EVALUATION OF A

SMALL UNMANNED AIRCRAFT SYSTEM (sUAS)

FOR BIG GAME SURVEY

By Robert L. Turner

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Front Matter

ABSTRACT

Small Unmanned Aircraft Systems (sUAS) technology employment is increasing rapidly. Project managers must weigh the benefits and challenges of sUAS technology as a data collection platform. In pursuit of safer and more efficient aerial survey within Arizona Game and Fish Department (AZGFD), this practicum identified benefits (capabilities / applications) and challenges of sUAS technology use within AZGFD. It also answered questions related to the spatial resolution capability of AZGFD's Phantom 4 sUAS camera payload. In doing so, this practicum served to record the first big game survey sighting via sUAS within Arizona. This practicum also documented the need for Beyond Line of Sight (BLOS) operations in pursuit of wildlife conservation. Literary analysis includes specific examples of sUAS technology use within wildlife conservation - Law Enforcement, and Population Management.

Keywords: small Unmanned Aircraft Systems (sUAS), wildlife management, Line of Sight (LOS), Ground Control Station (GCS), Federal Aviation Administration (FAA), Part 107

AUTHOR BACKGROUND

Robert Turner (rt496@nau.edu) is in pursuit of his Master of Science degree at Northern Arizona University (NAU). While studying at NAU, Robert received both the Arizona Geographic Information Council (AGIC) Tony Gonzales scholarship, and the Federal Employee Education Assistance (FEEA) scholarship. In 2017, Golden Key International Honor Society inducted Robert as a new member, and Homeland Security selected him as a UAS Futures team member under the Analytic Exchange Program (AEP). AEP, sponsored by the Office of the Director of National Intelligence (ODNI), facilitates collaborative research by members of Private, State, and Federal Government sectors. Robert earned his Bachelor of Science degree in 2001 from Old Dominion University (ODU) in Norfolk, VA, where he double majored in both Information Systems, and Accounting.

Robert began flying for Homeland Security as an Unmanned Aircraft Systems (UAS) Pilot in Command (PIC) in 2009. Robert's qualifications in the Predator-B (MQ-9) include Launch and Recovery Element (LRE) PIC, Mission Control Element (MCE) PIC, and Sensor Operator (SO). Robert's qualifications also include Homeland Security's small Unmanned Aircraft System (sUAS), the Instant Eye. Robert has logged over 1,700 hours of un-manned flight time, and another 2,700 hours of manned time. Robert retired from the military in 2013 where he flew both the EP-3 (Naval Air Station, Whidbey Island, WA 2003-2006), and C-12 (Naval Station, Guantanamo Bay, Cuba, 2006-2009). Robert is a licensed Airline Transport Pilot (ATP), and as a Remote Pilot in Command (Part 107) – both issued by the Federal Aviation Administration (FAA). Since 2009, Robert has lived in Southern Arizona with his wife and five children.

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I started this research following my son's achievement of Eagle Scout, Boy Scouts of America. As a young boy, I stressed to him the importance of not only volunteerism, but also ensuring the benefactor's mission was worthy of his time and effort. Through this research I have had the opportunity to practice what I preach. I have grown academically while contributing to Arizona Game and Fish Department's (AZGFD) research branch goals. My drive originates in my passions for aviation, Geographic Information Systems (GIS), and more importantly Arizona's wildlife. My entire family has benefited through AZGFD's focus upon mentoring not only new but also seasoned wildlife conservationists. I am forever grateful to the Arizona Game and Fish Department and many others who have mentored, challenged, and assisted me during the time it took to research and write this practicum.

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Purpose, Justification, sUAS Fundamentals

Purpose

Wildlife managers bear an awesome responsibility in the sustainment of wildlife populations for future generations. Wildlife managers serve to protect wildlife from the effects of global change, fire, and other environmental threats. Their decisions depend greatly upon current and accurate census surveys to include health, mortality, distribution, habitation, and location (Chabot and Bird 2015; Christie et al. 2016). Managers also consider locomotion – the study of wildlife position, velocity, and acceleration. Locomotion research includes methodologies such as Global Positioning System (GPS) and Radio Frequency (RF) transmitter tracking (Harvey et al. 2016).

Technology continues to drive lower entry costs for small Unmanned Aircraft System (sUAS) operations. Accordingly, field biologists have begun using sUAS for obtaining accurate wildlife census numbers, mapping migration corridors, and poaching prevention (Schiffman 2014). sUAS can provide accurate surveys of both mammals as well as easily disturbed species such as waterfowl populations. They provide archival data with fewer logistical issues than traditional methods such as manned aerial surveys (McEvoy, Hall, and McDonald 2016).

In October 2016, Arizona Game and Fish Department (AZGFD) became among the first states to issue policy (internal policy D6.13) which governs departmental use of small

Unmanned Aircraft Systems (sUAS). Accordingly, the purpose of this practicum is to identify the benefits and challenges of sUAS technology as applied to wildlife conservation. Three research questions guided the underlying research.

Research Question One (RQ1): What are the benefits of sUAS technology? This question broke down into two parts: (a) what are the capabilities?, and (b) what are the applications?

Research Question Two (RQ2): Is available camera spatial resolution sufficient for effective game management?

Research Question Three (RQ3): What are the challenges of sUAS operations?

Justification

In the decades since the advent of modern wildlife management, seven Arizonans have lost their lives in the line of duty in our state (Arizona Chapter of The Wildlife Society 2003). The Wildlifer Memorial Garden, located at AZGFD Headquarters in Phoenix Arizona, serves to honor their sacrifice. Six of these deaths occurred during aerial flight, the main cause for wildlife-related jobs nationwide. Wildlife Officer Estevan Escobedo died when the Bell 206B helicopter he was riding in crashed after striking power lines near Coolidge Dam while conducting a wildlife survey flight in January 1994 (Officer Down Memorial Page 1994). Similarly, Wildlife Manager Allen Severson died in a helicopter accident while conducting a wildlife survey in Alpine Arizona in February 1980 (Officer Down Memorial Page 1980). There is clearly a need for decreased risk when it comes to aerial survey methods that include live operators and wildlife managers. Because there is no human airborne, sUAS technology decreases risk, increases safety, and enables Wildlife Managers to accept previously declined airborne missions.

Associated costs for a manned ADA program can quickly exceed $200,000 for a typical single engine piston fixed wing aircraft. Through technology advancements, sUAS operations are more affordable than ever before. Lower procurement, maintenance, fuel, and aircraft inspection costs are all available through sUAS technology. Prudent managers must not overlook sUAS technology as a viable option under the overall ADA program for wildlife conservation.

Justification for this research includes increased safety for Airborne Data Acquisition, and lower operating costs. This research also supports AZGFD Research Branch goals, and it promotes Federal and State collaboration mandated under the Sikes Act of 1960. Finally, this research represents the first operational sUAS flight test by AZGFD and provides the foundation for further investigation. sUAS operations within AZGFD promises to aid the wildlife manager, general public, and most importantly – the wildlife populations managed.

sUAS Fundamentals

Background

Unmanned Aircraft Systems (UAS) find their origin in military operations, but as their capabilities have grown their footprint has expanded into the civil sector with applications in diverse industries (Muchiri and Kimathi 2016). UAS are known as “drones”, Unmanned Aerial Vehicles (UAVs), or Remotely Piloted Aircraft (RPAs). The term drone implies autonomous flight, while the other terms refer to a remote ground control operator with in-flight adjustment capability. The first UAS was a torpedo developed in 1915 for the United States Navy. It was designed to fly to its target and then detonate upon reaching the designated location (Finn and Wright 2012). In the Second World War, UAS served as radio-controlled targets and for reconnaissance missions. In the 1990s, National Aeronautics and Space Administration (NASA) and the Defense Advanced Research Projects Agency (DARPA) began research into additional UAS applications due to exceptional image quality. NASA, National Oceanic and Atmospheric Administration (NOAA), and Northrup Grumman collaborated on a three-year, $30-million project utilizing High Altitude Long Endurance (HALE) UAS to track tropical storms through their evolution and to increase predictive analysis capabilities. The Federal Highway Administration and Georgia Department of Transportation worked jointly on a project which employed UAS for road and bridge inspection as well as land surveying with laser mapping, which ultimately alerted officials to traffic jams and accidents. Precision agriculture utilizes UAS technology in the spot treatment of crops to eradicate fungal, pest, and weed infestations before they encompass entire fields. This ensures correct nutrient balance, prevents permanent crop damage, and increases agricultural efficiency by treating affected areas only (Hayhurst et al. 2016). A worldwide survey of existing UAS in 2004 found that 79 percent were aimed at civil research or dual-purpose operations (Arnett 2015). Between 2010 and 2014, international UAS transfers rose more than 35 percent from 322 to 439 transfers. Additionally, the estimated global UAS market in 2016 is USD $10-billion, and forecasted to exceed USD $15-billion by 2020.

As of 2016, the Federal Aviation Administration (FAA) reports the total number of UAS on the national registry exceeds the number of registered traditional aircraft (Crutsinger, Short, and Sollenberger 2016). In August 2016, the FAA issued Part 107 of the Federal Aviation Regulations (FAR), which provides for small UAS (sUAS) operations within the National Airspace System. Under Part 107, operators are allowed to fly sUAS not to exceed 55 pounds, less than 400 feet Above Ground Level (AGL), within Line of Sight (LOS), during daylight, and a list of other restrictions to include no overflight of personnel. Small UAS operators applaud the FAA for its action which in most cases no longer requires them to apply for Certificates of Authorization (COA) or waivers in order to fly within the National Airspace System (Federal Aviation Administration 2016c).

Typical UAS

The Department of Defense (DOD) categorizes UAS into five groupings based upon weight, operating altitude, and speed. Another operational consideration is endurance – how long can the aircraft stay aloft performing its intended mission. **Figure 1 – Typical Unmanned Aircraft Systems (UAS)** provides comparison of four typical UAS flown today.

Ikhana (upper left) is a Predator-B manufactured by General Atomics and flown by NASA for research and development to support Earth science missions and advanced aeronautical technology development (Cobleigh 2007; Conner 2015).

Weight: 10,500 lbs.	Wingspan: 66 feet
Operating Altitude: 50,000 ft.	Propulsion: Turbo-prop
Speed: 240 knots	Endurance: 30 hours

Also manufactured by General Atomics is Predator-A (upper right) and flown by the US Air Force as an "MQ-1".

Weight: 2,300 lbs.	Wingspan: 49 feet
Operating Altitude: 25,000 ft.	Propulsion: Piston-prop
Speed: 130 knots	Endurance: 40 hours

Insitu, a subsidiary of Boeing, manufactures Scan Eagle (lower left). The depicted rail launches Scan Eagle, and the large net later recovers her after mission completion. Scan Eagle approaches the maximum Part 107 weight restriction of 55 pounds. Scan Eagle's maximum operating altitude exceeds Part 107 restriction of 400 feet Above Ground Level (Wilke 2007).

Weight: 44 pounds	Wingspan: 10 feet
Operating Altitude: 20,000 ft.	Propulsion: Piston-prop
Speed: 50 knots	Endurance: 20 hours

Chinese based technology company, DJI, manufactures the Phantom (lower right). Phantom and many other small UAS are battery powered and limited to roughly twenty minutes of flight per battery charge (SZ DJI Technology 2017a).

Weight: 5 pounds	Wingspan: 1 feet
Operating Altitude: 19,000 ft.	Propulsion: Battery
Speed: 40 knots	Endurance: 20 minutes

Command and Control (C2)

A remote operator commands the Unmanned Aircraft System (UAS) through a communication link that provides control inputs to the aircraft and returns flight status and system health information to the operator. Line of Sight (LOS), Beyond Line of Sight (BLOS), or Satellite (Ku) data link communications provide the Command Link. UAS are operated without the possibility of direct human intervention from within or on the aircraft. UAS programming includes a lost link logic for return to launch site should data link communication fail. Large UAS require an airport runway environment for launch and recovery. Small UAS (sUAS) are typically launched from a road or a small vehicle, and are large enough to accommodate cameras, sensors, and other information gathering equipment (Finn and Wright 2012). **Figure 2 – UAS Command and Control (C2)** provides typical C2 configurations. The Fixed Ground Control Station (GCS) (left side) is used to control Predator type aircraft (General Atomics ASI 2018). Command input can be provided by either station, but not simultaneously, which makes Predator type aircraft single piloted. The right seat is where the Sensor Operator (SO) normally sits while operating the camera. Miniaturization in technology make the mobile configuration (right side) possible. The mobile configuration components are a handheld monitoring device and a Radio Frequency (RF) transmitter / receiver. This configuration coupled with smaller aircraft increases deployability and decreases response time through off airfield launch and recovery. sUAS flight planning software enables operators to conduct aerial observations through the use of pre-defined waypoints along a desired flight path and then engaging the pre-programmed flight plan (Chabot 2009; Linchant et al. 2015; Ward et al. 2016).

Camera Selection

Arguably, the sensing component is the most critical piece to any Unmanned Aircraft System - without it the UAS has no capability to observe or record. As UAS technology begins to find real world application, sensor capability is perhaps the fastest growing segment within this industry. Primary considerations to ensure mission effectiveness include desired electro-magnetic (EM) band, camera resolution, and C2 bandwidth for real time scenarios. Most entry level models include gyro stabilized imagery which compensates for UAS movement during in-flight recording and dramatically increases image quality. **Figure 3 – Electro-magnetic Spectrum / Camera Options** provides typical cameras for sensing within different portions of the electro-magnetic spectrum.

Wavelength regions divide the electro-magnetic (EM) spectrum into distinct sections. The regions employed in remote sensing range from shortwave (Ultra-Violet) radiation to longwave (microwave and radio) radiation energy. Wavelength bands further divide the electromagnetic regions. Common bands for UAS observation include visible light, infrared (IR), and near infrared (NIR) (Sabins 2007).

