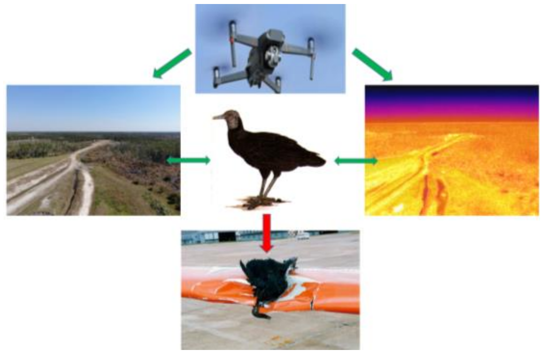
Applying UAS for Wildlife Hazard Management at Airports



Team Members

Anthony Chimino

Jose Cabrera

Matthew Schwarz

Nathan Woolf

B.S. in Aeronautical Science ***B.S. in Unmanned Aircraft Systems Science***

Primary Faculty Advisor

Flavio A. C. Mendonca, MBA; Ph.D. – Assistant Professor

Additional Faculty Advisors

John Robbins, Ph.D. – Associate Professor

Ryan Wallace, Ed.D. – Assistant Professor

Nickolas Macchiarella, Ph.D. – Professor

Kevin Adkins, Ph.D. – Associate Professor

Industry Partner

Christopher B. Burke Engineering, Ltd.

Technical Paper Quad Chart

Embry-Riddle Aeronautical University

Applying UAS for Wildlife Hazard Management at Airports

FAA Challenge
Smart Airport Student Competition

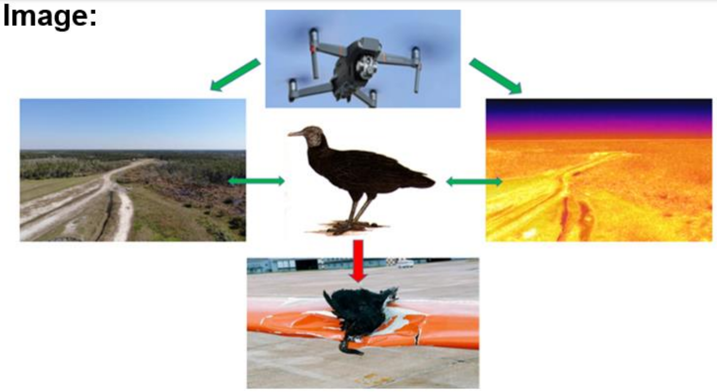
Objective and Description of Effort:

- The purpose of this study is to investigate how UAS technologies may be safely and effectively applied to identify hazardous wildlife species to aviation operations as well as potential wildlife hazard attractants within the airport jurisdiction.

Technical Approach:

- Develop and streamline the Concept of Operations and then utilize UAS and sensors to support the safety management of wildlife hazards to aviation by airport operators.

Image:



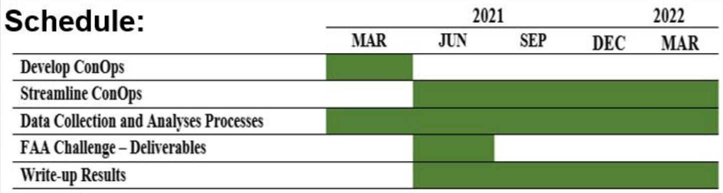
Key Findings:

- UAS can facilitate the identification of multiple hazardous wildlife species and habitats simultaneously during a Wildlife Hazard Assessment (WHA)
- The UAS "bird's eye view" allows the identification of wildlife species and/or habitats in areas that are difficult to access by ground-based means
- Safety risk management processes can help mitigate risks associated with UAS operations at the airport environment.

Potential Benefits:

- Data can be collected more thoroughly and faster over large areas, including areas that are inaccessible by ground-based means
- The use of UAS can help reduce the costs, labor, personnel, and time needed to accomplish most WHA tasks

Schedule:



Cost:

Academic Research, Development, and Data Collection and Analyses Costs			
Item	**Rate**	**Quantity**	**Total**
Student Efforts	$12 / Hour	2,500 Hours	$30,000.00
Faculty Advisor Efforts	$60 / Hour	350 Hours	$21,000.00
QAWB Efforts	$139 / Hour	150 Hours	$20,850.00
Utilization of Supporting Trailer	$25 / Hour	360 Hours	$9,000.00
Showcase our Project during the 2021 Bird Strike USA Committee Meeting	$125 / Participant	4 Participants	$500.00
		Estimated Total Costs	**$81,350.00**

Executive Summary

The Federal Aviation Administration (FAA) requires airports operating under the Code of Federal Regulations Part 139 to conduct a wildlife hazard assessment (WHA) when some wildlife-strike events have occurred at or near the airport. The WHA provides the empirical framework for the development of the Wildlife Hazard Management Plan (WHMP). It is important to note that a WHA also provides empirical information to assess the efficacy of an existing WHMP. Traditional data collection methods utilized during WHA, which rely on many assumptions (e.g., wildlife does not move before detection) often fail to provide essential information (e.g., wildlife activity at night; animals that do not congregate in groups; bird activity at higher altitudes). Needless to say, there are health and safety risks associated with dealing with wildlife in their habitats (e.g., trapping and marking mammals). Most importantly, the safety efforts by airport operators have helped prevent aircraft accidents resulting from wildlife strikes. Notwithstanding, analyses of wildlife strike data have clearly indicated that different strategies to mitigate such risk, including robust research projects, the use of new technologies and/or innovative approaches to current technologies, and outreach and education, are vital.

Unmanned Aircraft Systems (UAS) have been successfully used in several disciplines for data collection and research projects. UAS have a unique advantage to gather remotely sensed imagery for wildlife hazard identification. This is due to the UAS' versatility, easier logistics, and ability to collect information on demand at spatial resolutions that satellites, and especially piloted aircraft cannot.

Our team explored the use of UAS technologies to identify wildlife and their habitats, an important component of wildlife hazard management and a critical activity to mitigate the risk of aircraft accidents resulting from wildlife strikes. The purpose of this study was to investigate how UAS technologies could be safely and effectively applied to identify hazardous wildlife species to aviation operations as well as potential wildlife hazard attractants within the airport jurisdiction. In order to meet the purpose of this study, our intermediate goals were to:

1. Identify the most effective drone accessories (sensors) for the data collection process;
2. Create workflows and explore best practices for UAS technology applications to identify wildlife attractants and activities on and around an airport;
3. Apply Safety Risk Management concepts to identify hazards and mitigate the risks associated with operating UAS at an airport; and
4. Develop operational procedures and processes that support the safe and effective use of UAS.

Findings of this applied research project could leverage the application of UAS and related technologies to improve the safety management of wildlife hazards by airport operators, significantly improving the safety of the aviation industry.

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1. Problem Statement and Background

1.1 Wildlife Hazards to Aviation

Aircraft accidents resulting from wildlife strikes pose an increasing safety and economic concern (Martin et al., 2011). Safety events, such as the ditching of US Airways Flight 1549 in the Hudson River in 2009 have attracted both media and public attention to the risk wildlife pose to aviation operations (Marra et al., 2009; National Transportation Safety Board, 2010). There were 209,950 wildlife strikes to aircraft in the US between 1990 and 2019 (Dolbeer et al., 2021). Approximately 96% of these strikes involved birds. Over 83% of the total wildlife strikes, and roughly 80% of the damaging strikes occurred in the airport environment. Annually, the costs of wildlife strikes to aircraft in the U.S. is projected to be 116,000 hours of aircraft downtime and $200 million in direct and indirect monetary losses. However, even though previous studies have indicated an increase in wildlife strike reporting, many strike reports do not provide accurate cost estimates, and many strikes still go unreported. Therefore, actual total costs in the U.S. may be significantly higher (Anderson et al., 2015; DeFusco & Unangst, 2013).

According to the Federal Aviation Administration (FAA), the first step in the safety risk management process is the identification of hazards (FAA, 2016). The FAA (2018) requires airports operating under the Code of Federal Regulations (CFR) Part 139 to conduct a wildlife hazard assessment (WHA) when some wildlife-strike events have occurred at or near the airport. The WHA should be conducted by a Qualified Airport Wildlife Biologist (QAWB) and must contain several elements. The Code of Federal Regulations (CFR) Part 139.337 prescribes the required elements in a WHA, which include the identification of the wildlife species observed and their numbers; local movements, and daily and seasonal occurrences; and the identification and location of features on and near the airport that could attract wildlife (FAA, 2020). Habitats and land-use practices at and around the airport are key factors affecting wildlife species and the size of their populations in the airport environment. Cleary and Dolbeer (2005) as well as the FAA (2020) have presented guidance on land-use practices and habitats having the potential to attract hazardous wildlife that threaten the safety of aviation operations, and these include waste disposal operations, existing wetlands, agricultural activities, and water management facilities.

The WHA process can take a year because data and information about wildlife species should incorporate daily and seasonal factors (Cleary & Dolbeer, 2005). Processes and protocols to collect wildlife data and information during the WHA include the use of standardized surveys and the analyses of published data. Data collection points must include selected areas within five statute miles of the airport's Air Operations Area (AOA) with features known to cause hazardous wildlife to move across the departure and/or approach airspace. Based upon the results of the WHA, the aeronautical activity at the airport, the views of the airport operator and users, and any pertinent information regarding the safety management of wildlife hazards to aviation, the FAA could require the certificated airport operator to develop and implement a Wildlife Hazard Management Plan (WHMP). It is important to note that a WHA also provides empirical information to assess the efficacy of an existing WHMP.

