sUAS Hazard Detection System

For Mitigating Wildlife Hazards

April 2021

Design Challenge: Airport Operation and Maintenance Challenge: Innovative approaches to address wildlife issues at airports including bird strikes.

Team Members:

Undergraduate Students: Mihir Mehendale, Mary Ollis

Advisor's Name: Dr. Audra Morse

Michigan Technological University

02 Executive Summary

Wildlife incidents are one of the most dangerous hazards that can occur when operating an aircraft; animals including deer, coyotes, turtles, and avian species can collide with aircraft on departure or approach to airports. Wildlife strikes normally kill or wound the animal, cause damages to the aircraft, and endanger human lives. The Federal Aviation Administration (FAA) lists over 227,000 wildlife incidents since 1990, most causing minor damage. However, an estimated 271 aircraft were destroyed due to strikes during this period, resulting in damage ranging from 500 to 900 million dollars (Federal Aviation Administration, 2020b). In comparison to other animals, avian species pose the largest threat with the potential to collide with aircraft while on the ground and during flight.

The high risk and hazard posed by strikes makes it crucial for airports to take steps to mitigate wildlife encroachment. A thorough review of various developments around the airport such as land uses, vegetation, and human activities lessens, but does not eliminate risks of attracting and providing habitat for wildlife. The large variance in airport landscape and operations further complicates the effectiveness of such reviews. Work is necessary to develop an innovative solution to mitigate wildlife in various airport environments.

The team investigated a solution with a goal to safely deter wildlife from the runway area while maintaining natural habitats and activities. The team proposes a system that will detect, identify, and deter wildlife using emerging small unmanned aircraft system (sUAS) technology. The integration of sUAS technology is achieved with three phases to progressively advance the capabilities from detect and identify to autonomously detect, identify, and deter wildlife. Each phase shares the same detection and identification capabilities. sUAS technology in the airport environment during normal operations is new and creates additional safety risks; however, strategies to mitigate these additional risks can be implemented to improve safety. The cost of this system varies depending on the sUAS technology chosen, the specific sensors, computer equipment interfaces, operating personnel time and the size of the airport. A conservative estimate is $19,500 for a single sUAS unit, including purchase and annual maintenance costs. The system cost is significantly lower than up to $736,000 per year an airport would spend on damages incurred due to wildlife strikes (Cleary & Dolbeer, 2005). The use of sUAS technology in the airport environment aims to reduce wildlife strikes by identifying wildlife presence before an incident occurs.

03 Table of Contents

03.1 Table of Acronyms

Acronym	*Meaning*
ATC	Air Traffic Control
AC	Advisory Circular
BWE	Built World Enterprise
FAA	Federal Aviation Administration
KDEN	Denver InternationalAirport
KLGA	LaGuardia International Airport
MTU	Michigan Technological University
NAS	National Aerospace System
NTSB	National Transportation Safety Board
NWRC	National Wildlife Research Center
UAS	Unmanned Aircraft System
sUAS	Small Unmanned Aircraft System(s)
UAV	Unmanned Aerial Vehicle
US	United States
USAF	United States Airforce
USDA	United States Department of Agriculture
VIDP	Indira Gandhi International Airport
VASU	Surat Airport

04 Problem Statement and Background

04.1 Background of Wildlife Hazards

In the National Airspace System (NAS), wildlife hazards are a concern among pilots, airport operators, passengers, and other aviation professionals. A wildlife incident is defined as when birds or another animal collides with an airplane in the air, during takeoff, or during landing operations (US Department of Agriculture, 2020). The “Miracle on the Hudson" is one of the most well known wildlife incidents. At airports, wildlife hazards are prevalent and avian hazards range from small birds (pigeons) to large birds (pelicans, geese, cranes, and turkeys). Other wildlife hazards include deer and even reptiles. According to the Federal Aviation Administration (FAA), the most hazardous wildlife are gulls, waterfowl, raptors, and deer (Federal Aviation Administration, 2020b). In 2017 alone, approximately 14,400 wildlife incidents were reported and another 4,000 were reported by the United States Air Force (USAF) (US Department of Agriculture, 2020). Wildlife incidents have numerous consequences with the most extreme being loss of human life. Between 1960 and 2004, approximately 405 civilian and military lives were lost due to wildlife incidents (Cleary & Dolbeer, 2005). Wildlife incidents put human lives at risk and cause loss of revenue from aircraft damage and downtime.

04.2 Background on Land Uses that Attract Wildlife

Most wildlife hazards exist at airports because airports are an area of natural wildlife habitats and contain food and water sources (Federal Aviation Administration, 2020b). Wildlife are attracted to tall grasses, wetlands, and roost on buildings/towers. In Advisory Circular (AC) 150/5200-33C, the FAA identifies land use practices on or near airports that attract wildlife. The land use practices includes, but not limited to, waste disposal operations, water management facilities, dredge spoil containment areas, agricultural activities, aquaculture, golf courses, landscaping, structures, and wetlands (Federal Aviation Administration, 2020a). All of the specified land use practices either attract large (geese and gulls) or small (pigeons and starlings) avian species, all of which pose significant hazard to aircraft not only on the airport surface but in arrival and departure corridors.

04.3 Airport Habitats

Standard operations at airports can attract animals such as warm runways and parking lots act as a heat source for cold blooded animals. Additionally, large grassy areas near the pavement provide animals vegetation, water, and space to roam (Federal Aviation Administration, 2020a). Vegetation around airports attracts and deters different animals. Tall grasses act as shelter to some animals and a nuisance to others. Wetlands and areas where water collects attract waterfowl. Undesirable vegetation is placed around sources of water including detention ponds to preserve the pond's function in addition to deterring animals from the water. Structures including towers, rooftops, and light posts provide areas for nesting and loafing for birds (Federal Aviation Administration, 2020a).

04.4 Current Wildlife Mitigation Strategies

There are many strategies employed by airports to mitigate wildlife hazards. Advisory Circular (AC) 150-5200-33C indicates separation distances from hazardous wildlife attractants as one wildlife mitigation strategy. For example, airports that primarily serve piston-powered aircraft, potential wildlife attractants should be outside of a 5,000 foot perimeter of the aircraft operations area. Other recommended perimeters for turbine powered and all airports identified by the FAA are shown in Figure 1.

In addition to mitigating wildlife hazards outside of the airport environment, there are strategies for management at airports. Four primary ways to mitigate wildlife hazards include flight operation modifications, habitat modification and exclusion, repellent and harassment, and removal (Cleary & Dolbeer, 2005). Flight operation modifications include modifying aircraft flight schedules to minimize the risk of encountering wildlife. Increasing aircraft operations at night when birds are less active and identifying bird migration patterns to avoid operating during those high movement periods are two examples of flight operation modification.