The Zenmuse X5S (SZ DJI Technology 2017b) is a popular camera for sensing within the visible light band – often referred to as Red, Green, Blue (RGB), or Electro-optical (EO). Figure 21 provides greater detail on the Zenmuse X5S. The VuePro (FLIR 2017) is a popular IR sensing camera that enables thermal imaging and infrared photography. Infrared can be employed during hours of light, but is the sensor of choice for low resolution imagery during night hours when EO cameras prove to be ineffective (Chabot 2009; Colomina and Molina 2014).

Sentera's Double 4K NIR sensor simultaneously captures EO and NIR imagery which supports Normalized Difference Vegetation Index (NDVI) analysis (Sentera 2017). The Double 4K is a dual camera payload, which can simultaneously capture more than one EM bandwidth. NDVI analysis applies an algorithm to NIR imagery which then depicts moisture content within the observation area. Predictive analysis techniques can then warn for imminent drought areas and the need for supplemental watering. NDVI information also proves useful when estimating seasonal plant phenology and productivity to inform models of habitat use and movements of wildlife over large areas (Sesnie et al. 2012; Chrétien, Théau, and Ménard 2015).

Velodyne's VLP-16 Light Detection and Radar (LiDAR) Puck provides precise three dimensional (3D) distance and calibrated reflectivity measurements (Velodyne 2017). LiDAR is capable of mapping points underneath vegetation, a distinct advantage over standard EO which can only map tree canopy. Other LiDAR uses include site survey, archeology excavation planning, and analysis of rivers, lakes, coastal regions, climate, and forest fire hazards in the pursuit of forestry protection (Davies and Asner 2014; Crutsinger, Short, and Sollenberger 2016; National Public Safety Telecommunications Council 2017; Sankey et al. 2017).

Raytheon's Multi-Spectral Targeting System (MTS) provides EO / IR, low light television (LLTV), laser designation, and laser illumination capabilities integrated into a single sensor package. The MTS also provides long-range surveillance, target acquisition, tracking, range finding and laser designation for laser guided munitions. MTS sensors feature multiple fields of view, electronic zoom, and multi-mode tracking (Raytheon 2017).

Figure 4 – Electro-optical (EO) / Red, Green, Blue (RGB) Imagery provides sample EO, and RGB imagery. The Buffalo and Elephants were recorded from a UAS in Africa; the elk were recorded from a ground based photographer (Arizona Game and Fish Department 2016; Drone Africa 2017). Note the camera depression angle in each photo – depression angle is highest while recording the Elephants. Increased depression approaches an area called nadir, or directly underneath the UAS. Nadir presents a camera operator challenge as control gimbals approach their mechanical limits. Nadir positioning eliminates observation masking from rising terrain between the UAS and desired imagery. However, Nadir positioning also increases the acoustic signature of the UAS and increases detection likelihood.

Figure 5 – Infra-red (IR) / Thermal Imagery provides sample IR imagery. The author recorded Images on the left, which represent possible polarity selections – top is white hot, middle is black hot, and bottom is orange hot. Polarity refers to how the camera operator chooses to view the heat sensed within the image. The use of IR imaging is a valuable tool for inspecting and performing non-destructive testing of building structures, detecting where and how energy is leaking from a building's exterior (Balaras and Argiriou 2002). Note that thermal imaging does not include the ability to see through external walls.

Capabilities – *<u>Research Question #1 (RQ1)</u>*

What are the benefits of sUAS technology?

Part (a): What are the capabilities?

UAS are capable of a myriad of tasks, and unlike manned aircraft, are deployable from off airfield locations which translates to reduced response time and access to previously unreachable areas (Harvey et al. 2016). Due to their relatively low acoustic signature and size, UAS captured imagery resolution is superior to satellite and manned aviation based observations. This is because UAS can get closer (200 feet in most cases) to the observed species while avoiding detection. UAS vantage point is also better, allowing them to observe avian nests and otherwise obscured burrows (Chabot and Bird 2015). UAS are capable of deploying nets and tranquilizing darts, and can be employed in Law Enforcement scenarios to deter poaching activity (Schiffman 2014). In most cases, UAS presence causes minimal or no visible behavioral response from observed wildlife. However, UAS are capable of causing behavioral and physiological responses when observation range is too close (Christie et al. 2016; McEvoy, Hall, and McDonald 2016). Wildlife researchers have found that techniques learned from avian observation are generally transferrable to mammal observations, but the reverse is much less likely (Chabot and Francis 2016).

Miniaturization within electronic navigation, command and control, and remote sensing has ushered in a new age for users of sUAS technology. Proper combination of camera selection and post flight computer processing software results in a myriad of sUAS technology capabilities and products. Data quality is achieved through an understanding of both the purpose and capabilities of this evolving technology (Hodgson et al. 2016).

sUAS technology allows the Wildlife Biologist to be absent during flight execution due to the permanent nature of the observation recording. In terms of memory storage, the volume of collected data is enormous but also supports extensive post flight analysis. Algorithms for automatic counting of desired observation are available, and in many studies exceed manual counts (Lhoest et al. 2015). sUAS technology provides operational multipliers that include increased safety, cost savings, rapid employment, and remote deployment. Upon flight completion, geoprocessing software can render mensuration attributes that include length, width, height, volume, cut / fill calculations, and time analysis (Nex and Remondino 2014). Recorded imagery is high resolution, georeferenced, gyro-stabilized, and is available for real time observation through video down link directly from the sUAS. Figures six through nine provide sample products available following post flight processing.

Figure 6 – Orthomosaic provides a high resolution EO image of the observation area, which can be useful as a basemap upon which to place other geospatial information. The flight, conducted by AZGFD's Engineering Branch, collected numerous still images with overlapping features that software provider Drone Deploy later stitched together through the science of photogrammetry. Other software providers exist and are capable of automatically generating high-resolution georeferenced orthomosaics from up to thousands of individual aerial photos collected by UAS (Chabot and Bird 2015).

Figure 7 – Contour Lines represents another available product during post flight processing with Drone Deploy. These contour lines provide terrain relief; and AZGFD Engineering estimates their cost at over $15,000 if flown by a manned asset. Contour lines are a depiction of equal elevation relative to a certain point. They have many purposes to include forming the basis for Digital Elevation Models (DEMs) (Schiefer et al. 2014).

Figure 8 – Digital Elevation Model (DEM) depicts a heavily used and washed out dirt road that runs through Arizona State Trust land to the east of Flagstaff. Hill shading is an available method in which to visualize a DEM, and in this case, accentuates the featured trail. DEMs begin with an orthomosaic to create a surface model, which is then used to create a 3D triangulation of ground features as observed through aerial imagery which provides varying angular perspectives (Chabot and Bird 2015).

Figure 9 – Three-dimensional (3D) Modeling depicts the east yard of Ben Avery's shooting facility, located near AZGFD Headquarters. Model manipulation through computer mouse input allows the user to rotate and view the model through 360 degrees of rotation. Following a typical photogrammetric workflow, 3D results like Digital Surface or Terrain Models (DTM/DSM), contours, and textured 3D models can be produced, even on large areas (Nex and Remondino 2014).

UAS employment will continue with new and innovative capabilities to include weather monitoring, live-streaming camera feeds, aerial photography, forestry mapping, vegetation classification, dam infrastructure inspections, collared animal welfare checks, fence status checks, water catchment status checks, grazing assessment, and wildlife census mapping (Crutsinger, Short, and Sollenberger 2016; Hodgson et al. 2016; Verma, van der Wal, and Fischer 2016).

– Chapter Two –

Framework, Scope, Literature Review

Framework

Federal Regulation

A consistent regulatory framework for both manned and unmanned aircraft to safely and efficiently utilize the airspace they must share is critical to the employment of sUAS technology. This shared airspace is known as the National Airspace System (NAS), and begins at the earth's surface. The Federal Aviation Administration (FAA), operating under the Department of Transportation (DOT), manages Mid Air Collision Avoidance (MACA) within the NAS. The FAA has regulatory authority over matters pertaining to aviation safety, and ensures navigable airspace is free from inconsistent regulation. The FAA is responsible for aviation safety, Air Traffic Control (ATC), flight management and efficiency, navigational facilities, and the regulation of aircraft noise at its source (Federal Aviation Administration 2015). In 2012, the FAA released regulation under Public Law (PL) 112-95, also known as the FAA Modernization and Reform Act (FMRA) (Federal Aviation Administration 2012). FMRA purposed to improve aviation safety and capacity of the NAS, provide a framework for safely integrating modern technology, provide a stable funding system, and advance the implementation of the Next Generation Air Transportation System (NextGen). FMRA Section 333 provided an exemption process to allow commercial UAS operators to pursue safe and legal entry into the NAS. In 2016, the FAA released regulation under 14 Code of Federal Regulations (CFR), also known as the Federal Aviation Regulations (FARs) (Federal Aviation Administration 2016a). 14 CFR Part 107 now contains regulation for commercial sUAS operations, although operators may still utilize Section 333 exemptions through their expiration – at which time operations must then comply with Part 107 requirements. **Figure 10 – Current UAS Operations – FAA** provides an overview to include operational authority, operational requirements, and operational description. Future AZGFD sUAS operations will likely fall under either Part 107, or Public Aircraft – which will require a Certificate of Authorization (COA) issued by the FAA. All research for this practicum, to include Ben Avery test flights and the Fort Huachuca evaluation flights, fell under 14 CFR Part 107. Although commercial operators applaud the FAA for issuing Part 107, pressure remains strong to relax restrictions such as Line of Sight (LOS), nighttime operations, and flight over people. The UAS industry is expected to expand to over 100,000 jobs by 2025, with an economic impact of $82 billion (Christie et al. 2016).

State Regulation

While individual states do not have voice into the NAS, they do regulate within their authority to include land access – a critical consideration during the planning phase of any successful sUAS operation. While not applicable to this practicum, future AZGFD operations will likely need to comply with Arizona State Bill (SB) 1449. AZ SB 1449 includes the following restrictions: operation of a drone in dangerous proximity to a person or property is considered Disorderly Conduct; drones cannot interfere with manned aircraft, law enforcement, or firefighters; cities and towns in the state cannot create their own drone regulations or prohibitions; cities and towns with more than one park must allow drones in at least one; drones cannot fly within 500 feet horizontally or 250 feet vertically of a "critical facility" (oil & gas facilities, water treatment facilities, power plants, courthouses, military installations, hospitals, etc.) (Arizona State Law - SB 1449 2016).

Other Regulation

Besides notification to other airspace users, and announcements to the local police, it is always a good idea, and in some cases mandatory, to secure land owner approval for the identified UAS launch site (Stöcker et al. 2017). This practicum operated under the blessing of both AZGFD and Fort Huachuca. AZGFD permission to operate a state-owned asset came from by Mr. J Bullington, AD SSHQ under internal policy - AZGFD Daily Operations Manual, D6.13 Unmanned Aircraft Systems (UAS) policy. Permission to launch a sUAS from a military installation (Fort Huachuca) came from both Ms. D Rohr, Chief, Conservation Management Branch, and Ms. C Thompson, Airfield Manager, Libby Army Airfield.

Scope

This practicum focused upon a narrow segment of the larger field of Unmanned Vehicle Systems (UVS), which includes UAS, Unmanned Ground Vehicles (UGV), and Unmanned Underwater Vehicles (UUV). This practicum focused upon the aircraft segment, and specifically sUAS operating for AZGFD wildlife management purposes. This practicum operated under FAR Part 107, which requires sUAS weight of less than 55 pounds, and altitude of less than 400 feet above ground level (AGL) (Federal Aviation Administration 2016c).

Field observation focused upon Fort Huachuca Deer population estimation during the 2017 aerial survey. Previous year survey results informed sUAS transect selection to provide a meaningful comparison between sUAS technology and traditional manned methods. sUAS survey area ultimately focused upon manned survey Block 5 / Fort Huachuca range area Victor (see figures 11 through 13 below). Survey area was selected due the probability of meaningful data collection, and also due the proximity to base golf course where ample forage, cover, and water would likely attract deer for desired observation (Lawrence et al. 2004).

Figure 11 – Evaluation Airspace – Fort Huachuca, AZ uses a Visual Flight Rules (VFR) sectional as its base map. Range areas divide Fort Huachuca for land management purposes. Figure 11 depicts these range areas over the VFR sectional for reference purposes. Addressed during flight planning was the proximity to Restricted Area 2312 (R-2312), and Libby Army Airfield (LAAF) airspace classification during weekend hours. R-2312 surrounds a tethered balloon from surface to 15,000 Mean Sea Level (MSL) and marks an area where no aircraft may enter. LAAF Class D airspace surrounds the runway environment during the week, but on the weekend that same airspace reverts to Class G (Federal Aviation Administration 2017a). Outside LAAF Control Tower hours of operation (Class G airspace in effect), sUAS operations are legal within the NAS over Fort Huachuca. Note: since this practicum's evaluation flights, the FAA further restricts most military installations from sUAS operations. Future operations in

vicinity of national security interest locations will require pre-approval by the designated facility contact based on criteria established by the sponsoring federal agency in coordination with the FAA. Approval is unlikely unless the UAS flight operation is conducted in direct support of an active national defense, homeland security, law enforcement, firefighting, search and rescue, or disaster response mission. UAS flights with appropriate approval must comply with all other applicable FARs (ESRI 2017; Federal Aviation Administration 2017b, 2017c).

Figure 12 – Fort Huachuca, Game Management Unit (GMU) 35A uses a standard topographic map as its base layer, and then layers Arizona Game Management Units (GMUs) on top. Worth noting is the sizable percentage of GMU 35A that Fort Huachuca consumes. Twenty percent, or roughly 80,000 acres of 35A's 400,000 total acres are occupied by Fort Huachuca.

Figure 13 – Planned Transects for sUAS Evaluation uses a land ownership map as its base layer, and then adds to it geospatial information to include prior year survey areas with results, and also Fort Huachuca range areas. The 2016 Manned Aerial Survey Results map adds polygons to depict 2016 survey blocks, and numbers them 1 through 9 for reference. The inset adds Fort Huachuca range area Victor, which also depicts planned sUAS transects as green rectangles. Note the White Tail Deer density in Block 5 of the 2016 manned survey. Blocks 1 and 8 were mostly unavailable for this practicum due to Fort Huachuca Conservation Branch concerns for potential sUAS interaction with Threatened, Endangered, and Sensitive (TES) species. For the purpose of this practicum, the TES restriction presented little impact due to the abundance of wildlife near the Fort Huachuca golf course.