The safety efforts by airport operators have helped prevent aircraft accidents resulting from wildlife strikes. Notwithstanding, analyses of wildlife strike data have clearly indicated that different strategies to mitigate such risk are vital (Dolbeer et al., 2021). For example, the rate of wildlife strikes to commercial aircraft per one million aircraft operations increased from 22.78 in 2011 to 37.30 in 2019. Similarly, the rate of damaging wildlife strikes to commercial aircraft per one million aircraft operations increased from 1.27 to 1.55 during the same period. From 1990 through 2019, approximately 82% and 87% of the wildlife strikes to commercial and general aviation aircraft, respectively, occurred at and around the airport jurisdiction (up to 1,500 feet above ground level [AGL]). From 2011 to 2020 there were 132,961 wildlife strikes to aircraft. Considering the strikes in which the phase of flight was reported (n=75,205), almost 32% of the safety events occurred during the departures phase of flight. Considering the takeoff run (n=11,430), initial climb-out (n=10,534), approach (n=32,550), and the landing roll (n=13,607) phases of flight, almost 91% of the wildlife strikes in which the phase of flight was reported (n=68,121) occurred at the airport environment.

The reasons for this ever-growing safety concern are complex and include successful environmental protection programs and the adaptation of wildlife to living in an urban environment. According to DeFusco et al. (2015), contributing factors of wildlife strikes to aviation also include increased air operation movements, synergistic effects of airport and/or adjacent land uses, and land use developments around the airport that have significantly reduced habitats historically used by wildlife for food, water, and shelter. To effectively address this ever-growing safety risk, Dolbeer et al. (2021), the FAA (2020), and Mendonca, Keller, and Wang (2017) have suggested a multifaceted approach for mitigating the risk of aircraft accidents due to wildlife strikes. This approach should include robust research projects, the use of new technologies and/or innovative approaches to current technologies, and outreach and education.

1.2 UAS and Related Technologies

Unmanned Aircraft Systems (UAS) have been successfully used in several disciplines for data collection and research projects (Fraser & Congalton, 2018; Mlambo et al., 2017; Wallace et al., 2016). UAS activities are becoming common for research, and commercial and private purposes. For example, UAS have been used to survey disaster areas, to map archeological sites, for volcanic data collection (Jordan, 2019), as well as for marine and terrestrial ecological surveying and research (Erbe et al., 2017). Prather (2019) indicated that UAS can be used at the airport environment to inspect hazardous wildlife habitats, like ponds and agricultural activity. A unique benefit of using UAS to identify wildlife hazard attractants is that it facilitates access to areas that are inaccessible or difficult to access by ground-based means. Hamilton (2020a) suggested UAS can be used to monitor the presence of wildlife around airports and/or to offer a deterrent to some wildlife species.

UAS have a unique advantage to gather remotely sensed imagery for wildlife hazard identification. This is due to the UAS' versatility, easier logistics, and ability to collect information on demand at spatial resolutions that satellites, and especially piloted aircraft cannot. UAS can be flown in a congested airspace at low altitudes where piloted aircraft cannot operate safely. Furthermore, "fixed-wing UASs offer an opportunity to cover vast horizontal and vertical distances, at low altitudes, in a continuous manner with high spatial resolution" (Adkins et al., 2020, p. 4). Therefore, UAS have the potential to fill this important observational gap. Consequently, UAS can be an effective tool to assist airport operators while they are conducting a WHA and developing or assessing the effectiveness of a WHMP.

The use of UAS can increase the effectiveness of data collection as well as reduce the cost to conduct a WHA by:

1. Reducing the need for trapping and marking mammals for species identification;
2. Identifying the location of wildlife activities as well as features that have attracted or have the potential to attract hazardous wildlife species to the airport jurisdiction;
3. Establishing a relationship between identified wildlife species and habitats;
4. Obtaining information of different habitats and wildlife species simultaneously; and
5. Reducing the labor, personnel, and time needed to accomplish most WHA tasks.

Additionally, UAS can overcome other issues while identifying different wildlife species and/or recording their numbers. For example, this process is currently conducted by QAWBs who visually detect and record birds and other wildlife (with or without binoculars) within a quarter-mile radius for 3-5 minutes (FAA, 2018). Physical (e.g., human tolerance with respect to weather conditions) and physiological (e.g., vision limitations; fitness) factors are some of the human factors that could significantly degrade the effectiveness of the WHA data collection process (FAA, 2016). Traditional data collection methods utilized during WHA, which rely on many assumptions (e.g., wildlife does not move before detection) often fail to provide essential information (e.g., wildlife activity at night; animals that do not congregate in groups; bird activity at higher altitudes) (DeVault et al., 2013). Needless to say, there are health and safety risks associated with dealing with wildlife in their habitats (e.g., trapping and marking mammals). The versatility and speed of UAS, including their high-quality cameras and sensors, ensure that data can be collected more thoroughly and faster over large areas, including areas that are inaccessible by ground-based means (e.g., wetlands). Moreover, specific sensors (e.g., thermal) can help identify wildlife at the airport environment at almost all hours (Hamilton et al., 2020a) with minor disruptions to airport operations.

2. Literature Review

There were 178,051 wildlife strikes to aviation in the US from 2006 through 2020. Approximately five percent of these safety occurrences (n=9,275) caused damage to aircraft (FAA, 2021a). From January 2011 through January 2021 there were 219 significant wildlife strikes to civil aircraft in the US (FAA, 2021b). These safety events caused major damage to the aircraft and/or human injuries (n=17) and fatalities (n=10). Forty-six percent (n=106) of those significant events involved commercial aircraft. During this period, the direct and other monetary losses resulting from significant wildlife strikes to aircraft ranged from $2,000 to $15 million, totaling $101 million (mean of $462,000/significant wildlife strike). Only 69 wildlife-strike reports contained information about the aircraft downtime, which ranged from five hours to five months (mean of 4.47 days/significant wildlife strike). Interestingly, several reports indicated major maintenance repairs but did not provide costs and/or aircraft downtime information. For example, a Boeing 737-700 ingested birds into the #2 engine during approach to Sacramento International Airport (CA) in December 2014. The flight crew managed to safely land the aircraft. Nonetheless, one engine was severely damaged and had to be replaced. The direct and indirect costs as well as aircraft downtime information resulting from this accident was not reported.

"Land-use practices and habitat are the key factors determining the wildlife species and the size of wildlife populations that are attracted to airport environments" (Cleary & Dolbeer, 2005, p. 43). Public airports generally have large open underdeveloped areas that provide additional margins of noise and safety mitigation. Those areas, in turn, provide hazardous wildlife with ideal locations for roosting, loafing, feeding, and reproduction. The identification and management of those habitats are key to a successful WHMP. The FAA (2020) and other authors (Belant & Ayers, 2014; Cleary & Dolbeer, 2005) have identified land use categories and other features on and near the airport with the potential to attract hazardous wildlife to the airport environment, and they include water management facilities, wetlands, ponds, and lakes. Interestingly, some of these land uses and features may by themselves not cause risk to aviation operations. However, synergistic effects between some of those features can create a flyway for birds across the airport AOA. These attractants must be identified and then evaluated by a QAWB to determine whether they pose an aviation safety hazard. Even though several wildlife species can pose a threat to aircraft operations at and around the airport AOA, they are not equally hazardous (FAA, 2018). These hazardous wildlife species should be the focus of the safety efforts by airport operators. Nonetheless, attention should also be given to species of significant mass (e.g., deer), habitat preferences (e.g., airport AOA), and birds with flocking behavior.

Airport operators have used UAS to harass wildlife, especially birds from the airport premises through audio and visual interference. Gade et al. (2015) and Paranjape et al. (2018) have conducted studies to investigate the possibility of herding a flock of birds away from a designated area using UAS. Preliminary findings have suggested that a flock of birds can be successfully diverted from the airport environment following specific procedures using UAS. Hamilton (2020b) suggested UAS can be used to monitor the presence of wildlife around airports and/or to offer a deterrent to some wildlife species. The use of thermal sensors, for example, allows for the identification of wildlife at and around the airport premises 24/7. Nonetheless, according to Prather (2019), airport operators do not fully understand some of the benefits of UAS technology that could contribute to cost savings and operational improvements. Yet, key indicators to assess the impact of UAS on the airport environment, whether negative or positive, still need to be explored. Most importantly, the utilization of UAS to identify wildlife hazard attractants at and around airport property is still in the early stages.

3. Project Description

3.1 Introduction

Not all wildlife species pose the same level of risk to aircraft operations. Factors such as abundance in critical airspace, bird-mass, and flocking behavior can significantly increase the risk of an aircraft accident resulting from a strike (Cleary & Dolbeer, 2005). The FAA (2018) ranked the 50 most hazardous wildlife species to aviation operations in the US. Our team collected wildlife strike data in Florida from January 2006 through December 2020 from the FAA wildlife hazard webpage (FAA, 2021b) and identified those that caused damage to aircraft. We then referred to the FAA (2018) to identify those that were most involved in damaging strikes in Florida and that are also listed among the 50 most hazardous wildlife species to aviation in the US. Our team decided to select the New World Vulture (see Figure 1) as described in the next paragraphs to move forward with the study.

From 2006 through 2020 there were 12,298 wildlife strikes to aviation in Florida, approximately seven percent (n=855) of them caused damage to aircraft (FAA, 2021a). Two-hundred and eighty-six of the total strikes involved Turkey Vultures. Fifteen percent (n=128) of the damaging strikes in Florida resulted from collisions with this bird species, which is listed as the third most hazardous wildlife species to aviation in the US (FAA, 2018). DeVault et al. (2018) conducted a study whose goals included updating wildlife species relative hazard scores. During the data analyses, the authors included direct and indirect monetary costs associated with strikes as well as the number of damaging strikes while validating their wildlife hazard-risk model. Interestingly, findings of their study indicated that Turkey Vulture was the third most hazardous wildlife species to flight operations in the US. It is noteworthy to mention that Black Vulture was ranked as the 11th most hazardous wildlife species in DeVault et al. (2018) study even thought this species is not listed by the FAA (2018) as one of 50 most hazardous wildlife species to flight activities. Dolbeer (2020) ranked Turkey Vulture and Black Vulture as the second and third most hazardous bird species to aviation, respectively. Nonetheless, the FAA (2018) suggested that "Brown and White Pelicans, Black Vultures, Great Egrets, and other waders as well as several species of waterfowl, raptors, gulls, and shorebirds present a significant hazard to aircraft" (p. iii).