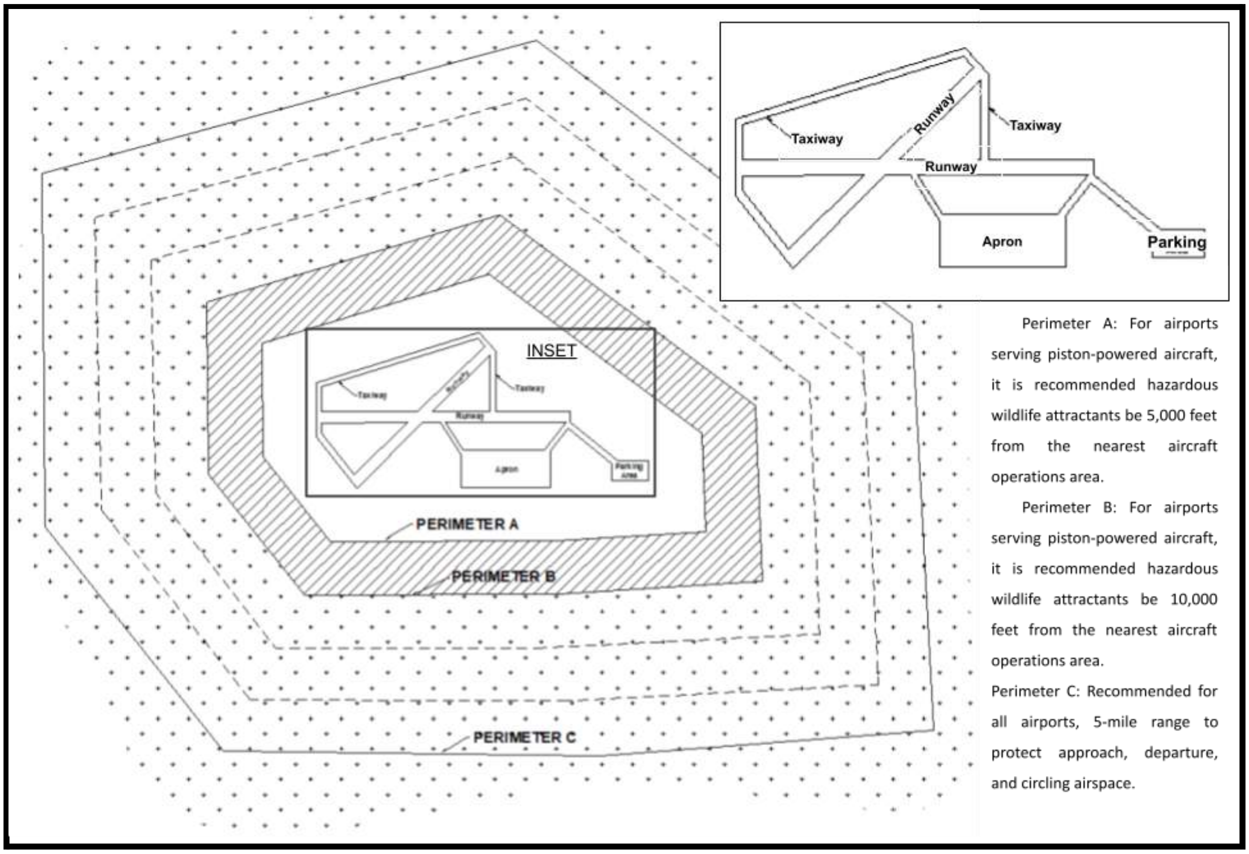
Habitat modification and exclusion identifies the three things wildlife need to survive -- food, shelter, and water. When one of the three items are taken away, there will be a potential decrease in wildlife populations in that area as the environment is less attractive to wildlife. Exclusion techniques include the installation of fences and minimizing exposed areas for perching (Cleary & Dolbeer, 2005).

Repellent and harassment techniques used by airports in the NAS are classified as light, noise, chemical, or natural deterrents. An example of a light repellent/harassment technique is the use of lasers. Propane cannons and polytechnics are an example of an audio repellent technique. Chemical repellents that harass wildlife are not a universally used mitigation strategy. Some natural repellent and harassment techniques include taxidermy mounts or falconry. The most common technique used to deter avian wildlife is playback of recorded avian distress calls.

The least desirable mitigation technique is removing hazardous wildlife through capture or extermination (Cleary & Dolbeer, 2005). Capturing dogs can be challenging and expensive.

Extermination through lethal control is used to mitigate seagulls but if possible is avoided. Current mitigation techniques are not effective in the long term. The optimal solution to the mitigation of wildlife hazards depends on many factors including location, animal, and severity of the issue.

Figure 1. Example of recommended separation distances where hazardous wildlife attractants should be avoided, eliminated, or mitigated. Redraw of FAA figure (Federal Aviation Administration, 2020a).



05 Summary of Literature Review

05.1 Incident Examples

Numerous occurrences of wildlife incidents at airports demonstrate that animals pose a significant danger. Major wildlife incidents are reported to the National Transportation Safety Board (NTSB), which responds to all noteworthy aviation incidents. The most well-known wildlife incident was the "Miracle on the Hudson" in January 2009 when US Airways flight 1549 struck a flock of Canadian geese just after takeoff from New York's LaGuardia Airport (KLGA), damaging the engines (National Transportation Safety Board, 2010). The pilots of US Airways flight 1549 executed an emergency landing on the Hudson River, all 155 occupants survived. The "Miracle on the Hudson" was one of the first wildlife incidents that captured public attention. As a result, bird strikes were highlighted as a significant obstacle to safe aviation in the public eye. Birds pose the largest concern to aviation; however, other wildlife present hazardous scenarios as well. In 2008, several monitor lizards, jackals, and birds of prey occupied the runway at Indira Gandhi International Airport (VIDP) in New Delhi, India (Associated Press, 2008). Flights were grounded for hours because wildlife of this size can cause significant damage to an aircraft at takeoff velocity. At Surat Airport (VASU) in India, a plane preparing for takeoff crashed into a water buffalo causing substantial damage to the aircraft (Dearden, 2014). Historical wildlife incidents demonstrate the importance of establishing effective mitigation techniques at airports.

05.2 Reporting of Wildlife Incidents

Airports, both commercial and general, are expected to report all wildlife strike incidents to the FAA who uses the data to prepare statistics and guidance on how to mitigate these events. In the FAA's standardized "Bird/Other Wildlife Strike Report" form, airport personnel complete key information pertaining to the strike, including the model of aircraft and affected parts, speed and height of aircraft at the time, location of incident, weather conditions, and the size and number of birds involved (Federal Aviation Administration, 2010). An estimate of repair costs incurred from the incident as well as number of hours the aircraft would be out of service, are also fields included on the form. It is important to note that less than one-fifth of wildlife strikes are reported to the FAA (Federal Aviation Administration, 2005), which means that any statistics related to the strikes and resulting damage are significantly underestimated in available data.

05.3 Small Unmanned Aircraft Systems (sUAS)

A Small Unmanned Aircraft System (sUAS), commonly referred to as a "drone", is defined by the FAA as "a small unmanned aircraft weighing less than 55 pounds, including everything that is on board or otherwise attached to the aircraft, and can be flown without the possibility of direct human intervention from within or on the aircraft" (Federal Aviation Administration, 2021a). A sUAS is different from a Unmanned Aircraft System (UAS) by the weight limitation of 55 pounds. sUAS have uses in civilian and military categories and perform tasks that are more difficult with manually piloted aircraft (Outay, 2020). A common use of sUAS is road and traffic safety; sUAS can photograph and reconstruct traffic accident scenes for analysis (Pan, 2019).

Use of sUAS technology is growing and the FAA lists regulations sUAS operators are required to follow to promote safety. FAA regulations include flying below 400 feet and keeping a constant line of sight between the operator and sUAS during the duration of the flight. Additional regulations exist for non-recreational sUAS flying. Individuals desiring to operate sUAS equipment must complete a written evaluation and additional training by the FAA (Federal Aviation Administration, 2021b). Recurring training is required to continue an operator's sUAS license. Regulations enforced by the FAA on sUAS use are rapidly changing to meet the needs of current technology and aid in safe flying practices.

05.3.1 Current sUAS Uses For Wildlife Hazard Mitigation

FAA regulations heavily limit usage of civilian sUAS at and around airports (Cleary & Dolbeer, 2005). There is minimal information on the current situation of sUAS for wildlife mitigation. One technique studied by the Stevens Institute of Technology in New Jersey regarding Unmanned Aerial Vehicles (UAVs) is "passive acoustic detection" (Sedunov et al., 2018). The study focused on deterring unauthorized UAVs from an airport management point of view. The study analyzed the emitted noise from various models of consumer UAVs using microphones and sensors on the ground and developed algorithms for detecting their presence.

05.3.2 sUAS Safety Hazards and Effects on Wildlife Behavior

There are numerous safety issues regarding sUAS operations. The primary concern when operating within the airport space is potential collision with aircraft. In a joint study by the University of Maryland and the China University of Petroleum, a set area of "collision space" within an airport area was determined that sUAS can safely operate. Conclusions were based on timing of aircraft movement and operations (Pan, 2019). Additionally, DJI models contain the geofence feature which prohibits flying outside of a predefined zone unless authorization is given (Fisher, 2020). The geofence and similar features by other companies can be applied to collision space to improve safety during flights. Planning measures by the operators of the sUAS technology and airport are necessary in order to ensure safer sUAS usage at airports.