Literature Review – Wildlife Applications of sUAS Technology (RQ1b)

Capabilities – *<u>Research Question #1 (RQ1)</u>*

What are the benefits of sUAS technology?

Part (b): What are the applications?

This literature review begins by identifying some potential applications for sUAS technology, and concludes by providing specific examples of the sUAS technology research and applications within wildlife management.

The imagination is the only limitation for potential applications of sUAS technology within wildlife research and management. sUAS technology is a useful tool for augmenting, and in some cases, altogether replacing traditionally manned missions. In August 2017, AZGFD's Geographic Information Science (GIS) Branch hosted an Exploratorium where key stake holders from varied disciplines met to brainstorm wildlife management applications of sUAS technology. Attendees numbered over 20, and included AZGFD Law Enforcement, GIS, Contracts, Research, and Information & Education, as well as three private vendors, and this practicum's author. Potential applications fall within five broad categories – Law Enforcement, Change Detection, Wildlife and Plant Conservation, Habitat Assessment, and Fieldwork Planning. More than any other category, Law Enforcement (LE) brings into focus the need for increased sUAS endurance. In most cases, 20 minutes of flight time would fall short of any LE mission. Potential LE applications include poaching detection and enforcement such as illegal game take, overfishing, and protected area entry. Coherent Change Detection (CCD) is an established technique for assessing the before and after affects from weather and other phenomenon. Potential Change Detection applications include fire, flooding, and soil erosion. Potential Wildlife and Plant Conservation applications include population estimation and demographics, radio collared animal welfare checks, game camera media retrieval, avian nest observation, vegetation classification, soil moisture analysis, and noninvasive plant surveys. Habitat applications include dam and other infrastructure inspections, water catchment checks, fence line status checks, and grazing assessments. Fieldwork planning applications include generating high-definition basemaps upon which to layer other geospatial data, and route planning for intended fieldwork excursions, as well as providing topographic data to be used in safe planning of aerial flight (e.g. potential vertical topographical and feature hazards).

Law Enforcement – Poaching

AZGFD Game Warden K Clay responded to three bull elk illegally poached and left to waste in an agricultural field located an hour east of Flagstaff in November 2016. This act was particularly inexcusable because the field is within an area that is open to elk hunting year round for anyone with a non-permit tag - available for over the counter purchase (Arizona Game and Fish Department 2016). Arizonans are not alone when it comes to illegal game take, as the number of recorded rhinoceros poached in South Africa exceed 1,000 in 2013, and continues to rise each year (Mukwazvure and Magadza 2014). Further, elephant tusks bring roughly $1,700 per pound on the black market, and global trade for illegal wildlife products generates approximately $10 billion per year. Even more alarming is this revenue has been linked to Al-Shabaab and other African terrorist groups (Bergenas, Stohl, and Georgie 2013; Shaffer and Bishop 2016).

Absent FAA Line of Sight (LOS) and daylight regulation, Kenya, Namibia, South Africa, Tanzania, Zambia and Zimbabwe are all using sUAS technology to detect and deter poachers (Nuwer 2017; The Economist 2017). Enforcement action is dangerous, and conflict between Game Wardens and poachers have led to several deaths. sUAS technology can assist in detecting and deterring rogue actors from poaching activity, and in one South African park a 60% reduction was realized over a two-year period (Rey, Joost, and Tuia 2016). Margarita Mulero-Pa´zma´ny and a team of Spanish researchers authored "Remotely Piloted Aircraft Systems as a Rhinoceros Anti-Poaching Tool in Africa" in 2013 (Mulero-Pázmány et al. 2014). Her work represents a firm foundation upon which to base implementation of sUAS technology for wildlife poaching enforcement. The table provided here summarizes significant findings from Mulero's research. Test flights

Characteristics	Best scenario	Worst scenario
Flight altitude	< 100 m	> 100 m
Range for low-cost RPAS	< 15 km	>15 km
Time period for visual camera	Morning-midday	Evening
Time period for thermal camera	Morning-night	Midday-evening
Meteorology	Wind < 15 km/h	Wind > 15 km/h
	No rain	Rain
	Dry areas	Areas with high humidity
Habitat Characteristics	Open habitats	Thick forest
	Non populated areas	Populated areas
	Low altitude areas	High altitude areas

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equipped with either visual (EO / RGB) or thermal (IR) camera payloads assessed system ability to detect rhinoceros and simulated poachers. The visual camera was capable of 11 mega-pixel (MP) still, and 1080-pixel (p) video, which yielded an average 5 cm resolution from observation height of 150 meters Above Ground Level (AGL). On average, a 60-minute flight yielded 500 still photos and required 45 minutes for post flight analysis. Neither grassland nor forest habitats presented a challenge for Rhinoceros detection. Still photography yielded greater resolution than video and better serves as evidentiary documentation. Video provides greater situational awareness and better serves real time pursuit scenarios. Thermal imagery results were better when relative humidity and ambient temperatures were low enough to provide sufficient contrast between rhinoceros or simulated poachers and their surrounding background. Lower flight altitude increases pixel resolution, but also increases flight risk for both aircraft detection and impact with rising terrain. Suggested employment for this technology includes covert surveillance, overt deterrence, and active pursuit. Focus areas of operation should include species' preferred locations for surveillance, and sensitive poaching areas for deterrence (Mulero-Pázmány et al. 2014; Olivares-Mendez et al. 2014) .

Wildlife Conservation – Population Management

In a perfect world, wildlife managers would have species census level information upon which to base population management decisions. Complete census is a recognized population monitoring method, but it is costly, time intensive, and typically reserved for Threatened and Endangered Species (TES). Instead, managers often use sample surveys to maintain gender ratios, direct habitat preservation and restoration resources, and foster positive interactions between humans and wildlife (Witmer 2005). The results of both good and bad decisions can have lasting consequences, thus raising the importance of accurate and precise interpretation of population survey results. Manned aerial surveys allow observers to cover more area than ground based sensors, though these observations are imperfect at best. The highest detection accuracy obtained among 49 observers during 72 identical flights over a four square mile moose survey in Alaska was 68 percent (LeResche and Rausch 1974). sUAS technology provides the ability to record individual flights, increase detection accuracy, and reduce perception bias through a variety of available sensor packages (Williams et al. 2017). sUAS provide a safer, more cost-effective, and quieter alternative to traditional research methods (Christie et al. 2016). sUAS technology is also capable of tracking radio collar signals through triangulation which can yield precise animal location, environmental information, and even retrieval of electronic logger information (Chabot and Bird 2015).

The California Department of Fish and Wildlife (CDFW) utilized sUAS to estimate elk population and map habitat areas within the Carrizo Plain Ecological Reserve (US Geological Survey 2014).

Sherbrooke University of Quebec, Canada researched sUAS technology utilization for the detection and counting of white-tailed deer in 2012. Sherbrooke found that a combination of visible and infrared spectral bands yielded the highest detection success for all methods evaluated. Object-Based Imagery Analysis (OBIA) is an imagery processing method based on a variety of attributes to include color, size, shape, texture, and spatial content. OBIA and classification enabled Sherbrooke's post-flight analyst to group contiguous pixels into objects and then classify them as white-tailed deer within their recorded imagery (Chrétien, Théau, and Ménard 2016).

McGill University of Quebec, Canada researched sUAS technology employment for aerial survey of surrogate caribou targets in 2013. Factors that influenced target detection included habitat type, target contrast, and the flight time of day. Thick foliage, lack of contrasting background, and high sun angle all negatively affected the ability to detect surrogate caribou. With Transport Canada's Civil Aviation Directorate approval, this research was conducted Beyond Visual Line of Sight (BVLOS) (Patterson 2015; Patterson et al. 2016).

National Oceanic and Atmospheric Administration (NOAA) operated sUAS to observe penguins and leopard seals near the Arctic Peninsula between 2011 and 2013. While observing Gentoo and Chinstrap penguins, NOAA determined sUAS to have minimal acoustic impact to observation and lower acoustic signature than internal combustion engine type aircraft. NOAA also used sUAS to estimate the abundance and size of individual Leopard seals. Ultimately, NOAA deemed sUAS particularly useful in wildlife applications due to their portability, hovering capability, minimal training requirements, safety, and quiet operation (Goebel et al. 2015).

World Wildlife Fund (WWF) partnered with the US Fish and Wildlife Service, Idaho State University, and Topcon Positioning Systems - a sUAS technology provider, to map and evaluate habitat for the reintroduction of endangered black-footed ferrets on the Fort Belknap Reservation in Montana (World Wildlife Fund 2015a, 2015b). Black-footed ferrets are obligated predators of prairie dogs and rely on their abandoned burrows for shelter and denning – ferret survival is directly linked to prairie dog habitation (Arizona Game and Fish Department 2007). sUAS technology provides critical information through methods that, when compared with traditional aerial surveys, are safer, more cost effective, quicker, and minimize observer bias and variation. This project yielded total prairie dog colony acreage, and approximate prairie dog density through the capture of high resolution imagery and GIS analysis following multiple sUAS flights. GIS software extracted features from imagery, and then classified those features into discrete classes that represented vegetation, burrow entrances, topsoil, and exposed sub soils. GIS software then converted burrow entrances into point data to provide a complete burrow count and population density estimate. Finally, field observers conducted ground truthing over sample plot data to provide confidence in result accuracy (Wade 2015; Dixon 2017).

The foundation of effective game management is an understanding of species habitation and accurate population estimates. Quality data is costly, and at times risky to obtain. Helicopter surveys cost over $1,000 per hour, which can drive annual aerial survey budgets into millions of dollars per year (Biderbeck and Swart 2017). As a result, nonrandom sampling designs are used more often than not to estimate population size (Rabe, Rosenstock, and DeVos 2002). In pursuit of safer, less costly, high quality data, Oregon Department of Fish and Wildlife (ODFW) collaborated with Oregon State University (OSU) to assess sUAS utilization over mountainous terrain for elk population estimation during their 2017 aerial survey. ODFW applied lessons learned from successful sUAS surveys of salmon spawning and cormorant activity in rivers along the Oregon coast. Research objectives included testing sUAS capability to capture imagery sufficient to allow biologists to classify elk by age and sex. Also tested was the ability to capture imagery over forest stand – typical elk habitation. ODFW painted the observation sUAS black and equipped it with strobe lights to increase LOS distance from the Pilot in Command. Observation payloads consisted of both EO/RGB and IR thermal imaging cameras. Reported barriers to project success included the FAA imposed visual LOS requirement, and maximum altitude of 400 feet AGL. Other challenges included flight endurance of roughly 20 minutes, narrow field of view (FOV) when compared with manned aerial surveys, and increased potential for animal recount due to narrow view field and lower altitudes. Reported benefits included safer and more cost effective operation, as well as ability to conduct extensive post flight analysis with permanently recorded imagery (Oregon Department of Fish and Wildlife 2017; Rocky Mountain Elk Foundation 2017).

– Chapter Three –

Methodology

A scientific method approach based upon the tenants of positivism was employed throughout this practicum because its content can be observed, measured, and associated with what is already known about remote sensing and wildlife management (Lew 2010). Data collection was that necessary to evaluate required camera resolution for wildlife biologists to classify deer by gender and age. Gender was determined by the presence or absence of antlers, while age was determined by observed animal relative size. This methodology is largely dependent upon temporal resolution, or time of year when the actual survey is conducted as male deer lose their antlers in the spring each year. Fort Huachuca evaluation flights flew in conjunction with the 2017 aerial survey to provide a comparison with manned survey results. Also, ground observers recorded animal sightings during the sUAS evaluation flights to provide ground truthing of the collected data.

sUAS Evaluation Parameters

Aircraft

Internal collaboration between AZGFD GIS and Engineering Branches resulted in a DJI Phantom 4 (P4) sUAS being available for evaluation during this practicum. P4 purchase price of less than $2,500 included the aircraft with controller, iPad controller display, and Lithium Polymer (LiPo) battery with charger. The P4 senses obstacles in the forward and downward directions, but not backward or upward. The aircraft utilizes obstacle sensing while in P-mode to reduce airspeed and avoid impact with objects encountered along the commanded flight path. DJI claims P4 battery endurance to be 28 minutes. P4 maximum airspeed is 31 miles per hour (mph) in P-mode, and 44 mph in S-mode. S-mode allows for a greater airspeed, but also disables obstacle sensing. Maximum wind component for the P4 is 22 mph, which results in a maximum forward speed of 9 mph when flying directly into the wind. For a manned comparison, fixed-wing aircraft typically fly at 70 mph for aerial survey, rotary fly at 50 mph. Selection of a fixed airspeed for evaluation is a balance between detection and identification capabilities. At high airspeed, aircraft cover more ground which increases probability of animal detection. Low airspeeds to include hover profiles increase ability to collect identification features necessary for wildlife biologists to classify observed animals. The P4 weighs 3 pounds and has a diagonal length of 14 inches.

Camera

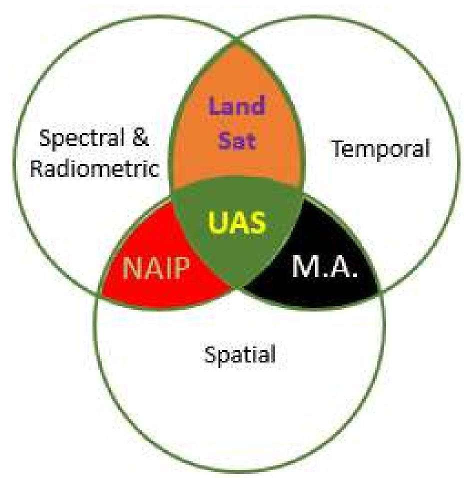
The P4 camera has a 1/2.3 inch (.43 inch) lens that senses in the RGB frequency band. In still burst mode, it is capable of 12MP image resolution at up to 7 frames per second (fps). In video mode, it is capable of recording in 4K resolution at up to 30 fps. The P4 is also capable of providing live video downlink at 720 pixels per frame. Selection of a fixed camera setting for evaluation is a balance between pixel resolution and recorded data volume. At higher resolutions, recorded detail is greater which increases value to wildlife biologists during the classification process. However, higher resolution results in large data volume – an important consideration not only during field operations, but also during archival when preserved.