Figure 1

New World Vultures Pose a Major Safety Risk to Aviation Operations

There were 102 strikes involving Black Vultures in Florida from 2006 through 2020, 62% of these strikes (n=63) caused damage to the aircraft. The FAA (2021a) also indicated that there were 72 wildlife strikes involving New World Vultures, and that 34 of these strikes caused damage to aircraft. It is important to note that there are seven species in the New World Vulture family, and they include the Turkey and Black Vultures (Cornell Lab of Ornithology, 2021a). The populations of Turkey Vulture and Black Vulture have increased by 118% and 347% from 1990 through 2018, respectively (Dolbeer, 2020). New World Vultures have similar habitat, behavior, and diet requirements. Scavengers, New World Vultures feed mainly on deceased animals (carrion). They do not build nests but lay eggs on bare surfaces. New World Vultures are highly sociable, roosting at night and mostly foraging during the day. Yet, New World Vultures generally wait in large trees till later in the morning when rising thermals can assist soaring flight where they can find dead carrion.

Engine and airframe certification standards are important for accident prevention. However, current standards do not consider strikes with bird species having a mean weight that exceed standards and or multiple strikes to the airframe and engine simultaneously. For example, Title 14 Code of Federal Regulations (CFR) Part 33 prescribes the airworthiness standards that engines are required to comply with in order to get an FAA type certificate. The large bird requirements range from a 1.85 kilogram (kg) bird to a 3.65 kg bird. For ingestions involving medium flocking birds, the bird’s weight ranges from 0.35 kg to 1.15 kg. Moreover, this safety standard considers ingestion of up to seven birds (Electronic Code of Federal Regulations, Title 14, Chapter I, Subchapter C, Part 33, 2021). According to Dolbeer (2020), the body mass of the Turkey Vulture and Black Vulture are approximately 2.0 kg and 2.16 kg, respectively. Thus, because of their size and flight behavior (e.g., flocking and / or soaring), strikes with New World Vultures “pose a substantial threat to air safety relative to FAA airworthiness standards for airframes, windshields, and engines” (Blackwell & Wright, 2006, p. 2).

3.2 Concept of Operations

This applied research project utilized a combination of exploratory research and case study design methodology. The researchers, with the support of QAWB as well as by conducting a thorough literature review, identified the land-use and habitats that could potentially attract New World Vultures as well as other hazardous wildlife species to the airport AOA. Our team started developing the concept of operations (ConOps) in February 2021. Hamilton et al. (2020a) defines ConOps as “a description of the nature of UAS operations and the resulting impacts on relevant stakeholders and the environment” (p. 3). The elements of UAS ConOps include the methods of operations (e.g., flight pattern, airspace segregation, and contingency plans). The development of the ConOps is a vital step in effectively integrating the UAS in the U.S. national airspace system, especially in the airport environment.

Key resources our team utilized during this phase of the project included the FAA (2020), Hamilton et al. (2020a, 2020b), Maddalon et al. (2013), and Valavanis and Vachtsevanos (2015). In addition, our team partnered with Christopher B. Burke Engineering, – Ltd. so that we could have the technical support of a QAWB throughout the entire project (see Appendix A). See the FAA (2019a) for further information about the training and experience of a QAWB involved in implementing FAA-approved WHMPs at certificated airports. It is important to mention that our team utilized a small trailer with different pieces of equipment, which included an Automatic Dependent Surveillance – Broadcast (ADS-B) (FAA, 2021d) flight box and two television (TV) sets that facilitated the safe and efficient completion of the drone operations (see Figure 2).

Figure 2
Trailer Utilized During the Data Collection Process

Note. (2a) External image of the trailer used by our team during the data collection process.
Note 2. (2b) Pieces of equipment in the air-conditioned trailer included two TV sets and an ADS-B flight box.

3.2.1 Airborne Equipment and Processing Sensors

Researchers used a DJI Mavic 2 Enterprise Dual with FLIR drone to collect data. This highly versatile drone comes with various safety and efficiency features that makes it suitable for short and detailed missions (DJI, 2021). The Mavic 2 Enterprise and its controller can connect to various smartphones and tablets including iPhone, iPad, and android smartphones. The endurance of this equipment is approximately 35 minutes. Nonetheless, batteries can be easily and fast replaced on the field, enhancing the data collection process. This UAS can fly at a maximum speed of 44 miles per hour with the ability to track various moving objects. Its operational temperatures range from -10℃ to +40℃. Rahman et al. (2020), who completed a study using the DJI Mavic 2 Enterprise survey platform have indicated that UAS combined potential and multispectral imagery (thermal infrared and standard red, green, and blue [RGB] bands of light) is a promising method to monitor target wildlife species. With a high-resolution visual camera that can record video in 4K Ultra HD, and a thermal camera, this drone supports up to 32× digital zoom and is capable of centimeter-level positioning accuracy with the real time kinematics module. The integrated visible/thermal camera has multiple functionalities. This gives the system the capability of switching between visual, thermal, or split-view feeds considering the project needs. Moreover, videos and images recorded can be viewed simultaneously or independently. The date, time, and ground position system (GPS) location of the videos and images recorded during the data collection process are recorded on GPS timestamping (see Appendix B). This study used a DJI smart controller as the live-feed screen during the data collection process. This process allowed the drone images to be viewed on a large screen by another researcher to observe the footage in greater detail.

3.2.2 Risk Mitigation

Our team conducted disciplined site surveys that could help the identification of hazards in the flight operations area. This was a standard procedure before each flight as suggested by Adkins et al. (2020). Care was exercised during the creation of each flight plan and the overarching data collection process. Some challenges were anticipated. Nonetheless, our team acknowledged that some challenges and hazards may not be anticipated. Thus, in order to proactively identify hazards and mitigate the risks associated with the identified hazards, a flight risk assessment tool (FRAT) was exercised prior to every flight operation (see Appendix C). The use of the FRAT was expected to enable proactive hazard identification and risk assessment, helping pilots make effective go/no-go decisions before each flight (FAA, 2016). The FRAT purposely made our team consider the accumulation of risk in an objective manner. Operational risks identified in preflight briefings were openly discussed along with consensus mitigation measures to mitigate these risks (Adkins et al., 2020).

The greatest risk in operating UAS in an airport environment is interference with aviation operations, especially during the takeoff, initial climb-out, approach, and the landing phases of flight. The Low Altitude Authorization and Notification Capability (LAANC), a partnership between the aviation industry and the FAA, supports the safe integration of UAS into the U.S. National Airspace System (FAA, 2021c). LAANC provides a streamlined automated application and approval process for drone operations in controlled airspace. Thus, there was no authorization required for UAS operations at Coe Field airport since we conducted our flights in Class G airspace (Hamilton et al., 2020a). To mitigate the risks associated with manned aircraft operations at Coe Field airport, our team used an ADS-B (FAA, 2021d) flight box that transmitted a Wi-Fi network that is connectable by cell phone or tablet. Once connected, our team was able to use ForeFlight to monitor air traffic (ForeFlight, 2021) and to identify manned aircraft around the data collection area. Researchers connected the cell phone or a tablet to a high-definition multimedia interface (HDMI) cable to mirror the screen onto a TV mounted inside of the trailer. We could tap/select on any aircraft displayed on the live traffic feed and identify the altitude, speed, and heading of the aircraft as well as the separation of the aircraft from the point of the ADS-B flight box (see Figure 3a). Noteworthy to mention that at least one member of our team stayed inside the trailer during the entire data collection process monitoring the live traffic feed and communicating with the drone's pilot and the visual observer (see Figures 3 and 6a). The goal was to increase the team's situational awareness (Airbus, 2007) and improve their aeronautical decision-making processes (FAA, 2016). Our team determined that if manned aircraft were seen to be approaching the area at or below 1,000 feet AGL, the UAS would be brought out of autonomous mode, lowered to a much safer altitude (at or below 150 feet AGL) and brought back to the operator's position.

Figure 3

Mitigating the Risks Associated with Aircraft Operations during the Data Collection Processes

Note. (3a) Safety risk management process using an ADS-B flight box to monitor the presence of manned aircraft at and around Coe Field airport.

Note 2. (3b) PIC collecting data using the drone with the assistance of a visual observer.

In addition, considering the possibility of aircraft operations at and around Coe Field airport during the data collection process our team also adopted the following procedures to help mitigate this specific risk:

1. UAS flights were conducted below 200 feet AGL;
2. UAS flights were not conducted in the Approach, Departure, and Circling Airspaces of Coe Field airport;
3. UAS flights were only conducted with a ceiling of at least 3,000 feet AGL and with visibility at or above five thousand nautical miles;
4. A visual observer, in addition to the drone operator, was present during the data collection process;

5. Any perceived flight activity in the area at or below a 1,000 feet AGL and/or in the traffic pattern was a factor that would determine UAS should not be flown or, in case the flight had already begun, that it should be terminated immediately (see Figure 3).

The visual observer roles included keeping eyes on the drone at all times and ensuring the aircraft was within line of sight. In addition, the visual observer would scan for the possible presence of manned aircraft at and/or around Coe Field airport. It is important to mention that crew resource management (CRM) principles (e.g., teamwork; inquiry, advocacy, and assertion; threat-and-error-management), as suggested by the FAA (2004) and Kanki et al. (2019) were instilled throughout our project. The benefits of CRM include enhanced aeronautical decision-making and improved situational awareness. Most importantly, effective CRM promotes aviation safety and efficiency. Additionally, our team ensured that pilots were sufficiently trained and appropriately rated to fly the drone, and that they were supervised by an experienced drone pilot during the data collection process. Another major risk during UAS operations is loss of UAS control, a lost link between the operator and the UAS. Researchers programmed the UAS to hover in place so that the operator would have time to reestablish the link. If not successful, the UAS would then return to a pre-established recovery area. During the disciplined site surveys our team also identified a number of alternative recovery areas in case of an emergency during any phase of the UAS flight. During our team's weekly and/or special meetings we had discussions on the hazards identified during the data collection process, the risk mitigation measures implemented, their effectiveness, and possible different risk mitigation approaches, if needed. This procedure certainly helped increase the situational awareness of the UAS pilots. Moreover, it helped our team develop a shared mental model, thus, enhance the safety of the flights. It is noteworthy to mention that our team acknowledge that not all hazards and associated risks could be effectively identified and or adequately mitigated, respectively. Therefore, safety and aircraft performance margins were built into the ConOps (Hamilton et al., 2020a).