Research on the effect of sUAS technology on wildlife behavior is sparse but growing due to the increase in use for recreational and scientific research. An article appearing in Cambridge University Press compiled scientific articles and YouTube videos involving wildlife and drone technology. The article summarized the wildlife's behavior in the articles and videos. Data collected showed wildlife demonstrated some behavioral changes in the presence of an aerial device (Rebolo-Ifrán et al. 2019). Additionally, wildlife in terrestrial and aerial habits were more affected than wildlife in aquatic areas. Some wildlife including reptiles showed no visible response (Rebolo-Ifrán et al. 2019). Birds demonstrated the greatest response and behavioral changes because aerial devices and birds fly at similar altitudes (Rebolo-Ifrán et al., 2019). In 55 percent of cases, wildlife's response to drone technology was to escape, 11 percent to attack, and 5 percent to approach due to curiosity (Rebolo-Ifrán et al., 2019). A collision between an aerial device and bird occurred in 6 percent of cases; however, the purposeful provoking of the bird was the intent in some of the cases (Rebolo-Ifrán et al., 2019).

06 Team's Problem Solving Approach

06.1 Initial Steps

The team consists of civil engineering students interested in transportation. Initially, the team analyzed topic areas in the Operations and Maintenance category. After analysis and discussion, the team decided to focus on Challenge C: "Innovative approaches to address wildlife issues at airports including bird strikes" (Airport Cooperative Research Program, 2020). Upon deciding on the challenge topic, the team began initially researching wildlife hazards and current wildlife mitigation strategies.

After the investigation of wildlife hazards and mitigation strategies, the team identified that many of the current mitigation strategies are not long term solutions. The team also identified that wildlife hazards exist in many areas of an airport and in the flight paths of aircrafts. This knowledge prompted the team to narrow the focus to the mitigation of wildlife hazards on the runway surface.

06.2 Problem Solving Approach

Using a design thinking process, the team compiled possible solutions through brainstorming sessions. The initial brainstorming session consisted of developing potential solution methods and organizing them into categories. From the session, the team focused their solution on mitigating wildlife hazards using a noise or light deterrent through either a ground based or aerial system.

In order to determine the direction of the final solution, the team created a decision matrix to evaluate a ground based and aerial deterrent system. The team defined and weighted thirteen categories for evaluation. Two rating scales were created, the first scale defined a value of 1 as least effective to a value of 5 representing most effective. The second scale defined a value of 1 as greatest cost to a value of 5 representing least cost. The team's initial decision matrix, shown in Table 1, identified a ground based solution as the most effective.

Upon evaluating the potential solutions associated with a ground based system, the team saw little room for innovation. The team also noted that the primary reason that an aerial based system received a lower rating was due to current FAA regulations associated with sUAS use at airports. After discussion, the team reevaluated their final solution with the premise that sUAS technology and regulations have evolved to allow for the incorporation of sUAS into the airport environment. After reviewing and reweighting decision matrix categories as shown in Table 2, aerial and ground based systems achieved similar scores. Seeing more room for innovation, the team pursued an aerial based solution to mitigate wildlife hazards on the runway surface.

06.3 Defining the Final Solution

After making the decision to focus on an aerial based solution, the team researched sUAS applications. In a brainstorming session, team members presented ideas to deter wildlife hazards with random sUAS operations and flight patterns, incorporating noise and light deterrents on sUAS, and sensing and notifying a user of wildlife hazards. Research indicated that sUAS have many sensing and information gathering capabilities and sUAS are an applicable solution to sensing and notifying a user of wildlife hazards.

Table 1. Initial decision matrix evaluating a ground based and aerial system for wildlife hazard mitigation.

Wildlife Mitigation on Runway Surface							
		Aerial System		Ground Based System		Do nothing	
Category/Topic	Weight	Rating	Score	Rating	Score	Rating	Score
Environmental Interactions	2	3.67	7.33	4.33	8.67	3.00	6.00
Fixed cost	0.5	3.00	1.50	2.67	1.33	5.00	2.50
Operational Cost	0.5	2.67	1.33	3.67	1.83	2.00	1.00
Training/Personel Requirements	1	2.00	2.00	3.33	3.33	4.67	4.67
Time to Deter Animals	1.5	2.83	4.25	3.50	5.25	1.33	2.00
Versatility (implementation)	1	4.00	4.00	3.33	3.33	2.67	2.67
Weather	1	2.33	2.33	3.67	3.67	3.00	3.00
Public Visual Impact	1.25	3.00	3.75	3.67	4.58	2.67	3.33
Public Noise Impact	1.25	3.00	3.75	3.67	4.58	2.00	2.50
Life Cycle	0.5	3.50	1.75	4.00	2.00	4.33	2.17
Randomness	0.75	4.50	3.38	3.33	2.50	0.67	0.50
Impact to Normal Operations	1.5	2.33	3.50	3.67	5.50	5.00	7.50
Improvement to Safety	2	4.33	8.67	3.83	7.67	0.67	1.33
			47.54		**54.25**		**39.17**

Rating Scale
1 - Least Effective
5 - Most Effective

Rating Scale
1 - Most Cost
5 - Least Cost

Environmental Interactions Explaination
Looking at how the environment surrounding (5 mi) an airport could be impacted through: loss of habitat (permanent or temporary), getting killed by an aircraft, and unintended damage to plants and animals
Fixed cost Explaination
Initail cost to obtain and install the system
Operational Cost Explaination
Costs associated with personnel (wadges/time), maintenance of system, updating the system, and minor damage to the system, or cost to fix aircraft
Training/Personnel Requirements Explaination
Time and resources to train personnel, that will operate the system, to have proper licencing, skills, and experience
Time to deter Explaination
Time to deter 80% of intended wildlife from the runway surface for aircraft operations
Versatility Explaination
Possiblility of implementing the system at multiple airports in different regions as well as potential use outside of the runway surface environment
Weather Explaination
Ability of the system to operate under inclement weather (precipitation, high winds, low visibility, low ceiling) conditions.
Public Visual Impact
How the system appears/impacts to the public within the airport and surrounding areas (5 mi).
Public Noise Impact
How the noise of the system impacts the public within the airport and surrounding areas (5 mi).
Life Cycle Explaination
The duration of time the system is uable before replacement is needed.
Randomness Explaination
Variety of system operations or methods (lights and/or visual) to deter wildlife.
Impact to Normal Operations Explaination
Operations in the current airport environment are not negetively affected through the implementation of the system
Improvement to Safety
How the system will improve runway surface safety for users and wildlife (mitigatin strikes on runway surface)

Table 2. Modified decision matrix to evaluate a ground based and aerial system assuming sUAS integration in the airport environment is achieved and sUAS technology has reached anticipated evolution.

Wildlife Mitigation on Runway Surface							
		Aerial System		Ground Based System		Do nothing	
Category/Topic	Weight	Rating	Score	Rating	Score	Rating	Score
Environmental Interactions	1.5	3.67	5.50	4.33	6.50	3.00	4.50
Fixed cost	0.5	3.00	1.50	2.67	1.33	5.00	2.50
Operational Cost	0.5	2.67	1.33	3.67	1.83	2.00	1.00
Training/Personel Requirements	0.5	2.00	1.00	3.33	1.67	4.67	2.33
Time to Deter Animals	1.5	2.83	4.25	3.50	5.25	1.33	2.00
Versatility (implementation)	1	4.00	4.00	3.33	3.33	2.67	2.67
Weather	1	2.33	2.33	3.67	3.67	3.00	3.00
Public Visual Impact	0	3.00	0.00	3.67	0.00	2.67	0.00
Public Noise Impact	1.25	3.00	3.75	3.67	4.58	2.00	2.50
Life Cycle	0.5	3.50	1.75	4.00	2.00	4.33	2.17
Randomness	0.75	4.50	3.38	3.33	2.50	0.67	0.50
Impact to Normal Operations	0	2.33	0.00	3.67	0.00	5.00	0.00
Innovation	1.5	5.00	7.50	2.00	3.00	0.00	0.00
Improvement to Safety	2	4.33	8.67	3.83	7.67	0.67	1.33
			44.96		**43.33**		**24.50**

Changes From Initial Decision Matrix	Description
Environmental Interactions	Lower weight because no unintended damage to plants and animals will be considered
Training/Personnel Requirements	Lower weight becasue assuming drone pilotage is common and less significat training required
Public Visual Impact	Lower weight because how the public will see and respond to the system will have changed
Impact to Normal Operations	Lower weight becasue assuming the question of how to implement into airport environment is answered
Innovation	Based on current systems, what would be more innovative?