Depression Angle

The P4's gyro-stabilized gimbal provides high quality imagery that is free from the effects of aircraft movements to maintain commanded flight path and altitude. The gimbal is capable of slewing the aircraft camera in elevation (up / down), but not azimuth (left / right). The PIC must yaw the aircraft either left or right of intended flight path in order to achieve changes in camera azimuth. Depression angle of 90 degrees is a unique position referred to as nadir – found directly beneath the aircraft. Depression of less than 90 degrees results in an oblique angle and requires the science of photogrammetry during analysis due to varying view field widths from bottom to top of the sensor lens. Oblique imagery allows the sensor to view more ground, but with decreasing pixel resolution from camera sensor bottom to top. Oblique angle imagery is also useful when the desired GIS output is a 3-D representation of the point of interest. Like aircraft speed, selection of a fixed depression angle for evaluation is a balance between detection and identification capabilities. At nadir, field of view width and pixel resolution remain constant across the camera sensor. Recording imagery at nadir increases identification ability for the wildlife biologist during classification. Ground cover is higher when using oblique depression angles which results in higher probability of animal detection.

Remote Sensing – Resolution

"Remote sensing is the science of acquiring, processing, and interpreting images, and related data, obtained from aircraft and satellites that record the interaction between matter and electromagnetic radiation. The science of remote sensing excludes geophysical methods such as electrical, magnetic, and gravity surveys that measure force fields rather than electromagnetic radiation." (Sabins 2007) Remote sensing serves to detect and classify features on the Earth using either active or passive methods. Active remote sensing occurs when the observation platform emits energy and then measures its reflected return. Passive remote sensing measures reflected energy from a source other than the observation platform – typically the sun. UAS technology has increased remote sensing resolution by reducing the distance between observation platform and the feature of interest. sUAS utilization as a remote sensing platform continues to grow within wildlife management, arctic ice investigations, polar and alpine research, coastal wetland mapping, flood and wildfire surveillance, and a myriad of other areas within environmental science (Colomina and Molina 2014; Klemas 2015; Bhardwaj et al. 2016).



The four remote sensing resolutions

Remote sensing resolution is classified into four types: spatial, temporal, spectral, and radiometric (University of Texas - San Antonio 2007; Gomez and Jones III 2010). Robert Davis is the founder and Chief Executive Officer for

Quiet Creek, an sUAS technology provider company based in Southern Arizona, as well as a private pilot and retired US Marine Corps Colonel. Davis presented the four aspects of remote sensing to a sizeable audience during the 2017 AGIC symposium. Davis' diagram here presents remote sensing resolution overlap along with ideal data collection platforms. Davis' diagram presents a good framework for considering available options once project requirements have been established. Note that UAS technology becomes the preferred platform over Manned Aviation (M.A.) when it comes to spectral and radiometric sensing (Davis 2017).

Spatial resolution is a measure of the amount of surface detail a sensor can detect, usually expressed in meters per pixel. Spatial resolution discussions often include the terms coverage and extent, which refer to the sensor's field of view. High spatial resolution comes at the expense of reduced coverage. The SPOT-7 satellite-based sensor is capable of 1.5m spatial resolution, suitable for 1:25 scale topographic mapping (Satellite Imaging Corp 2017). The National Agriculture Imagery Program (NAIP) acquires aerial imagery at 1m spatial resolution during the agricultural growing season (US Geological Survey 2017a) . An important specification when considering a UAS camera is sensor capability, expressed in the number of pixels used to record data. The P4 flown for this practicum has a 1/2.3 inch sensor that records 12MP still imagery, which from 100 feet AGL provides 700 x 700 feet spatial coverage, and 5cm spatial resolution (see Figure 17).

Temporal resolution refers to the frequency with which data can be collected, a function of the platform' s mobility. Temporal resolution can also refer to the observation's seasonal time of year – fall, spring, etc. The Landsat 8 and Landsat 7 satellites provide complete coverage of the Earth every 16 days (US Geological Survey 2017b). Moderate Resolution Imaging Spectroradiometer (MODIS) sees the entire Earth every 1-2 days (National Aeronautics and Space Administration 2017). Aircraft provide even greater temporal resolution.

Spectral resolution describes the sensors ability to differentiate between closely spaced EMR wavelengths. The P4's RGB camera has a higher spectral resolution than a black and white camera. MODIS senses in 36 discrete spectral bands (National Aeronautics and Space Administration 2017). The Advanced Very High Resolution Radiometer (AVHRR) senses in 6 spectral bands to provide weather specific information (National Oceanic and Atmospheric Administration 2013).

Radiometric resolution indicates the sensor's ability to detect variations in image brightness, or slight changes in energy return. A bit is the radiometric resolution unit of measure, and indicates the number of available grey-scale values. A 2-bit resolution has 4 grey scale-values; an 8-bit resolution has 256.

Camera Resolution – Research Question #2 (RQ2)

Is available camera spatial resolution sufficient for effective game management?

To answer this question, we flew multiple flights over randomly placed archery targets located at Ben Avery Shooting Facility (BASF), AZGFD headquarters – Phoenix. We flew in a variety of configurations which included changes to altitude, airspeed, depression angle, and imagery recording options. We defined effective game management as the ability for a wildlife biologist to classify animals in sUAS imagery by gender and age. For comparison, figures 14 through 16 present Ben Avery data, flown from 100 feet AGL with 45-degree depression angle in both 4K / 30 fps video resolution, and 12MP / 7 fps burst still resolution. This practicum did not evaluate the P4 camera's zoom capability.

Figure 14 – Flight Test Imagery – 12MP Still Mode depicts a deer on the right taken in maximum spatial resolution still mode. **Figure 15 – Flight Test Imagery – 4K Video, Paused** depicts the same setting in maximum spatial resolution full motion video. The paused video frame on the left displays a zoom to 267 x 150 pixel spatial resolution. **Figure 16 – Flight Test Imagery – Spatial Resolution Comparison** presents a side by side comparison of matching spatial resolution for still and full motion video modes. We concluded that the available camera spatial resolution was sufficient to determine gender and age for animals of deer size.

sUAS Workflow (Mission Planning / Execution / Analysis)

Mission Planning

The initial phase of sUAS workflow is mission planning, which should begin with a thorough review of all appropriate rules and regulations. FAA Advisory Circular (AC) 107-2 provides guidance in the areas of pilot certification, aircraft registration and marking, aircraft airworthiness, and the operation of sUAS in the NAS. Pilots are encouraged to use this information as best practice methods for developing operational programs scaled to specific sUAS, associated system equipment, and operations. Appendix A, Risk Assessment Tools, contains expanded information on Aeronautical Decision Making (ADM) and Crew Resource Management (CRM), as well as sample risk assessment tools to aid in identifying hazards and mitigating risks. Successful decision making is measured by a pilot's consistent ability to keep himself or herself, any persons involved in the operation, and the aircraft in good condition regardless of the conditions of any given flight. As with manned operations, complacency and overconfidence can be risks, and so there are several checklists and models to assist in the decision making process (Federal Aviation Administration 2016b) . The planning phase also includes reviewing project objectives and basemaps, selecting appropriate sensor payload, obtaining necessary approvals (landowner, agency, etc.), determining launch sites, preparing flight paths, and practicing the intended flight profile.

A critical piece to the success of this practicum was the BASF flight profile practice which aided in identifying key positions as the following: Pilot in Command (PIC) – responsible for the safe operation of the sUAS within the NAS in pursuit of project objectives. Visual Observer (VO) – assists PIC in maintaining visual contact with the sUAS to ensure compliance with 14 CFR Part 107, or COA as appropriate. Because this position can be mentally and physically challenging, best practice includes frequent rotation of this responsibility due to concerns for fatigue. Ground Coordinator – responsible for identifying launch locations, maintaining both battery and memory chip supply, and providing quality control to ensure desired data is present. Video monitor – this position is appropriate for missions that include real time observations. Responsible for alerting PIC when features of interest are within sUAS FOV and recommending flight path adjustments.

Practice flights also revealed P4 FOV width, which enabled flight path design. **Figure 17 – Georectification / Spatial Coverage (FOV) Calculation** began with the photo shown in figure top right and a geo-referenced basemap. The P4 sensor recorded the image in 12MP still mode from 100 feet AGL with a 45-degree depression angle. The photo's geo-tag shown in figure 17 top left provides geographic location information. A casual observer might miss the fact that this location does not exist in the photograph – it represents the P4's location when the photograph was recorded. A GIS analyst will receive the warning shown in figure 17 top left when attempting to layer the photograph over any geo-referenced basemap. Projecting the photograph first requires a process known as geo-rectification. Geo-rectification is a data editing (or creation in this case) function that digitally aligns an aerial image of undefined spatial reference to a geo-referenced basemap. Marking several corresponding control points on both the aerial image and the basemap enables a geographic transformation. Transformation is the next step and uses these control points to define the remaining pixels within the aerial image. Depicted in this figure are red and green control points. Red crosses mark the point selected in the aerial image, green crosses mark the matching point on the basemap, blue lines provide the distance between these points – a value used when computing Root Mean Square (RMS) error. RMS error provides a measure of how consistent the transformation is between the different control points. In this figure, the RMS error is less than .001 indicating a successful transformation. RMS acceptance thresholds vary with application, but in this case a visual comparison with the underlying basemap reveals the photo is aligned well and useful for mensuration (Whitehead and Hugenholtz 2015). Layered on top of the geo-referenced basemap is the transformed image for comparison. Note that the roads and trails line up - the parallelogram is a result of the P4 sensor's 45-degree depression angle. Distortion observed in truck size occurs because spatial resolution is not consistent from bottom to top in the original image. In 12MP still, there are 4,000 pixels from the P4 sensor left to right, which results in varying spatial resolution within the spatial coverage area (FOV). ESRI's ArcMap performed all mensuration and geo-processing for this figure (ESRI 2018). Other transformations exist, but projective transformation is the most consistent when working with images captured from aerial photography.

To comply with FAA regulation and the aviation principle of “see and avoid”, maximum LOS distance could not exceed 750 feet, beyond which the PIC was unable to determine spatial orientation necessary to avoid other aircraft operating near the sUAS. To maximize practicum ground coverage, flight path construction utilized 750 feet LOS and a sensor effective horizontal FOV width of 367 feet. **Figure 18 – Transect Design** depicts flight path construction. Figure 18 left shows flight path dimensions with the launch site depicted as a red dot. Flight path construction included maximum LOS of 750 feet from launch site to top and bottom right. Successive launch sites were 1,100 feet further in the direction of travel throughout desired coverage area. The P4’s maximum horizontal FOV width ranged from 243 feet at sensor bottom, to 1,145 feet at sensor top. Because desired coverage area (550 feet laterally from launch site) exceeded the P4’s highest resolution capability (2cm spatial and 243 feet coverage at sensor bottom), an S-pattern was chosen instead of a race track orbit. By design, some overlap exists within the flight path (transect). Figure 18 left depicts sensor effective horizontal FOV width of 367 feet (located just above sensor bottom) to visualize sensor overlap. Figure 18 right shows P4 flight path direction of travel over ground. The red dot indicates launch site, green arrow indicates outbound leg from launch site for flight path initial point, blue arrows indicate P4 travel throughout the flight path, red lines depict constructed flight path, black lines indicate sensor FOV outside flight path, and yellow lines indicate sensor FOV within flight path. Sequentially, the P4 started at the initial point located at flight path top left to fly south, turned east at bottom left and then north at flight path center, turned east at top center and then south at top right until reaching final point located at flight path bottom right. Upon reaching flight path final point, the P4 reversed course and returned to the initial point instead of returning directly to the launch site. The flight path covers the observation area twice (initial pass followed by path reversal) to account for possible terrain masking from vertical development and negative impact from sun angle. Figure center shows successive flight paths within the desired observation area – Fort Huachuca range area Victor. Ground travel was from north to south within Victor. Again, ESRI’s ArcMap performed all mensuration and geo-processing for this figure.

Mission Execution

The middle and shortest phase of sUAS workflow is mission execution. The execution phase includes ensuring both charged batteries and sufficient memory storage are available, monitoring weather, arriving on site and engaging the landowner, executing the flight plan, and performing in-field quality assessment to ensure data collection is complete.

Evaluation flights took place at Fort Huachuca during the weekend that followed their 2017 aerial deer survey to provide a meaningful comparison with manned results. Ground observers conducted ground-truthing concurrently with evaluation support by recording animal sightings observed from their position. The Pilot in Command was Mr. C Gunter, Visual Observer was Dr. R Lawrence, and Ground Coordinator was this practicum's author. Fort Huachuca Environmental, Range Control, and Military Police were all notified of the event through multiple means of communication prior to and during the exercise.

DJI claims P4 battery endurance to be 28 minutes, but our evaluation found duration to be closer to 20 minutes. Six additional batteries and one DC charger for field use from the ground support vehicle were available in anticipation of degraded battery performance, and extended flight requirement. The ground coordinator utilized a laptop computer, two external hard drives, and four memory chips to download data following each flight for quality assurance and to create a backup copy for data preservation. Flight time totaled 84 minutes and consumed 34 GB of memory storage.

Several days of high wind conditions preceded the evaluation flights, but began calming as the event approached. Evaluation winds of less than 10 mph were favorable for both aircraft performance and wildlife observation to include open field areas. The P4 flew the prepared flight path (transect) multiple times throughout the desired observation area. To maximize flight safety, spatial resolution, and ground coverage, the P4 flew at 100 ft AGL, 30 mph, and in P-mode with all obstacle sensing features enabled to minimize risk of collision with trees and terrain. The P4 gimbal slewed the sensor to 45-degree oblique depression angle as a compromise between detection and identification interests. The P4 recorded imagery in video mode at 4K / 30 fps resolution with practicum intent to utilize video editing slow playback mode during the processing phase to capture wildlife identification features.