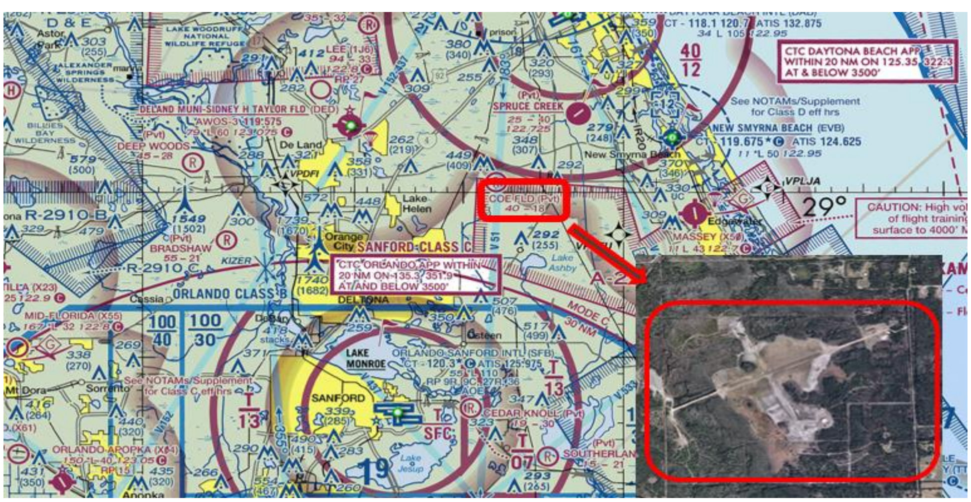
4. Research Testing

4.1 Field Campaign - Study Area

An exploratory field campaign to identify wildlife hazard attractants was conducted between April 19th and May 14th, 2021. During this study researchers collected data at Coe Field (8FA4), a private use airport (see Figure 4). Coe Field is located in a Class G airspace that extends from the surface till 700 feet above ground level (AGL), the base of the overlying Class E airspace. Coe Field is located at latitude of 29° 00' 37" N and longitude of 81° 07' 56" W.

Figure 4

Coe Field Airport



Note. Images retrieved from https://skyvector.com/ and from Google Earth.

The terrain within the operational area is mostly flat with an elevation of approximately 40 feet above mean sea level. The airport has an 1850 x 75 feet turf runway that is in fair condition. There are no published instrument procedures for that airfield. It is located at approximately 11 nautical miles (NM) south of Daytona Beach

International Airport (KDAB), at 10NM southwest of DeLand Municipal Airport-Sidney H Taylor Field (KDED), and at 10NM northwest of New Smyrna Beach Municipal Airport (KEVB). A partnership between ERAU with the airport owner has allowed ERAU students to be engaged in several UAS educational activities in that location. This airport is surrounded by large trees, fields, and farmland that are prone to various kinds of wildlife species. Species that have been observed include New World Vultures, Cattle Egrets, Herons, and Red-Tailed Hawks as well as cattle and boars roaming the field. The area is rural with little noise and light pollution. There were no aircraft operations at Coe Field airport during the data collection process. Nonetheless, the presence of air traffic at and especially above 1,000 feet AGL is frequent. Interestingly, the presence of aeromodelling operators at Coe Field is common.

4.2 Airborne Data Collection

Multiple flights were conducted in different days (n=5) of the week as well as different times of the day in order to capture daily, seasonal, and other possible factors affecting the presence of wildlife species in the surveyed area (FAA, 2018), but following similar protocols in order to increase the credibility of our findings. It is noteworthy to mention that we utilized a form similar to the *Wildlife Survey – Airport Observation Sheet* while recording the data collected with the UAS (FAA, 2018) (see Appendix D). Our form was developed by our team with the assistance of the QAWB. It is important to note that the QAWB assisted our team during the development and execution of this project. This professional met regularly with the team to provide technical assistance regarding the identification of land-uses and other features that have the potential to attract the hazardous wildlife species to the "airport AOA" as well as the identification of the found wildlife species after the data collection process. Most importantly, the QAWB assisted the researchers in organizing our data in a way that is meaningful for a WHA. Preliminary data collected until May 2021 were analyzed for the completion of a report to be submitted to the FAA Challenge - Smart Airport Student Competition (June 2021). The data collection processes observed the protocols a QAWB must follow while conducting a WHA (FAA, 2018). Therefore, the application of UAS and sensors was expected to allow researchers to also identify and record certain land uses that could not be compatible with safe aircraft operations (FAA, 2020).

Figure 5

Data Collection Area - Coe Field Airport.

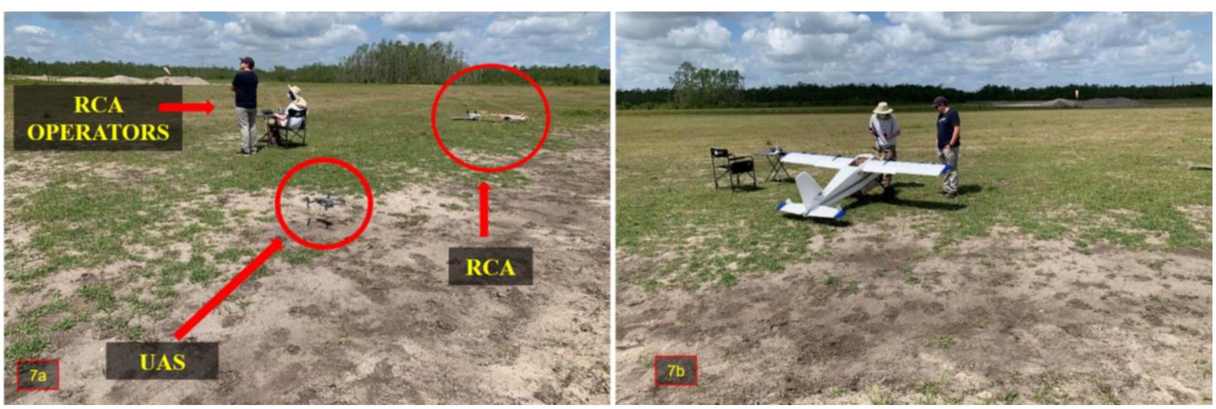
Note. *Image retrieved from Google Earth*.

The test flights were conducted over a plot sample area with an area of approximately 90,000 square meters north of Coe Field airport (see Figure 5). Flights were completed using the "DJI's Go 4 software" through the smart controller. This software allowed the researchers to create flight plans and store telemetry data from each flight. Moreover, it allowed the drone operator to monitor the UAS' flight on the screen at the ground control station, and this includes the UAS' altitude and current speed, global positioning system coordinates, estimated time of arrival after mission completion, and even the battery status. It is important to mention that the smart controller has a touch screen that shows exactly what the cameras are seeing. The camera's settings and also the flight parameters could be adjusted using this touch screen. The controller was hooked up via an HDMI cable to a TV set that was placed inside of a trailer where the outside elements would not affect what was being seen (see Appendix E). The pilot-in-command (PIC) collected data outside of the trailer controlling the aircraft while at least one member of the team was inside the trailer monitoring the TV and writing down any necessary observations on a data collection sheet including the presence of wildlife activities and or habitats with the potential to attract hazardous wildlife species to the airport AOA. Moreover, the team member(s) inside the trailer monitored the possible presence of manned aircraft (see Figure 6) using a process previously described in the risk management section of this report. The researchers had once to interrupt fight activities with the UAS due to the presence of manned aircraft performing a "low pass" over the runway at ~700 feet AGL. Other than that, there were no aircraft movements below a 1,000 feet AGL or in the traffic pattern at Coe Field airport during the data collection processes. However, we had to delay the beginning of the data collection process as well as to interrupt the data collection process few times due to the presence of radio-controlled aircraft (RCA) close to the data collection area (see Figure 7).

Figure 6
Data Collection Process at Coe Field

Note. (6a) Researcher monitoring the two TV sets in the trailer during data collection for the presence of wildlife and/or the presence of manned aircraft at and around Coe Field airport.
Note 2. (6b) PIC collecting data using the drone with the assistance of a visual observer.
Note 3. (6c) One TV set showed real time images from the drone while other TV set depicted images of manned aircraft at and around the Coe Field airport (information from the ADS-B Flight Box).

Figure 7
Radio-Controlled Aircraft Operations at Coe Field



Note. (7a) UAS flights were interrupted or delayed few times due to RCA operations at Coe Field airport.
Note 2. (7b) RCA operators preparing for a flight – some UAS operations were continued after coordination with the RCA operators by maintaining vertical and horizontal separation from the RCA (with the assistance of the visual observer).

The UAS was flown in two different ways: automatically in a basic grid pattern, and manually. In general, we conducted four flights every time our team was at Coe Field airport. The first and third flight flights were completed in a basic grid pattern (see Appendix E). It is important to note that the first and third flights were carried out autonomously after the drone was launched. To ensure complete area coverage, this study designed observation paths that were close to each other as suggested by Rahman et al. (2020). The second and fourth flights were manually executed by the PIC who collected various images from different angles, altitudes, and various cameras' parameters based upon the PIC's and the team member's (inside the trailer) observations during the first and third flights. This process was expected to facilitate the identification of the presence of hazardous wildlife, their numbers and behaviors, and whether they were being attracted to identified habitats (e.g., bodies of water) among other factors (Cleary & Dolbeer, 2005; FAA, 2018, 2020).

