge test at an independent testing center; Incorrect. Passing an initial aeronautical knowledge test is an option for qualification; however, the test must be administered by an FAA-approved knowledge testing center.
  - b) Complete a sUAS online training course provided by the FAA; Correct. Passing an initial aeronautical knowledge test administered by an FAA-approved knowledge testing center is one way to qualify for a remote pilot's certificate.
  - c) Be at least 18 years old; Incorrect. A person may be as young as 16 years old to qualify for a remote pilot's certificate.
  - d) Be vetted by the FAA; Incorrect. A person must be vetted by the Transportation Security Administration.

### Chapter 3

6. 3D models consist of many overlapping photos per object. A common amount of key points is \_\_\_\_\_ per photo.
- a) 20,000; Correct. Each photo is compared for key points by the computer to match the photos to one another. A common amount of key points is 20,000 per photo.
  - b) 8,000; Incorrect. A common amount of key points is 20,000 per photo.
  - c) 30,000; Incorrect. A common amount of key points is 20,000 per photo.
  - d) 10,000; Incorrect. A common amount of key points is 20,000 per photo.
7. Some off the shelf cameras which work well for 3D modeling are the:
- a) DJI X3; Incorrect. The DJI X3 is one of the correct answers, in addition to b. and c.
  - b) DJI X5; Incorrect. The DJI X5 is one of the correct answers, in addition to a. and c.
  - c) 3DR Sony R10C; Incorrect. The 3DR Sony R10C is one of the correct answers, in addition to a. and b.
  - d) All of the above; Correct. The DJI X3, DJI X5 and the 3DR Sony R10C are all recommended off the shelf cameras for 3D modeling that work well and are relatively inexpensive.

## Chapter 4

8. GPS is accurate to about 2-4 meters. There are a few methods to improve accuracy. One common method is:
- a) RTK (Remote Tested Kinematics); Incorrect. If this was Real Time Kinematics it would be correct, but Remote Tested Kinematics is not the correct term even though the initials are also RTK.
  - b) GCP (Ground Control Points); Correct. A common method to improve accuracy is GCP (Ground Control Points). It depends on hardware locating positions on the ground with high accuracy and adding this to the data.  
Receiver quality; Incorrect. Accuracy is dependent on receiver quality, but it does not improve accuracy. Atmospheric effects; Incorrect. Accuracy is dependent on atmospheric effects, but it does not improve accuracy.

## Chapter 5

9. Which is not an advantage of using a helicopter over a multirotor?
- a) A helicopter is more efficient than a multirotor; Incorrect. A helicopter is more efficient than a multirotor.
  - b) A helicopter is more stable in gusting wind conditions than a multirotor; Incorrect. A helicopter is inherently more stable in gusting wind conditions.
  - c) A helicopter is safer than a multirotor; Correct. The four smaller blades on a multirotor are safer than the one large main rotor on a helicopter. The main rotor of a helicopter is large and heavy thus it has a lot of inertia and can do more damage than several small props.
  - d) A helicopter can be gas operated; Incorrect. A helicopter lends itself to gas operation.

## Chapter 6

10. It is best to operate the drone at the maximum altitude allowable which is \_\_\_\_\_.
- a) 600'; Incorrect. The maximum altitude allowable is 400'.
  - b) 200'; Incorrect. The maximum altitude allowable is 400'.
  - c) 300'; Incorrect. The maximum altitude allowable is 400'.
  - d) 400'; Correct. It is best to operate the drone at the maximum altitude allowable which is 400' which provides about 3 cm/pixel GSD.
11. There are many methods to improve the stitching process. Which is **not** a method to improve stitching?
- a) Modifying the flight path; Incorrect. The Flight Direction feature allows you to change the direction that your drone flies. Changing the flight path can assist when you are mapping a narrow shape so that the drone conserves battery life.
  - b) Increasing sidelap; Incorrect. Flying with more sidelap between each leg of the flight is the easiest way to get more matched features in the imagery.

- c) Flying lower; Correct. Flying lower would not improve stitching, but flying higher gives the camera lens (with a given field of view) more land area to cover in a single image.
- d) Increasing frontlap; Incorrect. This will increase the number of photos taken during each leg by simply making your camera take photos more quickly.

12. In 3D modeling, what does RTB stand for?

- a) Rove to base; Incorrect. RTB is not an abbreviation for rove to base.
- b) Return the base; Incorrect. RTB is not an abbreviation for return the base.
- c) Return to base; Correct. RTB is an abbreviation for return to base.
- d) Remote to base; Incorrect. RTB is not an abbreviation for remote to base.

## Chapter 7

13. The propellers and the wings on an sUAS can be severely affected by\_\_\_\_\_.

- a) Fog; Incorrect. Neither Lidar or EO data can be collected when it is foggy, but it would not affect the propellers or wings.
- b) Altitude; Correct. The propellers and the wings are severely affected by altitude.
- c) Temperature; Incorrect. sUAS flight batteries are severely affected by temperature, but not the propellers and wings.
- d) Rain; Incorrect. For the most part data is not taken in the rain, but it would not affect the propellers and wings.

## Chapter 8

14. Currently, data crunching is very power intensive for large jobs. Which of the following is not a data crunching challenge?

- a) It requires a large amount of storage capacity; Incorrect. Data crunching requires a large amount of storage capacity.
- b) It is time consuming; Incorrect. Data crunching is time consuming.
- c) It requires multiple software programs; Correct. Data crunching does not require multiple software programs.
- d) It requires an expensive computer system; Incorrect. Data crunching does require an expensive computer system.

## **AUTHOR ACKNOWLEDGEMENTS –**

Photographs – All photographs in this course belong to their authors and have been kindly contributed to make this course possible. Those contributor's and their websites follow:

- 3DR <https://3dr.com/>
- AGERpoint <http://agerpoint.com/>
- AgPixel <http://www.agpixel.com/>
- Ardupilot <http://www.ardupilot.org/planner/index.html>
- DJI <http://store.dji.com/>
- DroneDeploy <https://dronedeploy.com/>
- FAA <https://www.faa.gov/>
- Pix4D <https://pix4d.com/>
- RICHTEK <http://www.richtek.com/>
- senseFly eBee <https://www.sensefly.com/home.html?L=0>