Mission Analysis

The final and perhaps longest phase of sUAS workflow is mission analysis, which focuses upon processing, metrics, and ultimately product creation and sharing results with key stakeholders. The Mission Analysis phase is highly software intensive, but serves as the foundation upon which to base predictive analysis. Aerial imagery provides adequate resolution for unambiguous species identification after GIS analysis and post mission processing is complete (McEvoy, Hall, and McDonald 2016).

Software utilized for this practicum included Terrain Navigator Pro, Autopilot by Autoflight, DroneDeploy, Dronelogbook, Wondershare's Filmora, ESRI's ArcGIS Earth, and ESRI's ArcMap. Terrain Navigator Pro is a mapping platform that combines topographic maps and aerial photos with mapping tools that include distance, slope, and location type information. Autopilot provides sUAS mission profile programming to include autonomous and semi-autonomous flight modes, flight execution, and camera control sequences. DroneDeploy is a web based software suite that automates drone flight programming, processes imagery, generates metrics, and assists in GIS product creation to include orthomosaics, digital elevation models, and 3-D presentations. Dronelogbook keeps track of individual flights, aircraft and battery health and maintenance, and provides a way to view onboard data loggers created during flight. Dronelogbook also tracks pilot currency, totals pilot and aircraft hours, and assists with FAA report writing when necessary. Wondershare's Filmora is a video imagery editor that enables video slicing, adding text and music, and supports a variety of compression ratios and file formats for export. ESRI's ArcGIS Earth enables users to browse and explore GIS data quickly and outside ESRI's other line of products. ESRI's ArcMap software enables the user to work with GIS information and perform geo-processing type functions. ArcMap compiles geographic data, analyzes mapped information, and provides an infrastructure for mapping and authoring GIS related content. ArcMap also provides a means to store data through a variety of supported geo-database types.

– Chapter Four –

Findings and Conclusion

Findings

Figures 19 and 20 summarize the practicum findings. **Figure 19 – Recorded Sighting** is the only deer recorded by the sUAS-mounted imaging device during the Fort Huachuca evaluation flights. Filmora's video editor slowed sUAS speed from 30 mph to 3 mph, paused the desired video frame, and provided a 75% digital zoom to produce the image in figure 19. With the P4 travelling in a northeasterly direction, the deer entered video camera field of view at screen top and left of center. A camera oblique depression angle of 45 degrees continued to record the deer from 100 feet AGL until it disappeared from screen left, mid-way between top and bottom. The deer would have gone unobserved utilizing a nadir camera depression angle due to screen width at screen bottom was insufficiently wide enough for observation – reverse direction flight path did not record the deer.

Figure 20 – sUAS Evaluation Flight Summary presents final analysis for all Fort Huachuca evaluation flights. ESRI's ArcMap version 10.4 provided all geo-processing and basemap imagery. Figure 19 presents the single deer that was detected by the P4 camera as a large green dot. Figure 20 presents other animal sightings recorded by ground observers but that were not detected by the P4 camera during the flight. Visual observations by ground observers during the flight were one method of "ground truthing" used during the exercise. Green triangles and yellow polylines represent sUAS launch sites and evaluation transects covered by the P4's flight path. P4 video imagery captured only one of a total 33 animals observed during ground truthing observations. Total sUAS flight time was 1.4 hours, which took 2.6 hours to complete due to necessary ground repositioning throughout the evaluation. sUAS ground coverage totaled 300 acres, with 23 acres flown per transect to yield a total 3.5 acres per sUAS flight minute. For comparison, a typical fixed-wing, manned survey takes 6 hours to cover 100,000 acres, and yields a total 278 acres per manned flight minute. This mission's sUAS camera spatial coverage limits observation, while manned observation focuses

on 400 feet either side of aircraft flight path as seen by airborne observers. sUAS spatial resolution is much finer when flown from 100 feet AGL than that of manned observation - typically flown from no lower than 500 feet AGL.

Challenges – Research Question #3 (RQ3)

What are the challenges of sUAS operations?

The FAA imposed Line of Sight requirement was the single greatest challenge to this practicum evaluation. 14 CFR Part 107.31 states that the PIC must at all times maintain the sUAS within a distance sufficient to determine the unmanned aircraft's attitude, altitude, and direction of flight. Additionally, the PIC's vision must be unaided by any device other than corrective lenses (Federal Aviation Administration 2016a). The FAA is silent when it comes to a stated LOS distance, which leaves the PIC with huge discretion and vast responsibility when it comes to liability while operating within the NAS. This practicum operated within a LOS defined as 750 feet. As a result, the P4 did not record animal presence within the immediate surroundings of aircraft operations.

During AZGFD's Exploratorium of August 2017, experts from a wide background met to brainstorm wildlife management challenges of sUAS technology. Potential challenges for sUAS technology fall within five broad categories – Regulation, Operational Management, Public Perception, Advancing Ground, and Aircraft Systems. Regulation exists at the Federal, State, and local levels. Regulation challenges include BLOS, night time operations, rapidly changing legislation, and lack of court case law (Chabot and Bird 2015). Operational management challenges include liability, technology obsolescence, large volumes of data, and increased time for data analysis processing. Machine learning, data acquisition and management, and integrating extracted information into management practices are all issues operations managers will need to address (Rey, Joost, and Tuia 2016). Public perception challenges include concerns for safety, insurance, security, and privacy (Carr 2013). Advancing ground while maintaining sUAS LOS and within close proximity to desired wildlife observations is a challenge for wildlife managers. This area includes wildlife disturbance, interaction with Threatened and

Endangered Species, and double counts during wildlife survey due to sUAS narrow field of view. sUAS operators must consider size and shape of their sensor platform during close range operations in order to remain undetected by observed wildlife (McEvoy, Hall, and McDonald 2016). Finally, aircraft system challenges include counter sUAS operations, loss of C2 signal, GPS jamming, battery endurance, interaction with other aircraft, terrain avoidance due to low altitude operations, and forest canopy penetration where much wildlife remains hidden (Chrétien, Théau, and Ménard 2016).

Despite an otherwise promising future, sUAS technology remains challenged on multiple fronts. However, the growing demand for sUAS in research and industry is driving rapid regulatory and technological progress, which in turn will make sUAS more accessible and effective as analytical tools (Christie et al. 2016).

Conclusion

Significance

In pursuit of safer and more efficient aerial survey, this practicum identified benefits (capabilities / applications) and challenges of sUAS technology. It also answered questions related to spatial resolution of the Phantom 4 sUAS RGB camera payload. In doing so, this practicum served to record the first big game survey sighting via sUAS within Arizona. This practicum also documented the need for BLOS operations in pursuit of wildlife conservation.

This practicum operated at a small fraction of the cost for traditional manned aerial survey. In addition, both test and evaluation flights operated in a much safer manner than manned survey. A risk based comparison of both manned and unmanned observation reveals far less risk when conducting an unmanned operation. For sUAS technology, a catastrophic failure when operated in accordance with FAA regulation yields nothing more than a lost asset. When it comes to manned survey, a catastrophic failure includes the loss of life. At best, sUAS technology can currently augment manned survey. Still, sUAS technology conducts Airborne Data Acquisition without placing lives at risk – a desirable increase in operational safety.

Recommendations

Continued research and additional small scope projects will assist AZGFD to harness the full potential of sUAS technology. Experience gained through this practicum suggests future recommendations under the broad categories of autopilot software and aircraft configuration.

An understanding of the need for quality data and associated acquisition costs are paramount to any systematic approach to sUAS technology employment. sUAS technology has greatly enhanced remote sensing resolution. Inflight command and control software enables the operator to place the aircraft in the most advantageous location for sensor employment. Real time observation requires an ability to interrupt programmed flight for desired observations, and then return to programmed flight following data collection. Autopilot software and pilot proficiency are essential to non-programmed flight. Ability to make inflight adjustments to flight path and camera manipulation is dependent upon the decision to employ proprietary or open source mission planning software. This practicum utilized Autoflight's Autopilot (open source) software, but there are many other providers available. Choosing the best software is not an easy task, but determines the quality of data collection and ultimately the level of mission analysis possible (Snow 2016). **Figure 22 – Management Recommendations** presents key takeaways from this practicum.

Aircraft configuration includes LOS distance, AGL altitude, and payload resolution. sUAS project managers should determine minimum LOS requirement early in the life of any project. Aircraft strobe lights and exterior paint schemes can increase effective LOS distance. Payload capability importance is secondary only to LOS effective distance. Spatial and spectrum resolution determine detail and product quality available during mission analysis. This practicum utilized 4K spatial resolution RGB video imagery for data collection. Similar projects should consider still burst mode and dual payload options to include thermal imagery. Minimum AGL altitude and spatial coverage are directly related to payload capability – project managers should consider 20MP still imagery as a minimum project requirement. **Figure 21 – DJI Product Comparison** provides a comparison of DJI products with related capabilities and associated purchase costs. Real time sUAS technology employment should include ability to monitor a large screen presentation from a darkened viewing area with PIC direct communication for inflight profile modifications.

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Acronyms

3-D	Three dimensional
AC	Advisory Circular
ADA	Airborne Data Acquisition
ADM	Aeronautical Decision Making
AGIC	AZ Geographic Information Council
AGL	Above Ground Level
ATC	Air Traffic Control
AVHRR	Advanced Very High Resolution Radiometer
AZGFD	Arizona Game and Fish Department
BASF	Ben Avery Shooting Facility
BLOS	Beyond Line of Sight
BVLOS	Beyond Visual Line of Sight
C2	Command and Control
CCD	Coherent Change Detection
CDFW	California Dept of Fish and Wildlife
CFR	Code of Federal Regulations
COA	Certificate of Authorization
CRM	Crew Resource Management
DARPA	Defense Advanced Research Projects Agency
DEM	Digital Elevation Model
DOD	Department of Defense
DOT	Department of Transportation
DSM	Digital Surface Model
DTM	Digital Terrain Model
EM	Electro Magnetic
EMR	Electro Magnetic Radiation
EO	Electro Optical
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FMRA	FAA Modernization Reform Act
FOV	Field of View
fps	frames per second
GB	Gigabyte
GCS	Ground Control Station
GIS	Geographic Information System
	Geographic Information Science
GMU	Game Management Unit
GPS	Global Positioning System
HALE	High Altitude Long Endurance
IR	Infrared

Ku Satellite Communication

LAAF Libby Army Airfield

LE Law Enforcement

LiDAR Light Detection and Ranging

LiPo Lithium Polymer

LLTV Low Light Television

LOS Line of Sight

MACA Mid Air Collision Avoidance

MODIS Moderate Resolution Imaging Spectroradiometer

MP mega-pixel

MSL Mean Sea Level

MTS Multi-spectral Targeting System

NAIP National Agriculture Imagery Program

NAS National Airspace System

NASA National Aeronautics and Space Administration

NDVI Normalized Digital Vegetation Index

NextGen Next Generation Air Transportation System

NIR Near Infrared

NOAA National Oceanic and Atmospheric Administration

OBIA Object Based Imagery Analysis

ODFW Oregon Dept of Fish and Wildlife

P4 DJI Phantom 4

PIC Pilot in Command

RADAR Radio Detection and Ranging

RGB Red, Green, Blue

RF Radio Frequency

RMS Root Mean Square

RPA Remotely Piloted Aircraft

SB State Bill

SO Sensor Operator

sUAS small Unmanned Aircraft System

TES Threatened and Endangered Species

UAS Unmanned Aircraft System

UAV Unmanned Aerial Vehicle

UGV Unmanned Ground Vehicle

UUV Unmanned Underwater Vehicle

UVS Unmanned Vehicle System

VFR Visual Flight Rules

VO Visual Observer

Figures

Figure 1 – Typical Unmanned Aircraft Systems (UAS)

Figure 2 – UAS Command and Control (C2)