The grid patterns and manual flights allowed our team to have multiple images that overlapped, giving researchers (and the QAWB) a better and more accurate picture of wildlife hazards, possible wildlife hazard attractants, and the interactions between those elements. Additionally, it allowed researchers to visualize a specific area from multiple viewpoints. An estimated 22–28 minutes flight was generally expected with the given area of approximately 300 meters x 300 meters at an average speed of 20 miles per hour. The average endurance of the drone was 35 minutes, thus, our team had to swap the drone's batteries between flights. Additionally, we had to swap the drone's battery before mission completion few times to ensure safety. Images were collected utilizing the integrated visible/thermal cameras. As previously mentioned, the date, time, GPS coordinates, and altitude of flight for each image obtained were recorded (see Appendix B).

We could not identify the presence of New World vultures during the data collection process, regardless of the technique being used (e.g., grid pattern). It is important to note that our team could observe the presence of different wildlife species at and around Coe Field airport with a naked eye (e.g., livestock; Sandhill Cranes), and that images of those wildlife species were collected with the drone. However, we rarely saw New World vultures whenever our team was at Coe Field. When we visualized these birds they were soaring and outside the data collection area. Nonetheless, researchers were able to identify and record the presence of other wildlife, their numbers, locations, local movements, and daily occurrences as suggested in the *Airport Wildlife Hazard Assessment Report Checklist* (see Appendix F) (FAA, 2018).

Figure 8

Images of Cattle at Coe Field Airport.

Note. (8a) Image collected using the RGB camera.
Note 2. (8b) Image collected using the thermal infrared camera.

There were 4,774 strikes to terrestrial mammals in the U.S. from 1990 through 2019. Twenty-five percent (n=1,166) of those strikes caused damage to aircraft (Dolbeer et al., 2021). Thirty-one aircraft were damaged beyond repair after strikes with terrestrial mammals. During the same period, twenty-three of the total strikes with terrestrial mammals caused one fatality and 31 human injuries. From 2011 through 2020 there were 79 strikes to terrestrial mammals in Florida, 14 of them caused damage to aircraft. There were no injuries nor fatalities resulting from those strikes. Coe Field is also used by the airport owner to raise cattle. Even though empirical data indicate cattle has not been a safety hazard for aviation operations in the U.S. (only 11 collisions with aircraft since 1990), other mammals that are of similar (e.g., Moose) and especially smaller sizes (e.g., White-Tailed deer) have caused aircraft accidents in the U.S. In fact, White Tailed deer is considered the most hazardous wildlife species to aviation operations (FAA, 2018). Empirical data have indicated that the wildlife body mass is an important factor in case of a strike with an aircraft (DeVault et al., 2018; Dolbeer, 2020). Our team could identify the presence of cattle, their location, behavior and movements, and preferred habitats mostly using the RGB camera. Interestingly, initial findings suggest that both the RGB and thermal infrared cameras hold the potential to identify the presence of "large" mammals (see Figures 8 and 9).

Figure 9
Image of Cows in a Wetland.

Figure 10
Images of Cattle Egrets at Coe Field Airport.

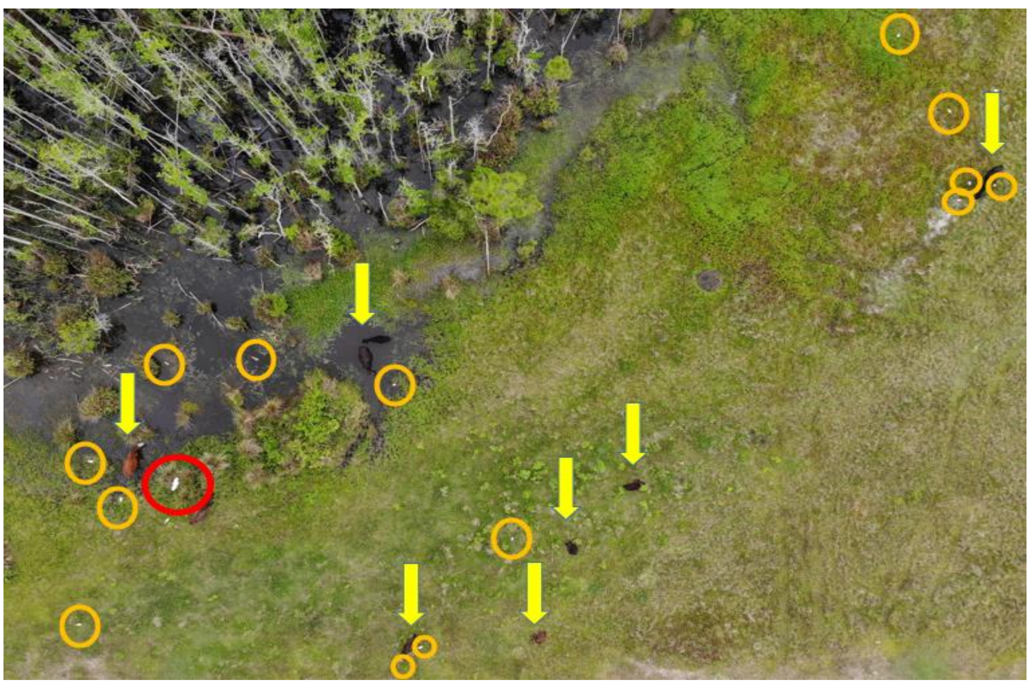
Note. (10a) Cattle Egrets close to cows and a body of water (image collected using the RGB camera).
Note 2. (10b) Tractor mowing the field and cattle egrets stalking insects and other small animals (image collected using the RGB camera).

There were 310 bird strikes in Florida involving Cattle Egrets from January 2011 till December 2020. Eight of those strikes caused damage to the aircraft (FAA, 2021a). Approximately 42% (n=128) of the total strikes occurred at the airport environment. This bird species is listed as the 14th most hazardous wildlife species to aviation operations in the U.S. (FAA, 2018). Cattle Egrets forage in flocks and frequently follow large animals to stalk insect and other small animals stirred from the ground. Their weight ranges from 9.5 to 18 ounces (oz) with a wingspan of approximately 36 inches (in). Their favorite habitats include marshes, farms, and plowed fields (Cornell Lab of Ornithology, 2021b). The presence of Cattle Egrets was common at Coe Field airport. We could identify them with the drone using the RGB camera and especially with a naked eye during every single data collection process. They were usually feeding on the ground usually close to the cattle and/or flying low. We also observed them close to a tractor that was plowing the field (see Figure 10). They were more abundant in the morning during sunny or partly cloudy weather conditions. It is important to note that by using only the images collected during the standard grid pattern it might be difficult to identify this bird species. Conversely, these images would favor the identification of the location and habitats being used by this animal, and especially the number of individuals using that specific habitat.

There were 17 strikes involving the White Ibis bird species in Florida from 2011 through 2020. Twelve of those incidents caused damage to aircraft (FAA, 2021a). In one of these events, the pilot of a Miami Dade police helicopter was forced to make an emergency landing after being injured by a White Ibis (Franklin, 2012). The aircraft suffered substantial damage resulting from the bird strike. During this period, only six of the reported strikes involving White Ibises in Florida included information about the phase of flight when the incident occurred. Anyway, all of them occurred at the airport environment. The wingspan of the White Ibis ranges from 56 in to 68 in, and their weight ranges from 26.5 oz to 37 oz (Cornell Lab of Ornithology, 2021c). This highly sociable bird species forage in groups in areas of standing water. Interestingly, "other wading birds such as egrets may follow them to catch prey stirred up by the Ibises" (Audubon, 2021, para 3). Our team occasionally observed small groups (~3 to 5 individuals) of White Ibises either flying over (medium or high [see Appendix D]) or foraging at the data collection area, especially close or at the bodies of water (see Figure 11). These not regular sightings occurred mostly in the afternoon during sunny weather.

Figure 11

Image of a White Ibis (Red Circle) Flying close to a Wetland.



Note. Orange circles indicate Cattle Egrets.
Note 2. Yellow arrows indicate cattle.

From 2011 through 2020 there were 54 strikes involving Sandhill Cranes in Florida. Twenty-nine (53%) of these safety events occurred at the airport environment. All 54 strike reports contained information about the level of damage to the aircraft, among them 15 indicated no damage, four indicated minor damage, four indicated substantial damage, and seven suggested an uncertain level of damage (FAA, 2021a). Sandhill Crane is a heavy-bodied, tall bird species whose weight ranges from 120 oz to 173 oz, a wingspan of approximately 79 in, and that can reach a height of 47 in (Cornell Lab of Ornithology, 2021d). Their preferred habitats include open wetlands and grassland, and pastures and prairies (frequently surrounded by forests). Resident Sandhill Cranes, which are common in Florida, are usually observed in small groups (Florida Fish and Wildlife Conservation Commission, 2021). The population of Sandhill Cranes increased by 29% from 1990 to 2018 (Dolbeer, 2020). From 1990 through 2020 there were 167 collisions between this bird species and aircraft in the U.S. Approximately 38% (n=64) of those strikes caused damage to aircraft.

Figure 12
Sandhill Cranes in the Wetland.

Note. Image of four Sandhill Cranes collected using the RGB camera (red circles).
Note 2. Image of a Cattle Egret collected using the RGB camera (yellow circle).

During the same period, sixty-four and forty strikes involving Sandhill Cranes caused damage to aircraft and had a negative effect on flight, respectively, in the U.S. Twenty-nine percent (n=48) of the total strikes with this bird species involved more than one animal. Considering their body mass and strong flocking behavior (Dolbeer, 2018), the risk of multiple strikes with this hazardous species should be of concern by aviation operators. Our team could identify this bird species with the drone, usually in small groups (~5 individuals) few times during the data collection process, but generally after observing them with naked eyes. We then decided to investigate and collect more data by manually flying the drone over their locations considering they were located in the data collection area. The Sandhill Cranes were observed (RGB camera) mostly during sunny weather conditions, usually foraging at the ground close to the bodies of water or roaming in the bodies of water (see Figure 12). We also sighted them flying low toward the bodies of water. According to the FAA (2018), Sandhill Crane is the fifth most hazardous wildlife species to aviation operations.