07 Description of Technical Aspects

07.1 sUAS Hazard Detection System Overview

The sUAS hazard detection system includes three phases that build off one another with anticipated sUAS technology evolution. The primary objective of the sUAS hazard detection system is to identify wildlife hazards at an airport and mitigate the hazard before potential life threatening incidents occur. A figure outlining the sUAS hazard detection system is presented in Figure 2.

07.2 Phase 1

Phase 1 is the first step of the sUAS hazard detection system which incorporates current sUAS flying practices and assumes new regulations regarding sUAS use at airports that provide greater accessibility for operations. According to current regulations, the use of drone technology is prohibited while aircraft are taking off and landing; however, the regulations are expected to adapt as drone technology advances. The focus of Phase 1 is to identify wildlife hazards at the airport and notify the proper personnel to take action. In Phase 1, a sUAS will fly over the runway surface and identify wildlife hazards on or near the runway surface using thermal imaging and computer vision. Upon identification of a hazard, the proper personnel will be notified. The personnel will then initiate hazard mitigation efforts. The sUAS will be piloted by a human operator and will be utilized when wildlife hazards are expected (migration periods), prior to flight operations, and randomly to identify possible hazards. Hazards will be identified using a thermal imaging sensor and high resolution camera on the sUAS. The area of identification will include the runway surface and the runway safety area which are defined on airport ALPs and can be determined through AC 150/-5300-13A. Personnel notified of wildlife presence may include air traffic controllers, operations managers/employees, or airport managers depending on the classification and personnel at the airport. The personnel will receive a notification displaying the hazard location on an aerial map of the airport. Mitigation of the wildlife hazard will consist of existing methods used by the airport.

	Phase 1	Phase 2	Phase 3
Overview	1) The sUAS flies over the runway surface and identifies wildlife hazards. 2) Upon identification of wildlife hazard, the system notifies the personnel of the hazard. 3) Upon notification, the personnel initiates deterrence efforts.	1) The sUAS flies over the runway surface and identifies wildlife hazards. 2) Upon identification of wildlife hazard, the system notifies the personnel of the hazard. 3) The sUAS initiates deterrence efforts.	1) The sUAS flies over the runway surface and identifies wildlife hazards. 2) The sUAS initiates deterrence efforts. 3) The system will subtly notify the personnel of the deterrence efforts.
	Details		
System Initiation	• Piloted by a human • Used when wildlife hazards are expected • Used randomly to identify potential hazards	• Piloted by a human • Used when wildlife hazards are expected • Used randomly to identify potential hazards	• sUAS is fully autonomous • Initiates flights when wildlife hazards are expected • Initiates flights randomly to identify potential hazards
Identification	• sUAS is retrofit with a thermal sensor and computer vision to identify	• sUAS is retrofit with a thermal sensor and computer vision to identify	• sUAS is retrofit with a thermal sensor and computer vision to identify
Identification Area	• Runway Surface • Runway Safety/Object Free Area	• Runway Surface • Runway Safety/Object Free Area	• Runway Surface • Runway Safety/Object Free Area
Notification	• Map indication of hazard location • Direct message to personnel	• Map indication of hazard location • Direct message to personnel	• Map indication of hazard location • Subtle message to personnel
Personnel	• Air Traffic Control • Airport Employees/ Management	• Air Traffic Control • Airport Employees/ Management	• Air Traffic Control • Airport Employees/ Management
Mitigation Efforts	• Use of current mitigation efforts	• sUAS is retrofit with a noise/light deterrence system	• sUAS is retrofit with a noise/light deterrence system

Figure 2. Table summarizing the characteristics of the sUAS Hazard Detection System.

07.3 Phase 2

Phase 2 builds off of Phase 1 and incorporates further anticipated technology evolution. The focus of Phase 2 includes identifying wildlife hazards, notifying the proper personnel, and initiating deterrence. Similar to Phase 1, a sUAS will fly over the runway surface, identify wildlife hazards, and notify the personnel of the hazard. Expanded from Phase 1, the sUAS will initiate deterrence upon identification. Phase 2 changes from Phase 1 with a retrofitted noise and light deterrence system on the sUAS to mitigate the hazard without the need for human intervention.

07.4 Phase 3

Phase 3 builds off Phase 2 and further incorporates anticipated technology evolution. Phase 3 focuses on autonomously identifying wildlife hazards and deterring the hazard. Phase 3 assumes technology has adapted such that autonomous sUAS flights are safe and can be performed in the airport environment. Similar to Phases 1 and 2, Phase 3 includes an autonomous sUAS to fly over the runway surface and identify wildlife hazards. The sUAS will then initiate deterrence and notify personnel of the hazard. Different from Phases 1 and 2, Phase 3 is fully autonomous and flights will be randomly initiated and can be externally initiated when hazards are expected. Additionally, the personnel notification will become more precise as the sUAS is mitigating the hazard.

07.5 sUAS Technical Aspects

Thermal imaging and computer vision are utilized concurrently by the sUAS to identify wildlife, with the technologies identifying heat signatures and interpreting the detection, respectively. A past challenge with animal surveillance procedures was the inability to detect wildlife when vegetation, ground depressions, or other visible obstructions were present. Thermal imaging relies on thermal contrast instead of visual contrast and is effective up to medium height vegetation. Large areas including vegetated land around the pavement are scanned using thermal imaging (Karp 2020). Computer vision is a growing technology that uses stored data to identify people, wildlife, or objects; however, computer vision is sensitive to visual obstructions causing part of the contour of an object to be covered. In this sUAS hazard detection system, the sUAS has visual identification information for different wildlife and sifts through the information until the wildlife hazard is identified. Computer vision will be mainly used for detecting wildlife on the runway surface with no vegetation obstruction and can differentiate between wildlife, airport staff, and other things present on the runway surface. Once wildlife is detected, the cartesian coordinates of the location will be sent to the computer program which uses the coordinate to output readable information to proper personnel.

07.6 Environmental Implications

A sUAS hazard detection system at airports can impact wildlife and vegetation. The sUAS-bird collision rate is expected to be lower than 6 percent because the sUAS does not have the intention to collide with birds. Safety precautions and prevention strategies to be implemented include protective rails to reduce collision risk and severity. Implementation of a sUAS hazard detection system will have some impact on wildlife's behavior however its purpose to increase safety outweighs the negative effects of introducing the sUAS into the airport environment.

Changes in vegetation and other aspects of the environment are expected due to the absence of wildlife deterred by the sUAS. It is important to note that the absence of specific wildlife can attract other wildlife to the area. Maintenance of the grounds could potentially increase if wildlife are not using the vegetation as a food source. Additionally, sUAS in the airport environment adds noise pollution; however, the present noise generated at airports is significantly greater than the noise created by the sUAS. The environmental implications of the sUAS hazard detection system in an airport environment should be recognized however the benefits brought by this system significantly increase the safety of passengers and airport staff.

07.7 Sample Notification

The sUAS hazard detection system is focused on integrating sUAS technology into the airport environment. A notification interface alerts personnel when wildlife is detected and displays pertinent information. Figure 3 is an example of a notification.