Figure 3 – Electro-magnetic Spectrum / Camera Options

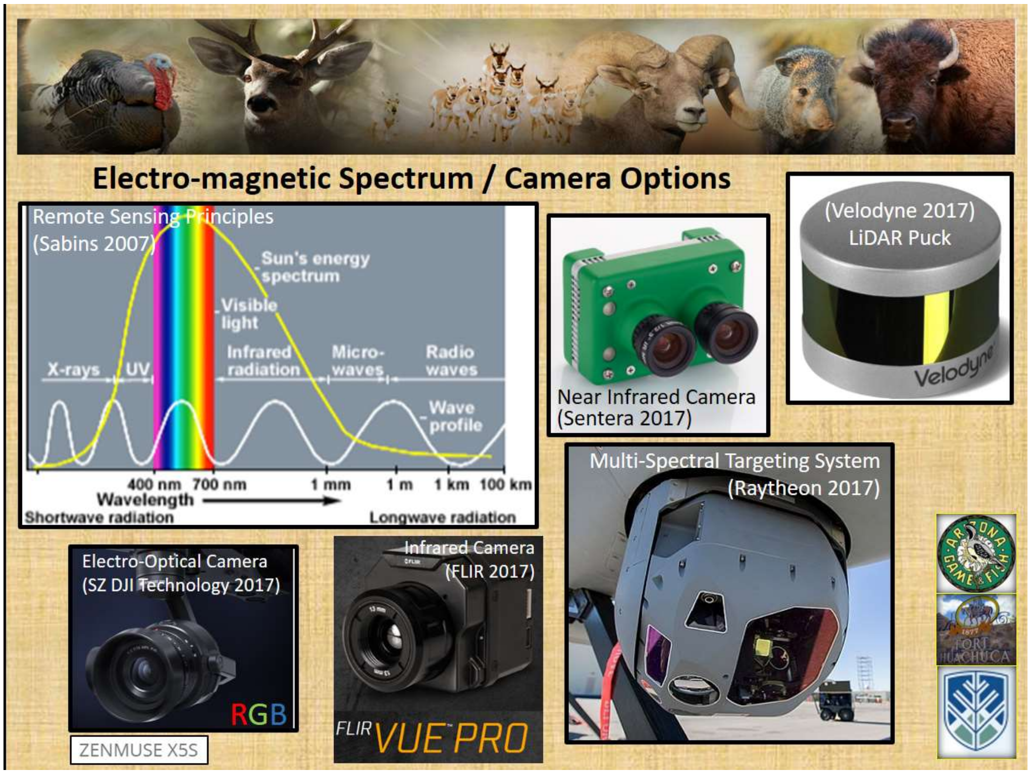


Figure 4 – Electro-optical (EO) / Red, Green, Blue (RGB) Imagery

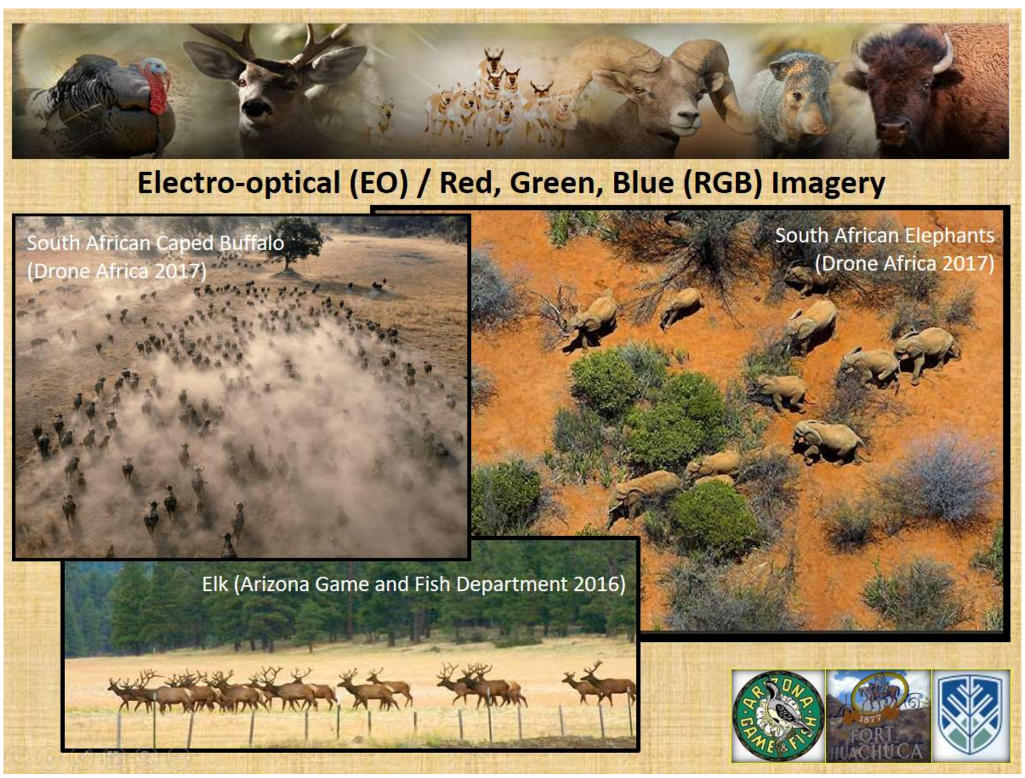


Figure 5 – Infra-red (IR) / Thermal Imagery

Figure 6 – Orthomosaic

Figure 7 – Contour Lines

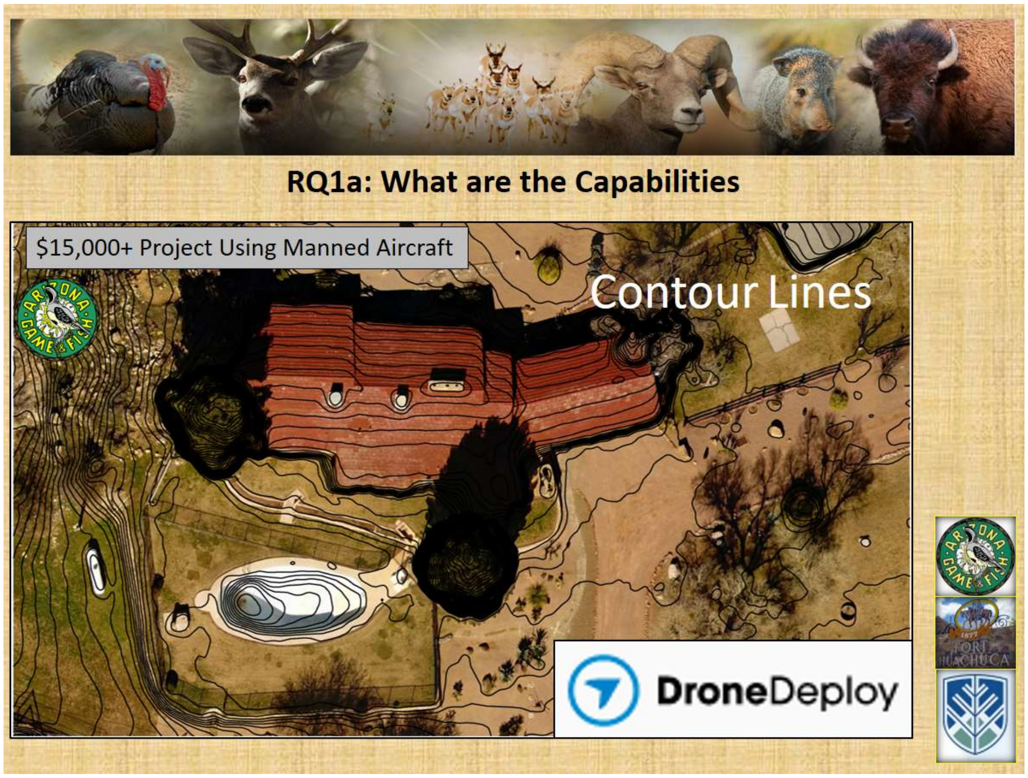


Figure 8 – Digital Elevation Model (DEM)

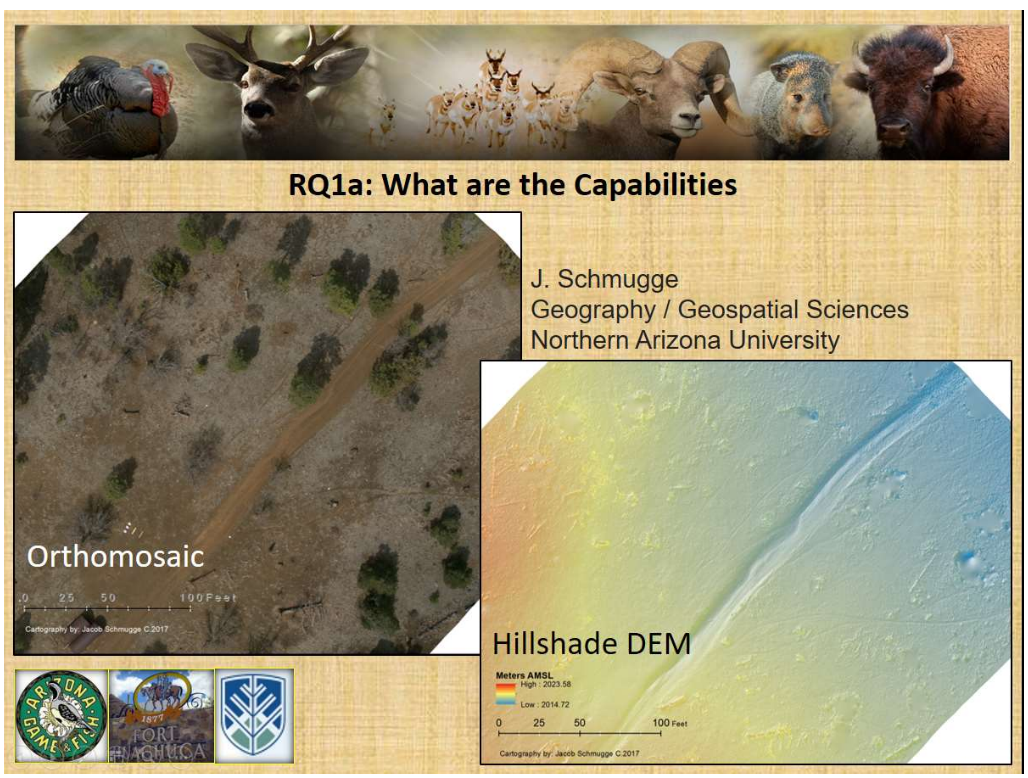
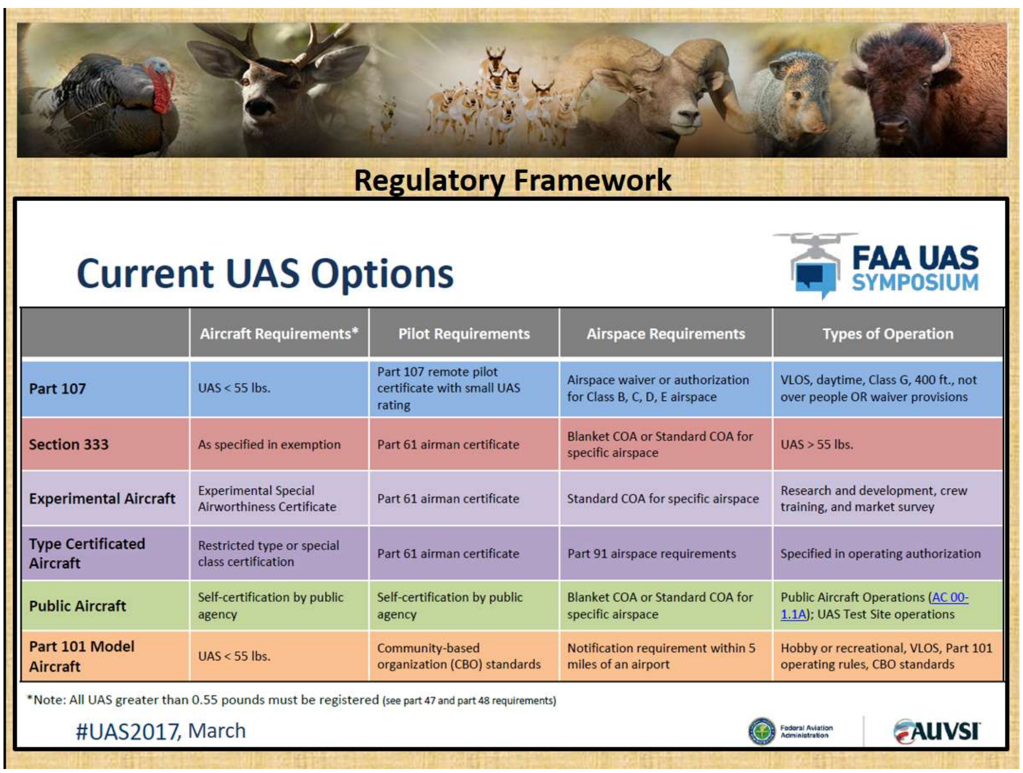


Figure 9 – Three-dimensional (3D) Modeling

Figure 10 – Current UAS Operations – FAA



	Aircraft Requirements*	Pilot Requirements	Airspace Requirements	Types of Operation
Part 107	UAS < 55 lbs.	Part 107 remote pilot certificate with small UAS rating	Airspace waiver or authorization for Class B, C, D, E airspace	VLOS, daytime, Class G, 400 ft., not over people OR waiver provisions
Section 333	As specified in exemption	Part 61 airman certificate	Blanket COA or Standard COA for specific airspace	UAS > 55 lbs.
Experimental Aircraft	Experimental Special Airworthiness Certificate	Part 61 airman certificate	Standard COA for specific airspace	Research and development, crew training, and market survey
Type Certificated Aircraft	Restricted type or special class certification	Part 61 airman certificate	Part 91 airspace requirements	Specified in operating authorization
Public Aircraft	Self-certification by public agency	Self-certification by public agency	Blanket COA or Standard COA for specific airspace	Public Aircraft Operations (AC 00-1.1A); UAS Test Site operations
Part 101 Model Aircraft	UAS < 55 lbs.	Community-based organization (CBO) standards	Notification requirement within 5 miles of an airport	Hobby or recreational, VLOS, Part 101 operating rules, CBO standards