Cleary and Dickey (2010) indicated that a mix of pastures, brush, trees, and bodies of water provide the ideal habitat for several mammals and birds. According to the FAA (2018), "wildlife are attracted to an airport because something exists on or near the airport that they desire" (p. 2-8). Livestock production, large trees, and especially sources of water (e.g., wetlands) at and around an airport are some of the land uses and/or habitats that can attract large numbers of hazardous wildlife to the airport AOA. Thus, the identification of potential wildlife hazard attractants and the recording of the relationship between hazardous wildlife species and the identified sources of attraction are fundamental during a WHA (Cleary & Dolbeer, 2005; FAA, 2018, 2020). For example, livestock operations and pastures often attract flocking birds, such as Cattle Egrets. Similarly, wetlands and other bodies of water can be attractive to several hazardous wildlife species, including White Ibises, and Sandhill Cranes (Cornell Lab of Ornithology, 2021b, 2021c, 2021d). Our team, using the RGB camera, was able to identify land uses (e.g., livestock operations) and habitats (e.g., pastures, trees, wetlands) with the potential to attract hazardous wildlife to the airport environment (see Figure 13).

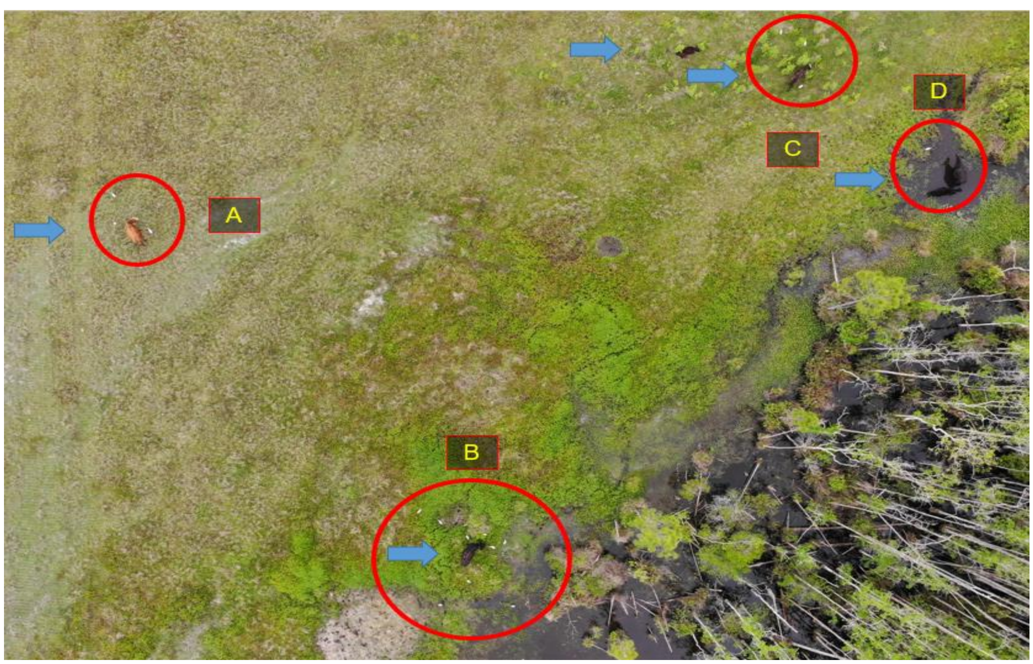
Figure 13

Land Uses and Habitats at and around Coe Field Airport.

Note. (13a) Image of large trees and bodies of water (including wetlands) collected using the RGB camera.
Note 2. (13b) Image of shrubs, some trees, and bodies of water collected using the RGB camera.
Note 3. (13c) Image of bodies of water surrounded by shrubs and some trees collected using the RGB camera.
Note 4. (13d) Image of pasture collected using the RGB camera.

Figure 14

UAS Allowed Researchers to Observe Wildlife and Wildlife-Habitats Interactions.



Note. Blue arrows indicate cows and red circles indicate Cattle Egrets (data collected using the RGB camera).
Note 2. There is one cow in each blue arrow.
Note 3. There are four birds in “A”, ten birds in “B”, four birds in “C”, and one bird in “D”.

As previously noted, the identification of the wildlife species observed including their numbers, their relationship with the identified land uses and habitats, and daily and seasonal occurrences (FAA, 2018) is vital during a WHA. The use of UAS and related sensors, especially the RGB camera, facilitated, for example, the identification of the presence of birds, and their local movements at Coe Field airport. Moreover, the "bird's eye" view of a drone significantly helped our team to observe the bird's behaviors in the identified habitats and land uses, and especially their numbers, even from a significant distance from the point where the researchers were standing (see Figure 14).

Figure 15

Small Unidentified Bird Species – Probably a Mottled Duck or a Mallard.

Our team was able to observe a bird swimming in a wetland. It is worth noting that it would be difficult for a QAWB to observe this bird even with binoculars due to natural structures (large trees and dense vegetation). Yet, this is a type of habitat that is difficult to access by ground-based means. The QAWB suggested this animal could be a Mottled Duck (Cornell Lab of Ornithology, 2021f) or a female Mallard (Cornell Lab of Ornithology, 2021g) (see Figure 15). We were not able to identify the bird species with confidence, though. Moreover, during one manual flight the PIC observed some ripples in a body of water (see Figure 16). Images were collected since those ripples could have been caused by bugs and/or fish, which in turn could lead this habitat to be an important attractant to hazardous wildlife species to aviation operations. Nonetheless, our team could not pinpoint the reason for the observed ripples.

Figure 16

Ripples in a Body of Water.

5. Conclusions and Key Findings

The increased risk of wildlife strikes has become a growing economic and safety concern for the aviation industry. Analyses of wildlife-strike data have indicated that safety strategies by aviation stakeholders, especially airport operators, have reduced the number of damaging strikes involving commercial aircraft at the airport environment (Dolbeer et al., 2021). Nonetheless, the number of strikes and damaging strikes increased by 74% and 21%, respectively, from 2010 through 2020. A multifaceted strategy, including research, innovation, and technology to effectively address the nature and magnitude of this aviation safety hazard is vital. Empirical data have indicated that drones can be used for an ever-increasing variety of applications, including the identification and/or monitoring of wildlife (Barnas et al., 2020; Lyons et al., 2019; McEvoy et al., 2016; Rahman et al., 2020). However, there are possible UAS applications that have not yet been fully investigated, especially at and around the airport environment. This study was completed to fill a gap in the safety management of wildlife hazards by airport operators. More specifically, to assess how UAS and related technologies can assist a QAWB during a WHA.

Findings from our study suggest that UAS can facilitate the observations made by a QAWB during a WHA, including the identification and assessment of potential wildlife attractants (e.g., wetlands), and the identification of wildlife species (e.g., White Ibis). Additionally, data and information collected with an UAS can help a QAWB quantify the risk presented by different wildlife species at a specific airport (e.g., number of species and their behaviors in a specific area). Not all wildlife species are easily detectable, and natural and/or man-made structures can make it almost impossible for a QAWB to observe the presence of animals, their numbers, behaviors, and interactions with the environment, even with binoculars. Additionally, there are inherent hazards while interacting with wildlife in their “natural” habitats. For example, a QAWB very often has to collect data at or close to a wetland where hazardous species (e.g., snakes) may pose a serious risk to humans (Johnson & Main, 2020). Moreover, important habitats (e.g., small body of water) could be surrounded by large trees (see Figures 11 and 13) making it difficult to access and/or observe wildlife by ground-based means. Additionally, human factors (FAA, 2016) can hamper the ability of a QAWB during a WHA. Our findings suggest that a bird’s eye view can certainly help overcome those problems.

Different types of habitats and land use practices could attract hazardous wildlife to the airport environment (FAA, 2020). Different wildlife species will seasonally exploit those habitats. Our team was able to identify these habitats using UAS (see Figures 9, 12, 13, 14, and 15) as well as their influence on wildlife behavior (see Figures 10 and 11). For instance, the presence of livestock seems to be an attractant to Cattle Egrets as suggested by the Cornell Lab of Ornithology (2021b). Nonetheless, it is important to mention that to better understand the *wildlife X habitat relationship* (FAA, 2018), the expertise of a QAWB is critical. The FAA (2018) recommends a QAWB should include images of hazardous wildlife observed as well as important habitats in the WHA report. In each flight our team collected hundreds of images that could not only be added to the WHA report but also be used for further analyses. For example, our team was not sure whether the observed Sandhill Cranes flying in the data collection area were using the wetlands. Post-flight analyses of collected images provided the needed response (see Figure 12). Yet, images collected using UAS during different times of the year (e.g., different seasons) allow the QAWB to account for the dynamics of species observed (and habitats), including numbers, locations, behaviors, and seasonal trends and patterns. Yet, it allows for consistent comparisons with previous WHA findings while assessing the efficacy of an existing WHMP.

The QAWB should make observations to include habitats and wildlife species from multiple different locations to “ensure complete visual coverage of the airport” (FAA, 2018, p.1-3). Additionally, wildlife that may not congregate in groups as well as synergistic effects of surrounding habitats and land uses should be observed and recorded during a WHA. Our team could identify four Sandhill Cranes (not a large group) in a body of water (see Figure 12) during a manual flight with the drone. Additionally, we could few times observe Cattle Egrets flying from the area where the cows were grazing close to the bodies of water (and vice-versa). Another key finding of this study was that our team could observe, and with the assistance of the QAWB identify different wildlife species and habitats simultaneously during each UAS flight. In different words, from a single image (video and/or picture), for example, a QAWB could obtain a lot of valuable information needed during a WHA (see Figures 10, 11, and 14). Lastly, traditional data collection methods utilized during a WHA rely on the assumption that wildlife does not move before detection. Our findings suggested that the observed wildlife maintained their normal behavior during the data collection processes.