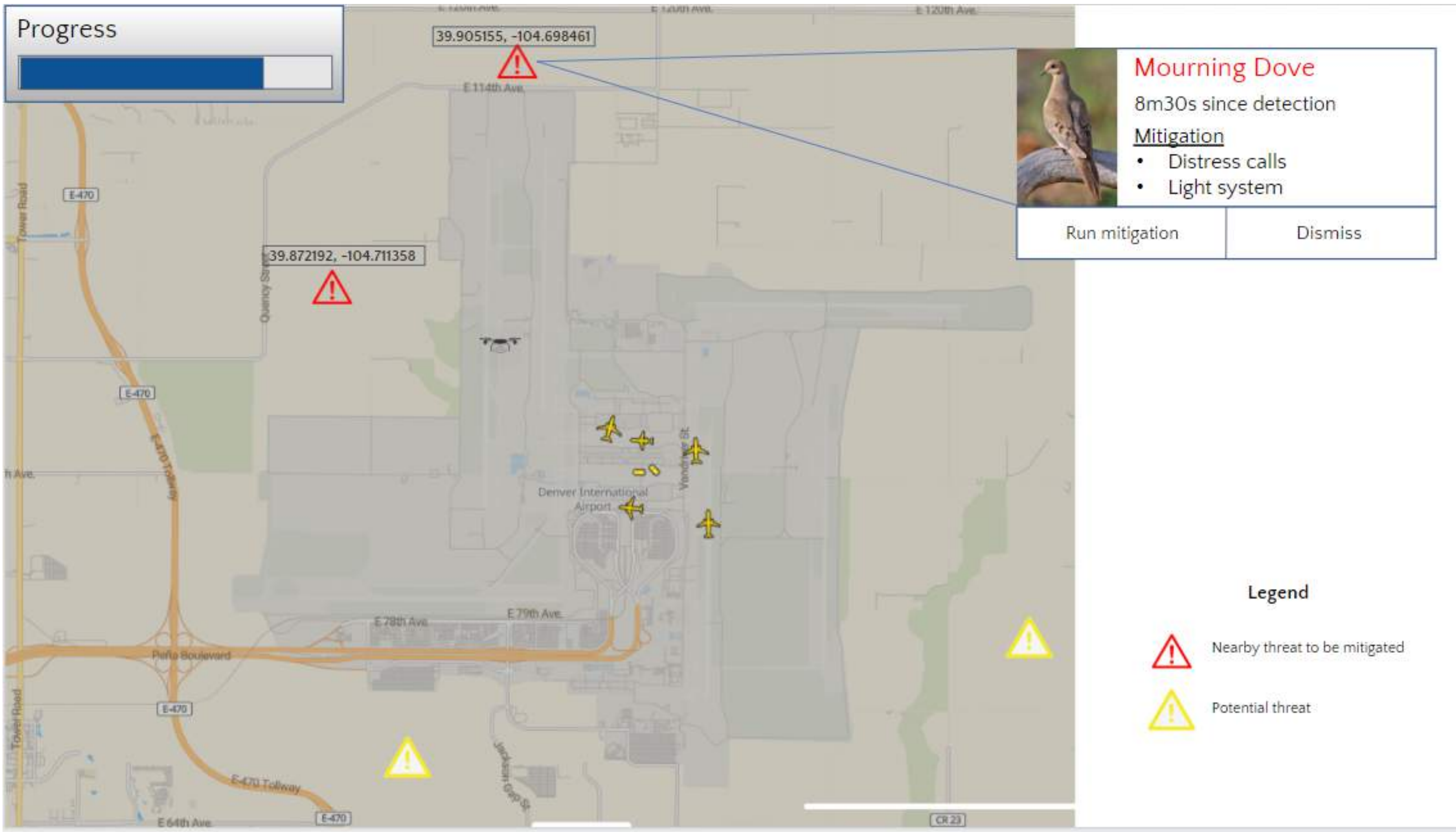


Figure 3. A sample notification displaying interpretable data retrieved by the sUAS technology for personnel.

Notification alerts include the type of wildlife, an image of the wildlife, time elapsed since detection, and effective mitigation techniques. Also provided are the cartesian coordinates and a color-coded pin symbol indicating the location on an airport aerial map. A red symbol indicates a high safety risk, a yellow symbol indicates a lower safety risk. The distinction between red and yellow changes depending on the individual airport layout and size. The wildlife type and image is displayed in a box when a specific pin symbol is pressed or hovered on with a cursor. There is a dismiss button at the bottom in the instance the wildlife is deemed to not be a safety risk.

The notification interface has fundamental differences based on the phase. Phase 1 is utilized for wildlife detection and notification alerts only. Phase 2 detects and provides notification alerts with the mitigation button option to manually start deterrence capabilities. Phase 3 autonomously detects, alerts, and mitigates the wildlife risks. The notification interface is delivered with factory default settings. Options are embedded in the software for custom tailoring the settings to align with an airport's specifications. For example, the proximity criteria for red versus yellow symbol color can be adjusted. Export options are available to assist with tracking time and location of repeat wildlife detections that may warrant additional deterrent measures. Adaptation of the notification interface from a computer program to an application can be performed if there is a need in the future.

08 Safety Risk Assessment

08.1 Defining the Risk of Project

Maintaining safe practices and techniques is vital and important to the FAA. Mitigating wildlife strikes and interactions increases the safety of passengers and staff at airports. While mitigating wildlife increases safety, studying and controlling the additional risk associated with the mitigation technique is critical. The safety risks of the sUAS hazard detection system can be divided into three categories: (1) sUAS malfunction, (2) wildlife, weather, foreign interference, and (3) human impact. The human impact can further be broken down into airport staff impact and passenger and general public impact.

A malfunction of the sUAS would result in the greatest safety risk and could create the most severe consequences. Loss of control of the sUAS could cause a collision with an aircraft, humans, equipment, or buildings. The sUAS could enter the air space when aircrafts are taking off or landing resulting in the aircraft needing to maneuver around the sUAS possibly causing additional safety risks. Data and video footage collected by the sUAS would be valuable and sensitive information, which could become compromised. Having the sUAS or software hacked is a possibility. A false negative reading, the sUAS not identifying wildlife present, and a false positive reading, the sUAS identifying wildlife that are not present are potential situations. There is a chance of a malfunction in either the auto landing feature or the autonomous feature (present in Phase 3). Power or mechanical failures are additional risks. A frequency interference or a jammed signal are possible malfunctions that could occur. Having accessory components of the sUAS including the camera, deterrent capabilities (present in Phases 2 and 3), and coordinate/location capabilities malfunction can happen.

Wildlife colliding with the sUAS is a situation that must be considered even though the purpose of the sUAS is to deter animals. Birds can be attracted to the lights on sUASs causing a collision to be more likely. There are risks associated with flying the sUAS in adverse weather including strong winds and heavy precipitation. Weather could cause a lack of control of the sUAS resulting in collision with an airplane or human. Fog or high humidity could decrease the visibility and increase the risk of an unintentional collision. Extreme temperatures could put strains on the equipment and increase risk for premature failure. Paved runways generate a considerable amount of heat in sunny conditions and could overheat the sUAS equipment. There is a risk of a foreign sUAS entering the airport property and interfering or colliding with the airport's sUAS.

The safety risk for airport staff mainly focuses on interference with normal operations. Interference can be in the form of the sUAS physically getting in the way of a task or additional audible noise produced by the sUAS could distract ground staff. Any additional lights from the sUAS could interfere or become a distraction, especially if the light is flashing or at night. The sUAS's surface could reflect light and create more of a distraction if the surface is glossy in appearance. Staff may also see sUASs as a form of surveillance monitoring and tracking their normal operations and they could be concerned if they make a mistake, which is caught on camera. For passengers and the general public, unfamiliarity with a sUAS in this environment would be the greatest safety risk and could create concern and questions. A sUAS would create additional noise and visual distractions. The public could view the sUAS as a further invasion of privacy because a machine with a camera is recording what is going on.

08.2 Mitigation Strategies

To help reduce the safety risk in the event of the sUAS malfunctioning, an auto landing system will be programmed. The auto landing feature will automatically turn on if the frequency or signal is lost or jammed for more than a specific duration of time or the sUAS flies into a region outside of its boundaries. The auto landing system will be an autonomous feature not requiring human interaction. An abort switch will be present in the Air Traffic Control (ATC) tower and with the personnel flying the sUAS (in Phase 1 and 2). Resolving the risk of the equipment or software being compromised is challenging. Incorporating regular security software and updates, encrypting past collected data and information, plus an abort switch that can drop the sUAS at it's current location will further reduce this risk. In addition to the auto landing feature and abort switch, daily routine inspections will be conducted on the equipment to reduce the risk for mechanical, power, or accessory failures. Daily inspections will include a check of: mechanical parts, power and battery conditions, camera, location/coordinate calibration (with sample locations), deterrent mechanisms (present in Phases 2 and 3), communication check with ATC and necessary personnel, and general observation for material fatigue or wear. The sUAS will not be flown unless it passes the daily inspection. Attention to battery condition reduces risk of failure mid flight.