Figure 11 – Evaluation Airspace – Fort Huachuca, AZ

Figure 12 – Fort Huachuca, Game Management Unit (GMU) 35A

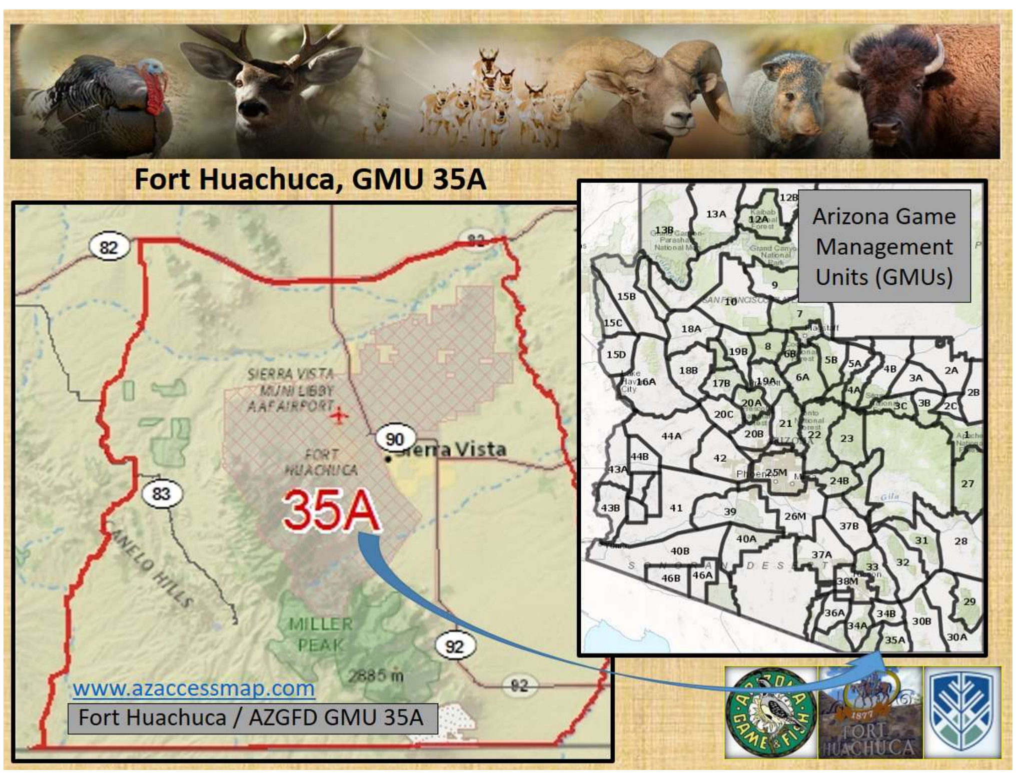


Figure 13 – Planned Transects for sUAS Evaluation

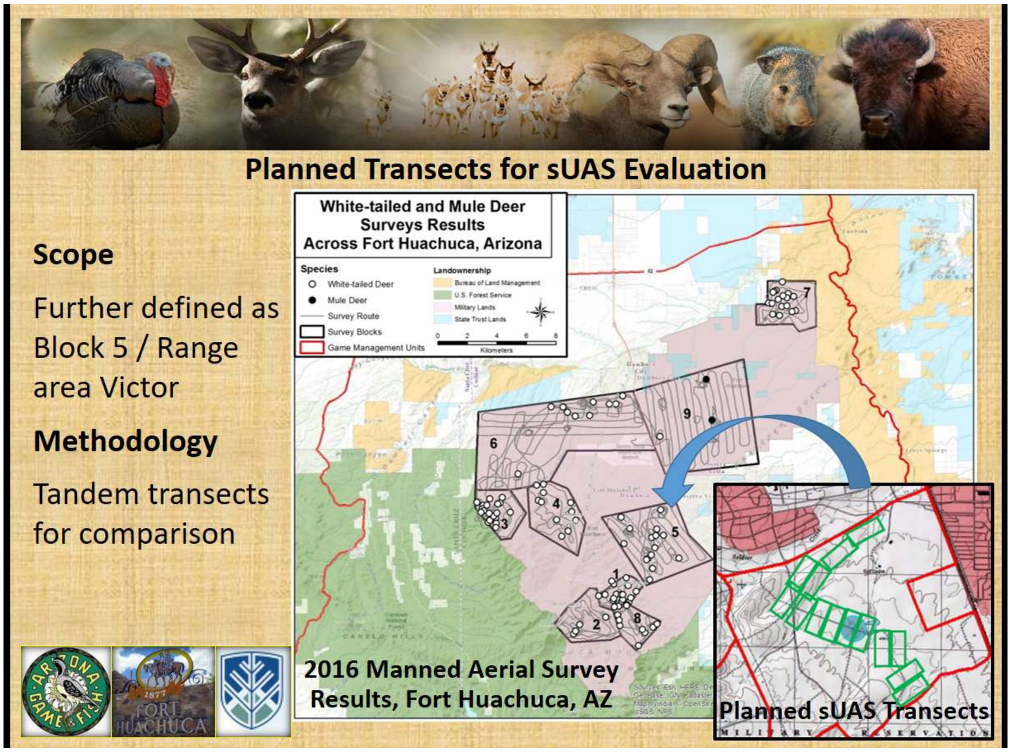


Figure 14 – Flight Test Imagery – 12MP Still Mode

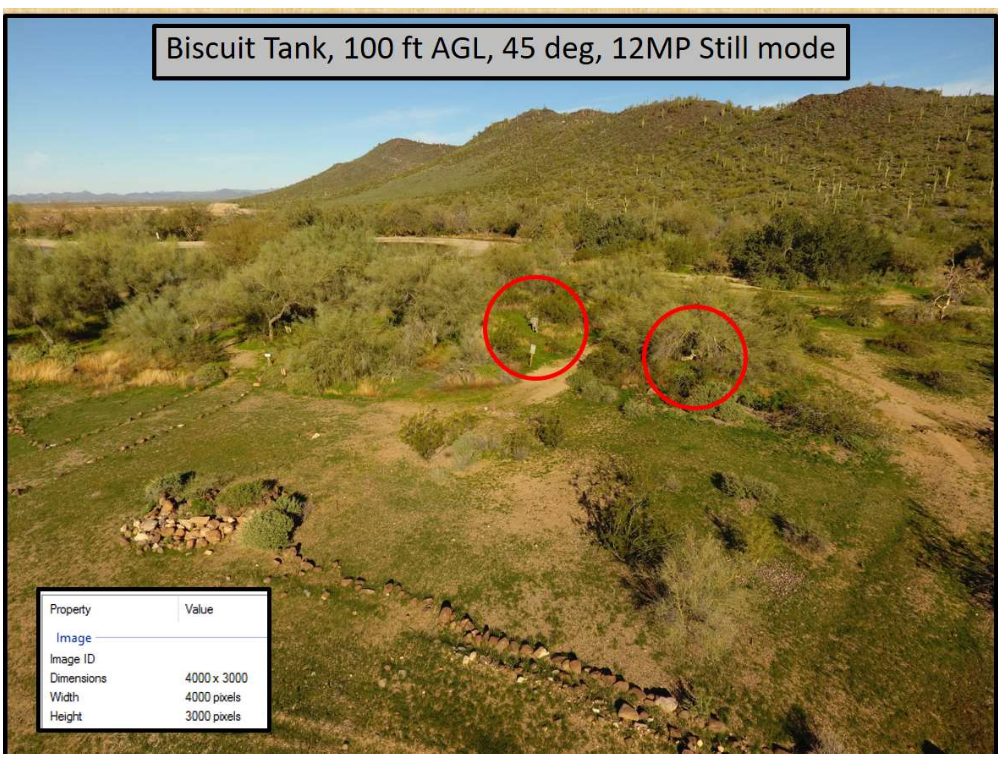


Figure 15 – Flight Test Imagery – 4K Video, Paused

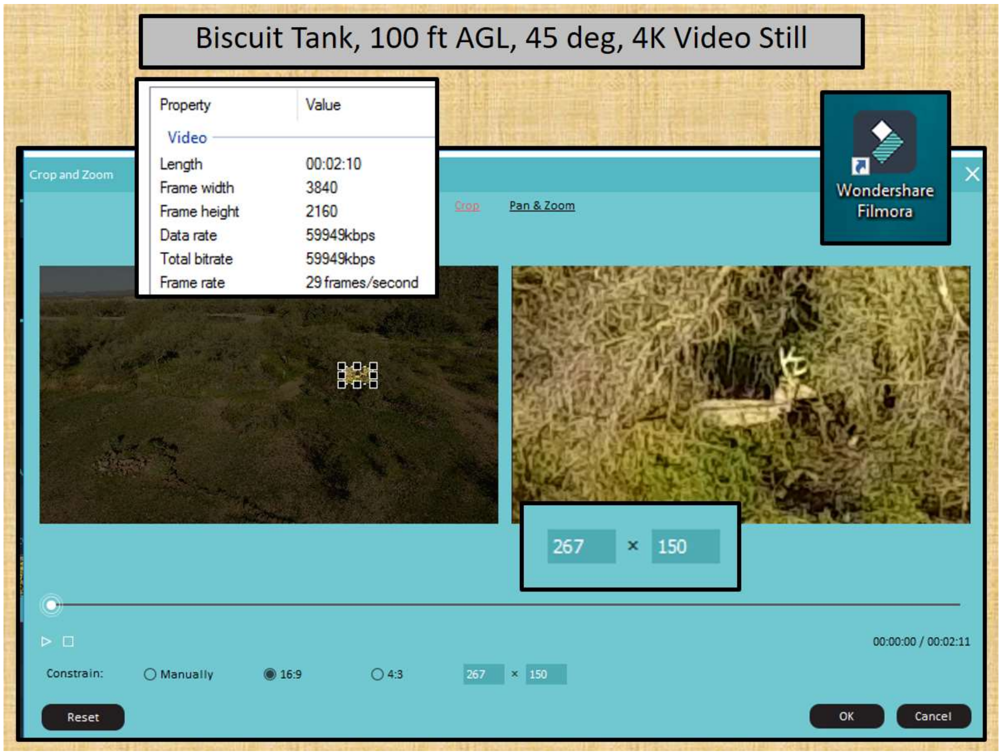


Figure 16 – Flight Test Imagery – Spatial Resolution Comparison

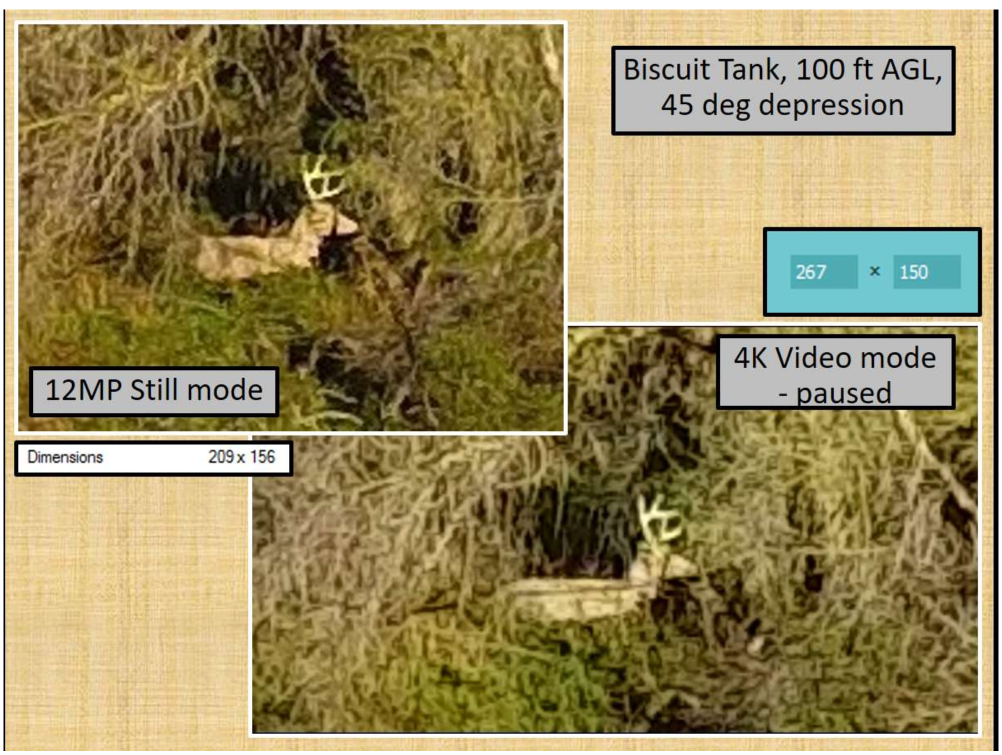


Figure 17 – Georectification / Spatial Coverage (FOV) Calculation

Figure 18 – Transect Design

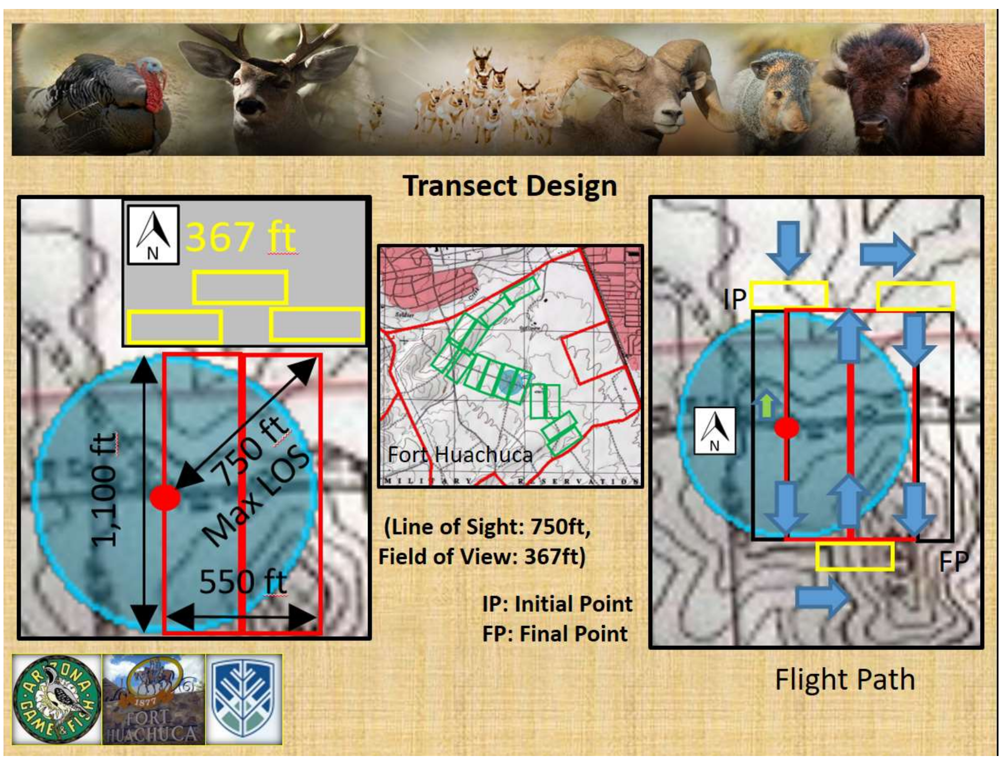


Figure 19 – Recorded Sighting

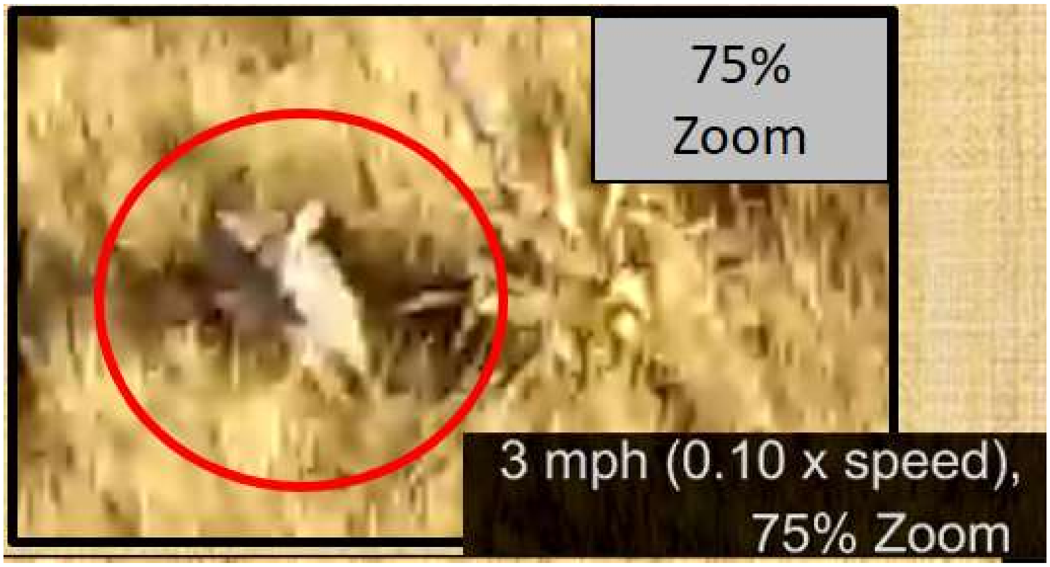


Figure 20 – sUAS Evaluation Flight Summary

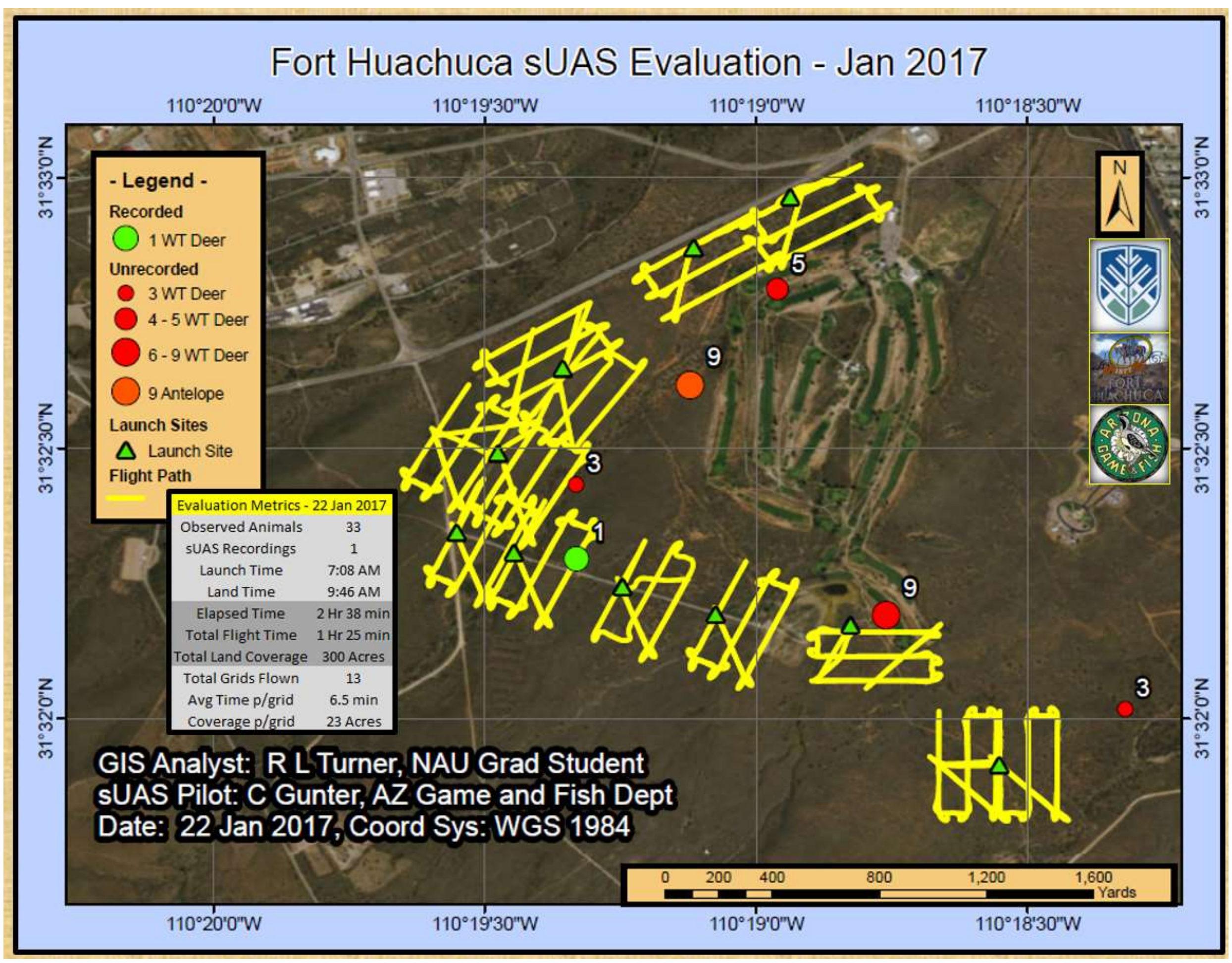
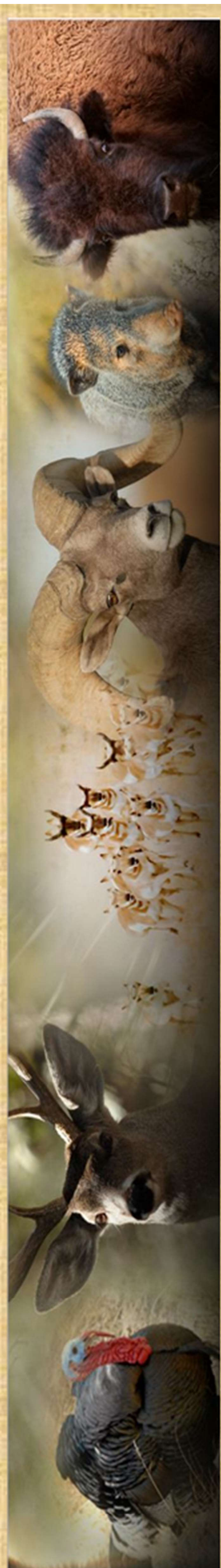


Figure 21 – DJI Product Comparison



DJI Phantom 4 / Inspire Comparison

Phantom 4		Phantom 4 Pro		Inspire 2 (X5S)	
Initial Cost	$1,200	Initial Cost	$1,500	Initial Cost	$3,000
Controller Display	$300	Controller Display	n/a	Controller Display	$300
Camera	n/a	Camera	n/a	Camera - X5S	$1,900
Total Cost	$1,500	Total Cost	$1,500	Total Cost	$5,200
Sensor Size	1/2.3 inch	Sensor Size	1 inch	Sensor Size	4/3 inch
Max Still Pixels	12 MP	Max Still Pixels	20 MP	Max Still Pixels	20 MP
Max Still Burst	7 fps	Max Still Burst	14 fps	Max Still Burst	20 fps
D/L Resolution	720 p	D/L Resolution	1080 p	D/L Resolution	1080 p
Max Video - Record	4K @ 30 fps	Max Video - Record	4K @ 60 fps	Max Video - Record	5.2K @ 30 fps
C2 Frequency	2.4 Ghz	C2 Frequency	2.4, 5.8 Ghz	C2 Frequency	2.4, 5.8 Ghz
C2 Distance	3 miles	C2 Distance	4 miles	C2 Distance	4 miles
Obstacle Sensing	Fwd, Down	Obstacle Sensing	Back, Fwd, Down	Obstacle Sensing	Up, Back, Fwd, Down
Flight Time	28 min	Flight Time	30 min	Flight Time	26 min
Max Speed - P/S Mode	31, 44 mph	Max Speed - P/S Mode	31, 44 mph	Max Speed - P/S Mode	58, 67 mph
Max Wind	22 mph	Max Wind	22 mph	Max Wind	22 mph
MTOW	3 lbs	MTOW	3 lbs	MTOW	9 lbs
Diagonal Distance	14 in	Diagonal Distance	14 in	Diagonal Distance	24 in
FPV camera	n/a	FPV camera	n/a	FPV camera	Yes
Dual Controls	n/a	Dual Controls	n/a	Dual Controls	Yes
Detachable Camera	n/a	Detachable Camera	n/a	Detachable Camera	Yes

Saturday
4/15/2017

Figure 22 – Management Recommendations

Consideration / Limitation	Management Recommendation
Aircraft	
Pricing – should include all equipment required for operation to include a extra batteries, charger, and transport case	Operating UAS to conduct inspections, surveys, etc. can be significantly less expensive than obtaining satellite images, conducting ground surveys, and/or operating manned aircraft with the overall cost expected to go down over time.
Endurance – time the system is able to remain operational and aloft	UAS generally possess shorter flight endurances than manned aircraft, which limits their overall operation and work area coverage.
Batteries – quantity and in-field recharing capability determine mission duration	The majority of sUAS platforms on the market today are battery-powered quadcopters carrying a simple camera or similar payload for a sensor and can only fly about 20 min before needing to land to be charged.
Line of Sight (LOS) distance – PIC or deployed VO must be able to visually discern spatial orienation at all times	UAS location, attitude, altitude, and direction of flight must be know at all times by the PIC in order to ensure safety of flight within the National Airspace System.
Maximum Speed – greatest speed of the aircraft	UAS speed is roughly half that of manned Fixed Wing aviation which results in increased time to survey a given area.
Lift Capacity – over and above components required safe operation	UAS are capable of dropping objects which could prove useful in capture, re-capture operations.
Communication Range – distance aircraft could travel from GCS and maintain command signal	Presently effective communication range far exceeds the ability to maintain LOS distance. As LOS requirements are laxed, increased communication range will result in greater coverage area.
Camera	
Spatial resolution – sensor capability to record in fine detail	High definition imagery from sUAS can result in 5cm resolution. More expensive sensors can yield even higher spatial resolution.