In order to mitigate the risks associated with this study students completed the FRAT before each flight, and then developed and implemented risk mitigation measures to ensure the safety of their flights (FAA, 2016). In addition, CRM concepts (Kanki et al., 2019) were instilled during the entire study. Teamwork, threat-and-error-management, and effective communication were three of the several CRM competencies our team applied to identify hazards and mitigate the risks associated with those hazards. There were no aircraft operations at Coe Field airport during the data collection process. Nonetheless, enhanced situational awareness by the visual observer as well as data obtained with the ADS-B flight box certainly helped our team mitigate risks associated with manned aircraft operations at and around Coe Field. Even though we had to postpone and terminate a few flights due to RCA operations at Coe Field airport, our team considered these as valuable experiences since we treated those as "*manned aircraft operations*" at the airport environment that required risk mitigation. Interestingly, after coordination with the RCA operators some UAS flights were safely conducted simultaneously during RCA operations (e.g., by maintaining vertical and horizontal separation). Nonetheless, we acknowledge that there are risks associated with UAS operations at and around an airport environment. Thus, the ConOps should be periodically revised to incorporate procedures that improve aviation safety and efficiency.

The current study experienced a number of limitations. In general, our team could not obtain usable images of wildlife, especially birds, by utilizing the thermal cameras. Possible reasons for that include limitations of the utilized thermal camera (e.g., resolution of 160x120), and / or a combined effect of thermal radiation from the ground and the effect of surface reflection from sunlight (Rahman et al., 2020). Factors such as the students' and/or advisor's academic schedules, poor weather conditions, the COVID-19 pandemic, and construction in progress at Coe Field reduced the number of opportunities for data collection. Ideally our team would have collected data multiple times in a year timespan, during different days of the week, and during different times of the day to capture factors (e.g., season of the year; time of the day; weather conditions) affecting the presence and behavior of wildlife at the data collection area (FAA, 2020). We could not identify (using the drone) the presence of New World vultures at Coe Field airport. The non-identification of New World vultures could have been the result of the period of the year and/or the time of the day in which our team collected data. According to the FAA (2018), food sources and bird behaviors could vary seasonally or temporarily. As previously mentioned, from 2006 through 2020 there were 460 wildlife strikes in Florida involving New World vultures. Only thirty-three and ten of those strikes occurred in April and May, respectively (period when our team collected data). Moreover, just five percent (n=20) of these events occurred at the airport environment (FAA, 2021b). Additionally, considering that our flights generally began after 10:00am, this bird species could be already "soaring above open areas to seek their food" (Cornell Lab of Ornithology, 2021e, para. 4). Other plausible reasons for the non-detection of New World vultures using the drone include the inexistence of habitats at the data collection area that could produce substantial attractions for this bird species (FAA, 2020). We assume those could be some of the reasons for this limitation of the study. Noteworthy to mention that our team frequently observed, with naked eyes, the presence of Cattle Egrets and White Ibises, and few times Sandhill Cranes during the data collection processes, but rarely did we see vultures at Coe Field. Lastly, the technical support of a QAWB, as for example, by identifying the wildlife species we found during the data collection process, and by providing guidance to our team was fundamental during this entire project. Nonetheless, the expertise of a QAWB while we were collecting data would certainly have helped our team focus our efforts on the key factors of a WHA (e.g., establishing a relationship between an observed wildlife species and an identified habitat). Our team acknowledges that these limitations may constrain the generalizability of our findings. Nevertheless, the results can still provide the foundation for using UAS technologies to identify hazardous wildlife species to aviation operations as well as potential wildlife hazard attractants within the airport jurisdiction.

Integrated research and the effective use of technologies to mitigate the risk of aircraft accidents resulting from wildlife strikes is vital. The following are recommendations to continue this path of investigation:

1. Researchers should utilize more sophisticated (e.g., increased endurance; better sensors) UAS technologies that do not have specific restrictions on use of federal funds for drone operations;
2. Researchers should consider the issuance of Notice to Airmen and coordination with air traffic control as strategies to enhance aviation safety during data collection;

3. Researchers should consider other methodologies (e.g., double-grid pattern followed by manual flights) during the data collection processes;
4. Researchers should strive to partner with the FAA and an airport operator (e.g., Class D airspace) to collect data in a more complex environment; and
5. Researchers should make efforts to allow the presence of QAWB during the data collection process providing real-time guidance and feedback to the UAS team.

6. Technical Demonstration

Our team will showcase the work accomplished during this project via an edited prerecorded video that will include:

1. A brief explanation about the project (e.g., ConOps; data collection);
2. Images of UAS pilots operating the drones during the data collection process; and
3. Multiple images (pictures and videos) of wildlife and/or their habitats identified with the UAS.

7. Project Timeline

The ConOps was streamlined throughout our entire project as we identified (and noted) the challenges and limitations of using UAS to collect information about hazardous wildlife species and or their habitats, as suggested by the FAA (2018). See Table 1 for the project timeline.

Table 1

High-Level Project Timeline

	2021				**2022**
	MAR	**JUN**	**SEP**	**DEC**	**MAR**
Develop ConOps					
Streamline ConOps					
Data Collection and Analyses Processes					
FAA Challenge – Deliverables					
Write-up Results					

Note. The data collection and analysis processes will continue until early March 2022.
Note 2. Our team is looking for a partner airport(s) for future data collection so we can apply the knowledge obtained from this pilot study to improve the ConOps.

8. Budget

Students pursuing a Bachelor's of Science in UAS Science degree at Embry-Riddle Aeronautical University (Daytona Beach campus) and who are enrolled in a capstone course (*Special Topics in Aeronautical Science*) were eligible to participate in this project. In our current team (spring semester 2021) there were four of those students. The students' role ranged from streamlining the ConOps and collecting data with the DJI Mavic 2 Enterprise drone to obtaining useful information from the collected data with the support of a QAWB. Nonetheless, our team used some of the Embry-Riddle Aeronautical University resources that are available to students enrolled in a capstone course to complete this project (e.g., drone; trailer). The QAWB kindly provided guidance during this project at no costs. Anyway, Table 2 shows the estimated costs that are associated with the development and application of the current project.

Table 2

UAS Project – Estimated Costs

Academic Research, Development, and Data Collection and Analyses Costs			
Item	**Rate**	**Quantity**	**Total**
Student Efforts	$12 / Hour	2,500 Hours	$30,000.00
Faculty Advisor Efforts	$60 / Hour	350 Hours	$21,000.00
QAWB Efforts	$139 / Hour	150 Hours	$20,850.00
Utilization of Supporting Trailer	$25 / Hour	360 Hours	$9,000.00
Showcase our Project during the 2021 Bird Strike USA Committee Meeting	$125 / Participant	4 Participants	$500.00
		Estimated Total Costs	**$81,350.00**

Note. The QAWB kindly mentored students and provided guidance to the faculty advisor at no cost during this project.
Note 2. These are only estimated costs associated with this project till March 2022.
Note 3. ERAU provided the support needed during the first phase of the study.

9. Broader Impact

This project has far-reaching impacts on aviation safety and education. Airport operators are ethically and legally obligated to take actions to mitigate the risk of aircraft accidents resulting from wildlife strikes (Rillstone & Dineen, 2013). Considering that the majority of strikes occur within the airport jurisdiction, safety efforts should target wildlife hazards at and around the airport environment. Historically, wildlife management on airport premises has focused on the presence of overabundant species and their effects on safety (DeFusco & Unangst, 2013). However, airport operators frequently deal with species that may not be overabundant, yet still pose significant risks to aviation safety and human health. Regardless, when effective use of wildlife population control measures on airports is used, a reduction in wildlife collisions with aircraft is possible. Information obtained from the analyses of wildlife strike data (Dolbeer et al., 2021), population increases of large and medium birds (many with flocking behavior) in North America (Dolbeer, 2020), and the economic and safety issues associated with wildlife strikes (DeVault et al., 2018; Mendonca et al., 2017) are some of the key elements indicating that innovative approaches to mitigate this aviation safety risk is vital.

All certificated airports are expected to conduct a WHA and implement a WHMP in accordance with the FAA (2018) standards and guidance materials. As previously mentioned, the safety efforts by airport operators have certainly helped prevent aircraft accidents resulting from wildlife strikes. Nonetheless, these efforts have done little to prevent, for example, strikes during the climb and approach phases of flight. The application of UAS has significantly increased over the last years. “Smart airports of the future could safely use UAS in a variety of functions” (FAA, 2021e, para. 3). Currently, several airports see the potential of applying UAS for wildlife management (Hamilton et al., 2020a, 2020c). The safe application of UAS to streamline the WHA process is expected to provide several benefits to the airport operator, including task completion in reduced time, enhanced level of accuracy during the data collection process, reduced risks for the QAWB, and cost efficiencies. In addition, researchers are expecting to collect data and information that can facilitate the effective integration of UAS into the airport environment, as suggested by Hamilton et al. (2020a, 2020b), Neubauer et al. (2015), and Prather (2019). Most importantly, this multi-phased project is in alignment with the FAA’s multifaceted approach for mitigating the risk of aircraft accidents due to wildlife strikes, which includes research and innovation.

Aviation programs accredited by the Aviation Accreditation Board International (AABI) (2019) must demonstrate students, upon graduation, are able to:

1. Apply mathematics to aviation, science, and applied sciences to aviation-related disciplines;
2. Apply pertinent knowledge to identify, formulate, and solve applied aviation problems;

3. Work effectively on multi-disciplinary and diverse teams;
4. Make professional and ethical decisions;
5. Communicate effectively, using both written and oral communication skills;
6. Engage in and recognize the need for life-long learning;
7. Assess contemporary issues;
8. Analyze and interpret data; and
9. Use the techniques, skills, and modern technology necessary for professional practice.