Some features of the sUAS can be altered to reduce the risk and severity of damage caused by interactions with wildlife. Specific levels of color contrasts and intensities have been found to more effectively deter various wildlife. Specific contrasts and intensities vary depending on the species and type of bird (Goller et al., 2018). Individual airports can consider the birds they wish to mitigate and choose colors accordingly. The sUAS will be programmed with the ability to perform defensive maneuvers to prevent a wildlife collision. If the collision cannot be avoided or prevented, implementation of rail guards on the sUAS will reduce the severity of a collision. The best way to reduce safety risks due to adverse weather and temperatures is to initially choose a sUAS designed for the environmental conditions for which it will operate. Sensors can be installed on the sUAS to send a message to ATC if a component is overheating during flight. If the sUAS detects the presence of a foreign sUAS within the geographic boundary, it will send a message to ATC and the necessary actions will be taken to mitigate the situation.

Informing airport staff is an important step in keeping them safe. Education would focus on how the drone would function performing its normal duties and operations, and what will likely be seen. Seeking a design with quieter running noise will reduce risk of distracting airport staff and adding noise to the airport environment. The exterior surfaces will have a matte finish to reduce risk of reflections. Lights on the sUAS could distract staff, especially at night; however, the lights indicate to others the presence of the sUAS (anti collision lights) and removing these lights would pose a greater safety risk. The longer the sUAS is present in the airport environment, the more accustomed the staff will become of the sUAS and the less of a distraction it will be to them. The best way to reduce the safety risk for passengers and the general public would be to keep them informed about the use of sUASs as wildlife deterrents. Information, pamphlets and signs on the walls at various locations within the airport should be available where people are waiting and often stationary. The public and passengers would be educated on what is normal to see and hear and how this is contributing to their safety. Emphasizing the improvement to safety for both humans and wildlife will help passengers and general public understand how sUAS technology is providing benefit.

08.3 Safety Risk Matrix

Table 3 lists the safety risks associated with the sUAS hazard detection system and labels their severity and probability of occurrence with a number and letter combination corresponding to a specific square on the Safety Risk Matrix in Figure 4. The Safety Risk Matrix considers the likelihood and severity of a potential situation occurring to and assigns the safety risk accordingly.

Table 3. Potential safety risks assigned safety ratings by likelihood and severity of incident.

Risks	Severity and Occurrence Rating
sUAS Malfunction	
Hacking	4E
False Negative	4E
Auto Landing Feature Malfunction	3D
Autonomous Feature Malfunction	3D
Mechanical Failure	3C
Power Failure	3C
Coordinate/Location Capabilities Malfunction	4B
Accessory Components Failure	4B
False Positive	4B
Signal/Frequency Malfunction	3B
Wildlife, Weather, Foreign Interference	
Collision with Wildlife	4C
Adverse Weather Conditions	4C
Extreme Temperatures	5C
Foreign sUAS Interference	3B
Human Impacts	
Distraction for Airport Staff	3B
Passenger/General Public Confusion	1A

sUAS Hazard Detection System		Severity				
		Insignificant (A)	Minor (B)	Moderate (C)	Major (D)	Catastrophic (E)
Likelihood	Almost Certain (1)	1A	1B	1C	1D	1E
	Probable (2)	2A	2B	2C	2D	2E
	Possible (3)	3A	3B	3C	3D	3E
	Unlikely (4)	4A	4B	4C	4D	4E
	Rare (5)	5A	5B	5C	5D	5E

Figure 4. Safety Risk Matrix used to evaluate potential situations to determine the safety risk.

As noted above, hacking is the greatest safety concern. Even after implementing safety measures, it is still possible but unlikely. Although unlikely, the consequences could be catastrophic. False positive and negative wildlife detection readings would be less severe and a false negative reading is more likely than false positive. Malfunctions of the autonomous and auto landing features are not likely to occur however could create catastrophic consequences. Daily inspections significantly lower the likelihood of a mechanical, power, or accessory failure; however, they are still possible. The likelihood of the location calibration malfunctioning is unlikely since the sUAS uses GPS to navigate and run. Weather related incidents are rare due to careful attention to weather conditions and monitoring to ensure safe flying conditions. Additionally, planes are not flown in extreme weather conditions and sUAS do not need to be flown when flights are not occurring. The likelihood of a foreign sUAS entering airport property is unlikely due to heavy regulations and fines associated with trespassing enforced by the FAA. The likelihood of distraction from workers and staff is very likely but minor in its severity. After the discussed safety measures are in place, no risk is within the red section of the Safety Risk Matrix.

09 Cost Benefit Analysis

09.1 Cost Analysis

The total monetary costs incurred in the sUAS hazard detection system can be divided into implementation and maintenance costs. As previously described, the ideal sUAS system to mitigate wildlife at airports includes thermal imaging sensors to allow wildlife detection around the airport from a greater distance. A high resolution camera is necessary to detect hazards within the computer vision field and work in conjunction with thermal imaging to help detect and identify wildlife and appropriately mitigate. The team spoke with Dr. Ricardo Eiris Pieria, a faculty member at Michigan Tech whose research interest is in sUAS technology. Eiris provided knowledge on drone technology, including using DJI models since the FAA requires American drone manufacturers. An example sUAS camera used in the sUAS hazard detection system is the DJI Zenmuse XT2. The XT2 is designed for commercial use and has a thermal sensor and 4K lens. The XT2 would be attached to the Matrice 600 Pro sUAS aircraft from DJI, which has a high battery life making it ideal for on-demand deployment. The average purchase costs of the XT2 and Matrice 600 Pro are $10,300 and $6,600 respectively, for a total of $16,900 (Shenzhen DJI Sciences and Technologies Ltd, 2021).

Time investment in operator training is also essential for commercial sUAS usage. Certification is required based on the FAA's sUAS rule, which involves completing a written test to obtain an sUAS pilot's certificate. Guidelines that commercial sUAS pilots are expected to follow include keeping the aircraft within their view at all times, maintaining a maximum altitude of 400 feet above ground level, and avoiding flying the aircraft directly over individuals or under a covered structure (Federal Aviation Administration, 2016). The cost of this training is the time it takes for sUAS pilots to learn the various rules and regulations necessary to be able to safely operate an sUAS device. The cost to train staff to operate sUAS technology is about $2000 (DartDrones, 2021).

Maintenance costs of the system after installation should also be considered. It is crucial to keep all components of the sUAS hazard detection system functioning at all times. The costs of maintenance involve replacement or repair of sUAS hardware for both the sUAS and attached camera system. These components include but are not limited to motors, GPS system, sensors, sUAS filters, and antennae. Quotes from DJI's "Repair Component Price Inquiry" for various components of both the XT2 and Matrice 600 Pro estimated the average repair costs totals to around $1,300 for each (Shenzhen DJI Sciences and Technologies Ltd, 2021).

09.2 Benefit Analysis

The sUAS hazard detection system will decrease the cost airports spend on wildlife strike damages. The FAA Wildlife Hazard Management at Airports manual reports that over a 14-year period, a total of 52,000 reported wildlife strikes at US airports over a 14-year period annually amounted to $7 billion in damage costs and 7 million hours of lost flying time (Federal Aviation Administration, 2005). As listed earlier, the sUAS hazard detection system costs about $20,200 per year for a single sUAS unit including training and maintenance costs; this is significantly less than the costs that would be incurred from the accidents and incidents that the system is designed to help prevent.

The Denver International Airport (KDEN) recorded the most bird strikes of any commercial airport in the US, largely due to its location along a main migratory corridor for several bird species. A total of 4,245 strikes were logged at KDEN from 2008 to 2018 (Embry Riddle Aeronautical University, 2020). Based on unit cost estimates from the FAA Wildlife Hazard Management at Airports manual, KDEN loses $736,000 and 470,000 flying hours due to wildlife strike incidents.