Spectral resolution – targets different segments of the RF spectrum	UAS are well suited to recording multi-spectral imagery - options include thermal imagery, LiDAR, and radio tracking payloads.
Pricing – dependent upon desired resolution	UAS have the capacity to produce high-resolution images. However, the higher the image resolution, the more expensive the system required. An organization must determine how to balance data requirements versus cost.
Utility – number of identified applications supported	UAS ability to record multi-spectral imagery increases overall utility.
Mission Altitude - Spatial Resolution is dependent upon both camera capability as well as altitude from which it records.	Mission altitude must also be sufficient to avoid terrain below the UAS as the mission is executed.
Field of View (FOV)	The Phantom 4 FOV from 100 feet above ground and with 45 degrees depression is about 250 feet near screen bottom, and over 1,000 feet near screen top.
GCS	
Monitor – Ability for more than PIC to observe real time information	Real time survey information is difficult to exploit unless it can be observed from other than the GCS. Most GCS's are capable of routing a signal to a nearby terminal for this purpose.
Batteries – quantity and recharing capability determine mission duration	A separate battery supplies power to the GCS and will terminate the mission should it be depleted.
Command and Control (C2) Signal Strength – Radio Frequency (RF) energy utilized to control the UAS while airborne.	Most GCS are capable of provide command signal beyond 2 or 3 miles. Use of forward deployed Visual Observers with positive communciation with the PIC can take advantage of this capability.
Display – Resistence to wash out from sun	Appropriate glare sheilding is important to ensure the PIC has usable information on the GCS.
Software	
Autopilot – ability to fly pre-programmed missions, and also interrupt mission	Autopilot software options are plentiful. Desirable features include the ability to fly pre-programmed missions, as well as an ability to interrupt pre-programming and then return to the same mission.
GIS – ability to convert raw data into actionable intelligence	Software is necessary to exploit the data harvested from any UAS mission. The result is intelligence that can be used to inform decision makers through predictive analysis.
Data Storage – both in the field and for historical purposes	UAS collect large quantities of data. An organization must have appropriate and secure storage for this data. Multiple memory chips should be carried during mission execution to provide continuous operations.
Other Considerations	
Camera Record Format – Video or Still Imagery	Desired output must be identified during pre-mission planning. Still imagery is suggested in most cases. Video serves evidentury purposes better than still.
Camera Depression – Nadir versus oblique imagery	Nadir imagery results in more uniform spatial coverage when comparing screen bottom with screen top. Obilique imagery is required for most photogrametric applications.
FAA Compliance – Part 107 versus Public Use COA	AZGFD could easily pursue a Public Use COA, and should be considered in special cases. Part 107 provides a good framework for most missions.
Training – PIC certification and proficiency	While UAS are easier to deploy than manned aviation, there is still a need for adequate training, certification, and proficiency.
Maintenance – Includes Aircraft, Camera, and GCS	All equipment operated within the NAS must be well maintained. A preventive maintenance schedule should be established for the aircraft, sensor package, and batteries.
Deployability – One of the great advantages of UAS technology is the ability to quickly deploy from off airfield locations.	With sufficient power supply, mission duration can be sufficient to satisfy nearly any requirement. Multiple batteries vice recharging should be considered due to lengthy recharge cycles.
Flight Crew Duties	A plan should be discussed during pre mission planning to ensure PIC, VO, and assistant responsibilities are covered and understood. Exhaustion for the Visual Observer is expected and this duty should be shared.
Flight Safety – Weather, Rising Terrain, Crew Fatigue	Weather can negatively affect any airborne mission. Wind in excess of 15 will most likely ground a UAS mission. Aviation weather sources should be consulted prior to and during mission execution.