This multiphase study will benefit students by providing then unique opportunities to develop or enhance competencies (AABI, 2019; Kanki et al., 2019) that are valued by the aviation industry. Aviation training and education through applied research that involves a multidisciplinary team benefit students by providing them with real-world scenarios where they develop innovative solutions through exploration. For the faculty mentor, benefits include collaboration in a research project addressing major safety issues afflicting the aviation industry worldwide, which is in alignment with two of the FAA (2019b) strategic goals and objectives:

1. Reduce civil aviation and commercial space transportation-related fatalities and serious injuries; and
2. Lead in the development and deployment of innovative practices and technologies that improve the safety and performance of the national airspace system.

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Appendix A: Letter of Support

CB

CHRISTOPHER B. BURKE ENGINEERING, LTD.
9575 W Higgins Road, Suite 600 Rosemont, Illinois 60018-4920 Tel (847) 823-0500 Fax (847) 823-0520

February 26, 2021

Embry Riddle University
1 Aerospace Boulevard
Daytona Beach, FL 32114

Attention: Dr. Flavio Antonio Coimbra Mendonca
Assistant Professor of Aeronautical Science

Subject: Letter of Support for the Proposed Project:
APPLYING UAS FOR WILDLIFE HAZARD MANAGEMENT
AT AIRPORTS

Dear Dr. Mendonca,

Thank you for requesting advisory assistance for your proposed project entitled above. It is our understanding that you are requiring the assistance of a qualified airport wildlife biologist for your proposed upcoming project to act in an advisory capacity regarding wildlife topics in your proposed study. It is also understood that the assistance will be on Senior Wildlife Biologist Robert Sliwinski's own time and at no charge. We appreciate this opportunity to assist as an Industry Partner capacity on this project.

We will establish our contract in accordance with the attached General Terms and Conditions. These General Terms and Conditions are expressly incorporated into and are an integral part of this contract for professional services.

Sincerely,

Michael E. Kerr, PE
President

N:\PROPOSALS\ADMIN\2021\Embry Riddle.030121.doc

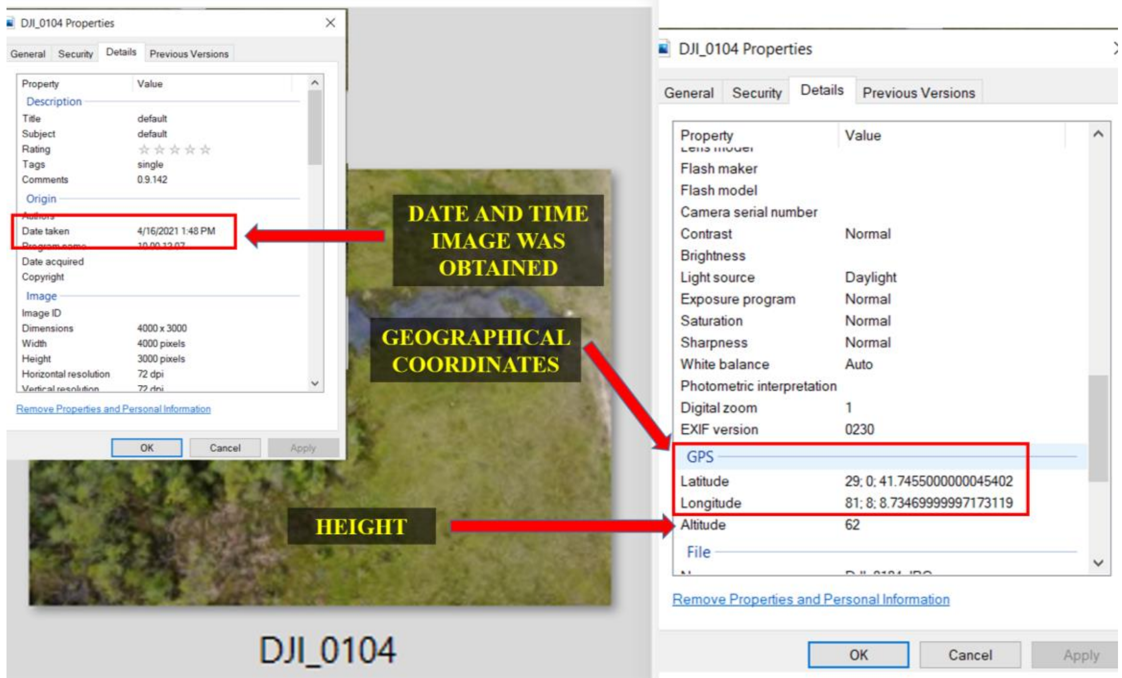
THIS PROPOSAL AND GENERAL TERMS AND CONDITIONS ACCEPTED FOR EMBRY RIDDLE UNIVERSITY:

BY: FLAVIO A C MENDONCA

TITLE: ASSISTANT PROFESSOR

DATE: MAR-01-2021

Appendix B: Images Collected - Information Recorded



Note. The date, time, GPS coordinates, and altitude of flight for each image obtained were recorded.

Appendix C: Flight Risk Assessment Tool (FRAT)

		0	1	2	3	4	Rating
Operational Factors	Type of Operation	Proficiency	Demo	Recurrency / Subsequent	Training	Initial Experimental or Service Learning Flight	
	Duration of Operation	< 1 hour	1 - < 2 hours	2 - < 4 hours	4-6 hours	> 6 hours	
	Simultaneous Operations	1 UA		2 UAs	3 UAs		
Crew Factors (any member)	Hours of Rest in Last 24 Hours (from prior duty)	> 14	> 12 - 14	> 10- 12	> 8 - 10	8 or less	
	# of Flights in UAS category (multi-rotor vs. fixed-wing)	> 50	50 - 41	40 - 31	30 - 20	< 20	
	# of Flights in Last 90 Days	> 12	> 7 - 12	> 5 - 7	> 3 - 5	3 or less	
	Student Crew	VO		PMC		RPIC	
	Total UAS Hours	> 50	40 - 50	30 - 40	20 - 30	< 20	
Environmental Factors	Surface wind (% of OEM UAS max; if not OEM prescribed)	50% or < 8 kts	60% or 9 - 12 kts	70% or 13 - 15 kts	80% or 16 - 19 kts	90% or > 20 kts	
	Weather Forecast for Operation	14 CFR 107 Minimums					
	Surrounding Area	Flat, no obstacles	Flat, with obstacles	Hilly or mountainous	Urban	Confined	
						Total Risk Score →	

No unusual hazards. Use normal flight planning and operational procedures. Requires PIC signoff.	< 21
Elevated risk. Conduct flight planning with extra care. Review personal minimums and operating procedures to ensure that all standards are being met. Consider alternatives to reduce risk. Requires UAS-S Program Coordinator signoff or, for operations outside of the local area, their designee.	21-35
Conditions present much higher than normal risk. Conduct flight planning with extra care and review all elements to identify those that could be modified to reduce risk. If available, consult with a more experienced pilot or instructor for guidance before flight. Develop contingency plans before flight to deal with high risk items. Decide beforehand on alternates and brief crewmembers on special precautions to be taken during the flight. Consider delaying flight until conditions improve and risk is reduced. Requires Department Chair signoff.	> 35

Appendix D: Wildlife Survey Data Sheet

Survey Area /Location:________________________ **Investigator/Biologist:______________________**

DATE:			**TIME(Z):**		**WEATHER:**	
LOCATION	**SPECIES**	**NUMBER**	**BEHAVIOR**	**DIRECTION**	**HABITAT**	**NOTES**

WEATHER	**BEHAVIOR**	**HABITAT AREA**	**DIRECTION OF MOVEMENT**
SU- SUNNY	FD- FEEDING	PND- POND	N- NORTH (NS, NW, NE)
CL- CLOUDY	RS – ROOSTING	RES- RESERVOIR	S- SOUTH (SE, SW, SN)
RN- RAIN	NS- NESTING	RIV- RIVER	E- EAST (ES, EW, EN)
SN- SNOW	VO- VOCALIZING	WDL- WOODLAND	W-WEST (WE, WS, WN)
FG-FOG	MT- MATING	MAR- MARSH	
PC- PARTLY CLOUDY	LF- LOAFING	CRK- CREEK	
PS- PARTLY SUNNY	FH- FLYING HIGH	OFLD- OPEN FIELD	
	FM- FLYING MEDIUM	SHB- SHRUB	
	FL- FLYING LOW	SHR- SHORELINE	
		GSH- GRASS, SHORT	
		GLG- GRASS, LONG	

Note. Adapted from the Federal Aviation Administration (FAA). (2018). *Protocol for the conduct and review of wildlife hazard site visits, wildlife hazard assessments, and wildlife hazard management plans* (AC 150/5200-38). Retrieved from https://www.faa.gov/airports/resources/advisory_circulars/index.cfm/go/document.current/documentNumber/150_5200-38

Appendix E: "Real time information" during data collection

Note. "Real time information" during data collection include GPS coordinate and altitude of flight, drone speed, and pattern of flight.

Appendix F: Airport Wildlife Hazard Assessment Report Checklist

	Yes or Not Applicable	**Comments**
Identification of wildlife species observed and their numbers, locations, local movements, and daily and seasonal occurrences.		
Identification and location of features on and near the airport that attract wildlife (assess both natural and man-made attractants).		
Identification and location of features (land uses and habitats) “near airport” that attract wildlife.		

Note. Adapted from the Federal Aviation Administration (FAA). (2018). *Protocol for the conduct and review of wildlife hazard site visits, wildlife hazard assessments, and wildlife hazard management plans* (AC 150/5200-38). Retrieved from https://www.faa.gov/airports/resources/advisory_circulars/index.cfm/go/document.current/documentNumber/150_5200-38
Note 2. Not all elements of the *Airport Wildlife Hazard Assessment Report Checklist* are applicable to this project.
Note 3. Land-uses and habitats to be assessed are described in the FAA AC150/5200-33C - Hazardous wildlife attractants on or near airports.