Even though the airport is responsible for the cost of the sUAS hazard detection system, the airport and airlines both benefit from its use. Airlines face fewer wildlife strikes which increases safety and reduces total cost on the damages. Airports will appear safer to the public eye and receive higher customer satisfaction ratings, increasing revenue.

09.3 Comparison with Alternatives

The cost of current wildlife mitigation strategies at many airports, will largely depend on the specific airport and the degree to which they use current techniques. There are cheap mitigation techniques such as the use of plastic owls, however they are not effective in the long run. Some of these existing methods can also be expensive, for instance training predatory falcons to drive away animals that can cause wildlife strikes can cost up to $100,000 per bird used, according to former USAF member Darren Daniels who works with bird hazards in aviation. Often large airports wait to mitigate wildlife until after severe wildlife incidents occur and cause a negative impact for all stakeholders involved. As shown in Table 5, The FAA sorts aviation incidents into three “mishap” classes based on the total cost of damage and long term consequences. In the decision to invest the time and money needed to set up a mitigation system such as an sUAS, airports should consider the statistics and likelihood of wildlife strikes in their area, especially those that can be classified as “A” or “B”, leading to severe damage, loss of life or injury, and significant financial costs. When the sUAS hazard detection system mitigates these serious incidents, the benefits far outweigh the implementation and maintenance costs of the system, as reliable and safe operation is always paramount.

Table 5: FAA aviation mishap classes with associated cost and characteristics. (FAA, 2005)

Class of Mishap	Total cost	Characteristics		
A	>$1,000,000	Fatality	Permanent total disability	Air Force aircraft destroyed
B	$200,000- $1,000,000	Permanent partial disability caused	Three or more people hospitalized	
C	$20,000- $200,000	At least one lost workday	Occupational illness causing absence from work	

10 Interactions with Airport Operators

10.1 John Wehner

John Wehner is the former airport manager at Fond du Lac County Airport, a non-towered field. He is also a pilot holding his private certificate and instrument rating. The team contacted Wehner in the initial research stage and asked him about wildlife mitigation practices in his experience. Wehner shared the biggest problems he has encountered were with geese and seagulls (large birds) and stated that the use of propane cannons was occasionally effective.

10.2 David Nelson

David Nelson is a Professor at Michigan Technological University (MTU) and was formerly a civil engineering officer in the USAF and worked for the Maine Department of Transportation in the aeronautics division. Nelson noted that in his experience seagulls were a problematic species as airports provided habitat, food, and water for them. Some current mitigation measures that Nelson noted were the use of sUAS, falcons, and sheepdogs.

10.3 Darren Daniels

Darren Daniels is the Assistant Director of Aviation - Facilities & Service Desk at Las Vegas McCarran International Airport. Daniels was formerly in the USAF for 28 years. During Daniels' time in the USAF he worked as a civil engineer. In his current position he works with bird hazards and specifically mentioned the effectiveness of falcons to mitigate bird hazards. Daniels gave other examples of mitigation strategies and discussed their downfalls. In the team's conversation with Daniels he emphasized the importance of taking a holistic approach to developing a solution to mitigating wildlife. He presented examples of when a newly implemented strategy effectively addressed a specific wildlife hazard but also created additional wildlife hazards.

10.4 Derek Rausch

Derek Rausch is a certified pilot who works in Iowa City and flies private charters around the country. Rausch provided insight into when he experienced wildlife interactions and bird strikes. At take off and landing he incurred most of the interactions including small bird strikes and deer and other wildlife on the runway. Rausch provided information about the vulnerability of the engines and windshields to bird strikes. Additionally, Rausch listed the birds he found to be most problematic which includes doves, vultures, and waterfowl. One specific bird strike incident he shared with the team happened to a plane he was scheduled to fly the following day, a bird struck the leading wing on departure and created significant damage to the plane.

10.5 Nate Fuller

Nate Fuller is the Executive Direction at Sarett Nature Center located in Southwest Michigan. Fuller provided insight and advice from a Naturalist point of view. The team reached out to Fuller initially to ensure all necessary factors and angles were considered when seeking a solution. Fuller stressed deterring one species can inadvertently attract another and shift the problem to another species.

10.6 Morgan Pfeiffer, PhD

Dr. Morgan Pfeiffer is a research biologist and ornithologist at the National Wildlife Research Center (NWRC) branch of the United States Department of Agriculture (USDA). Dr. Pfeiffer described her research on how human activity can affect movement of birds that cause wildlife strikes. Dr. Pfeiffer also explained how different species react to different mitigation methods, explaining that "one solution does not fit all" and research regarding how birds might respond to sUAS is still in its infancy. As such, a number of factors need to be considered in its design, such as how the birds perceive the sUAS in terms of risk. After initial research, Dr. Pfeiffer assisted in providing incite into the environmental implications of the sUAS hazard detection system, most notably, behavioral changes in wildlife due to sUAS presence.

10.7 Ricardo Eiris Pereira, PhD

Dr. Ricardo Eiris Pereira is an assistant professor in the department of Civil and Environmental Engineering at Michigan Technological University. His research interests include human-technology interaction and unmanned aerial systems. Dr. Eiris provided the team with an overview of the current sUAS technology that would be applicable to this project, such as thermal imaging and computer vision. Dr. Eiris also gave insight on the safety concerns associated with the team's solution such as battery life of the sUAS, likelihood of a false positive or negative, and potential hacking of the system. He pointed out that another important part of the solution is how the public might perceive sUAS systems. Positive public perception is vital to successful integration of sUAS technology at airports.

11 Projected Impacts

11.1 Meeting FAA Goals

The overall goal of the sUAS Hazard Detection System is to mitigate wildlife hazards prior to causing life threatening scenarios. As a part of the FAA Strategic Plan for 2019-2022, the FAA listed a strategic objective to improve safety. The objective strives to, “mitigate risks and encourage infrastructure and behavior change by using a data-driven systemic safety approach to identify risk, enhance standards and programs, and evaluate effectiveness” (FAA, 2019). The sUAS Hazard Detection System is designed to identify risks and mitigate them, thus improving safety. As the sUAS Hazard Detection System has the capabilities to send notifications to users, the system can be used to collect data on wildlife hazard frequency associated with a particular location on an airfield.

11.2 Other Potential Uses

Outside of the primary focus of mitigating wildlife hazards on the runway surface the sUAS Hazard Detection System can be used in other areas of the airport environment. As previously mentioned, the system can be used to collect data on wildlife hazards. Data such as wildlife hazard frequency at a particular location and times of increased wildlife hazards could be collected. The data could be used to improve mitigation practices, making airport users more aware of hazards, and overall improving airport surface safety. Additionally, the sUAS Hazard Detection System can be used in many other disciplines to identify hazards and collect data.

Appendix A

List of Complete Contact Information

Faculty Advisor:

Audra Morse, Ph.D., P.E., BCEE, F.ASCE, ENV. SP

Michigan Technological University

anmorse@mtu.edu

Students: The team consists of two undergraduate students. The undergraduate students are working on Bachelor of Science degrees in Civil Engineering.

Mihir Mehendale

Michigan Technological University, College of Engineering

msmehend@mtu.edu

Mary Ollis

Michigan Technological University, College of Engineering

meollis@mtu.edu

Other Student Contributors:

Kaitlyn Wehner

Michigan Technological University, College of Engineering

kmwehner@mtu.edu

Appendix B

Michigan Technological University is a four year public school located in Houghton, Michigan. The largest program at Michigan Tech is the College of Engineering, which includes 16 degrees. The university also has an enterprise program, which gives undergraduate students the opportunity to receive real world experience before entering a professional environment. Enterprise is student led and provides opportunities to apply skills learned in the classroom to real world problems in a variety of fields. There are 25 different enterprise teams, each with a different focus. The team pursuing the Airport Cooperative Research Program is part of the Built World Enterprise (BWE), which was established in the spring of 2019. Previously, the enterprise program lacked a civil and environmental engineering focused group. Hence, BWE was created to fill the need to address problems related to civil and environmental engineering.

Appendix C

Airport operators and industry experts contacted

Darren Daniels

David Nelson

Derek Rausch

John Wehner

Morgan Pfeiffer, PhD

Nate Fuller

Ricardo Eiris Pereira, PhD

Appendix D

See attached page that follows.

Appendix E

Student Questions

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

Yes, the ACRP competition was a meaningful experience as the team was able to learn about major challenges faced by airports and work with aviation professionals to construct an innovative solution.

2. What challenges did you and/or your team encounter in undertaking the competition? How did you overcome them?

The largest challenge in this project was narrowing down the solution. While the problem of wildlife presence at airports was clear from the start, the range of actions that can be taken to solve the problem, each with their own sub-goals was very broad and took additional time and thought in order to refine. A similar problem was faced when deciding on the final prototype design, with many options available. Contacts and professionals gave feedback on the feasibility of the solutions and helped us narrow down our solution.

3. Describe the process you or your team used for developing your hypothesis.

We utilized the design thinking model to refine the various topics we had researched and develop a solution. After choosing our topic of wildlife interference at airports, we contacted aviation professions to learn about their experience with wildlife and empathize with them. Using their feedback we defined our problem and started to ideate and brainstorm possible solutions. We narrowed down our solutions and created a prototype. We tested our prototype by receiving feedback from professionals and making changes accordingly.

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

Yes, experts in industry were very helpful throughout the course of the project. They provided personal incitement, further information into areas of the project, and provided a different perspective on the problem and solution. We received communication back from many of the professionals we reached out to in a timely manner.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

Through this project we learned about airport interactions with external stakeholders and the environment, as well as a major challenge actively faced in the industry today. Collaborating as part of a team, sharing ideas, communicating with experts outside of the organization, and conducting and presenting research are valuable skills gained from this project that pertain to what is expected in a professional setting.

Faculty Questions

l. Describe the value of the educational experience for your student(s) participating in this competition submission.

The students chose the topic to address, which pertains to wildlife mitigation on runways. This topic is significantly outside of the topics covered by the courses in the undergraduate civil engineering program curricular. As such, the students conducted research to learn why wildlife would be attracted to runways, strategies that would be effective, as well as the appropriate use of drones at airports. Absolutely, this experience provided a meaningful educational experience for these students.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?

Our participants are undergraduate students. As they are able to set the scope of work and the problem they solved, the learning experience was appropriate to the course level and context of the competition.

3. What challenges did the students face and overcome?

The students knew very little about drone use around airports and even less about wildlife mitigation strategies. Therefore, the learning curve to identify the problems as well as develop meaningful solutions was steep.

4. Would you use this competition as an educational vehicle in the future? Why or why not?

As long as students are interested in exploring challenges that exist at airports, I will continue to support their participation in the ACRP challenge.

5. Are there changes to the competition that you would suggest for future years?

One of the biggest challenges for us is infrastructure to connect to airport personnel. If more professionals were willing to support the students by answering questions, providing feedback on designs, and helping the students fully define the problem to be solved, the students will be more successful and will learn more in the process.

Appendix F

References

Airport Cooperative Research Program (2020). 2020-2021 Design Competition Guidelines. Retrieved from https://vsgc.odu.edu/acrpdesigncompetition/

Associated Press. (2008, June 17). Lizards, Jackals, Raptors Overtake Runway. CBS News. https://www.cbsnews.com/news/lizards-jackals-raptors-overtake-runway/

Baxter, A. (2000, April 21). *Use of Distress Calls to Deter Birds from Landfill Sites near Airports.* International Bird Strike Committee.

Beason, R. (2004) *What Can Birds Hear?.* Proceedings of the Vertebrate Pest Conference. US Agriculture & Natural Resources

Beaty, Kevin. "Planes Strike Far More Wildlife at DIA than at Any Other U.S. Airport, but It Could Be Worse." *Denverite*, Colorado Public Radio, 30 July 2018, denverite.com/2018/07/30/dia-wildlife-strikes/.

Cleary, E. & Dolbeer, A. (2005, July). Wildlife Hazard Management at Airports (2nd ed.). Federal Aviation Administration.

Dearden, L. (2014, November 7). Plane grounded after crashing into water buffalo on runway in India. The Independent UK. https://www.independent.co.uk/news/world/asia/plane-grounded-after-crashing-water-buffalo-runway-india-9847827.html

DartDrones. (2021). Professional Drone Pilot Package. https://secure.dartdrones.com/drone-pilot-training-package/

Embry-Riddle Aeronautical University. "DENVER INTL AIRPORT - KDEN Wildlife Strike Summary and Risk Analysis Report ." Center for Wildlife and Aviation, ERAU Prescott, 2020, wildlifecenter.pr.erau.edu/strike_index/KDEN.html.

Federal Aviation Administration. (2010, March 31). Bird / Other Wildlife Strike Report (Form 5200-7).

Federal Aviation Administration. (2016, June 21). Summary of Small Unmanned Aircraft Rule (Part 107).

Federal Aviation Administration. (2019). *FAA Strategic Plan: FY 2019-2022.*

Federal Aviation Administration. (2020, February 21). Hazardous Wildlife Attractions on or near Airports (Advisory Circular 150/5200-33C). Director of Airport Safety and Standards: John R. Dermody

Federal Aviation Administration. (2020, August 28). Wildlife Management. Retrieved November 30, 2020, from https://www.faa.gov/airports/airport_safety/wildlife/management/

Federal Aviation Administration. (2021, February 1). Small Unmanned Aircraft System (Small UAS) (Advisory Circular 107-2A). Deputy Executive Director, Flight Standards Services: Robert C. Carty

Federal Aviation Administration. (2021, March 11). Recreational Flyers & Modeler Community-Based Organizations. Retrieved April 13, 2021, from https://www.faa.gov/uas/recreational_fliers/

Fisher, J. (2020, January 29). Drone Regulations: What You Need to Know. PC Magazine. https://www.pcmag.com/news/drone-regulations-what-you-need-to-know

Goller et al. (2018), Assessing bird avoidance of high-contrast lights using a choice test approach: implications for reducing human-induced avian mortality. PeerJ 6:e5404; DOI 10.7717/peerj.5404

Hamershock, D. (1992, April). *Ultrasonics as a Method of Bird Control*. Air Force Systems Command

Karp, D. (2020, March 23). *Detecting Small and Cryptic Animals By Combining Thermography and a Wildlife Detection Dog* (Rep. No. 5220). doi:https://doi.org/10.1038/s41598-020-61594-y

National Transportation Safety Board. 2010. *Loss of Thrust in Both Engines After Encountering a Flock of Birds and Subsequent Ditching on the Hudson River, US Airways Flight 1549, Airbus A320-214, N106US, Weehawken, New Jersey, January 15, 2009.* Aircraft Accident Report NTSB/AAR-10/03. Washington, DC.

Outay, F., et al. (2020, September 18). *Applications of Unmanned Aerial Vehicle (UAV) in Road Safety, Traffic and Highway Infrastructure Management: Recent Advances and Challenges.* Retrieved November 30, 2020 from https://doi.org/10.1016/j.tra.2020.09.018

Pan, Y. et al. (2019). *Safe and Efficient UAV Navigation Near an Airport.*

Rebolo-Ifrán N, Graña Grilli M, and Lambertucci SA (2019). Drones as a Threat to Wildlife: YouTube Complements Science in Providing Evidence about Their Effect. Environmental Conservation 46: 205–210. doi: 10.1017/S0376892919000080

Sedunov, A., Salloum, H., Sutin, A., Sedunov, N., & Tsyuryupa, S. (2018). *UAV Passive Acoustic Detection.* Cornell University Library.

Shenzhen DJI Sciences and Technologies Ltd. (2021). Repair Component Price Inquiry. Retrieved March 18, 2021 from https://repair.dji.com/repair/price-inquiry

US Department of Agriculture. (2020, August 17). Airport Wildlife Hazards Program. Retrieved November 30, 2020, from https://www.aphis.usda.gov/aphis/ourfocus/wildlifedamage/pr ograms/SA_Airport