Eagle Eye

Design Challenge Addressed:

Airport Management and Planning

Team Members:

Benjamin Travelyn: Undergraduate

Grace Sanita: Undergraduate

Scott Liguori: Undergraduate

Julian Andriulli: Undergraduate

Advisor:

Bahram Nassersharif, Ph.D.

University of Rhode Island

2017 - 2018 Academic Year

April 23, 2018

Executive Summary

This report outlines the concept generation, design, testing, and implementation process of a drone-based automated inspection system. This project was completed for submission in the ACRP Design Competition and for the University of Rhode Island Mechanical Engineering Capstone Design Course. Throughout the course of the year the team was sponsored by their Professor and faculty advisor, Dr. Nassersharif, and worked closely with their airport sponsor, the Rhode Island Airport Corporation.

The category chosen for the competition is the Airport Management and Planning category and the "planning for the integration and mitigation of possible impacts of drones into the airport environment" subcategory. The team addressed this subcategory with a solution that automates the daily inspections for runway and taxiway lighting as well as airport perimeter and security of a General Aviation (GA) airport using a drone. The final design was created and validated using Westerly State Airport to complete calculations and perform flight tests. The design is scalable and transferable with the ability to adapt to other GA and private airports, and potentially larger airports. The team demonstrated the adaptability and versatility of the design by also testing the system at Newport State Airport.

The design requirements include automating aspects of the daily airfield inspection process and significantly reducing the required man hours to complete the respective inspection tasks. Typical perimeter and security inspections and lighting inspections take approximately one hour to complete. The automated inspection process demonstrated in this project completes each inspection in under 20 minutes. The system uses a video recording feature attached to the drone so that inspections can be logged and archived as well as used as evidence in the event of an incident such as a crash. The design allows for ease of use with a low learning curve to implement and operate the system for different airports.

The costs for implementing the system are \$4,017. After implementation, airports will save \$23,233.5 the first year of operation and \$27,250.5 each year thereafter.

Table of Contents

1 Problem Statement and Background

Within the past few years drones have become pervasive. With this popularity comes potential problems for airports as has been demonstrated in multiple instances with drone invasion into restricted airspace. However, the developing technology also has the potential to benefit airports. For this reason, the design team decided to explore potential benefits of drone integration into airports, and to compete in the ACRP Design Competition. The team chose the category of Airport Management and Planning with a focus on the challenge of planning for the integration and mitigation of possible impacts of drones into the airport environment.

After meetings with the Rhode Island Airport Corporation and concept generation, the team defined the problem as identifying a process and method to automate the daily inspections for runway and taxiway lighting, and perimeter and security of a General Aviation (GA) airport using a drone. Central to the solution was the ability of the design to be adaptable and scalable to 139 airports. The design was created and validated using Westerly State Airport to complete calculations and tests, with the ability to adapt to other GA airports, private airports, and potentially larger airports (139 airports) if a drone with a long range is purchased. The process of utilizing an unmanned vehicle to optimize the daily inspection process was designed and tested to determine the routes and distances that resulted in the highest efficiency of inspection tasks. General aviation airports are used for this project due to their relatively small size, low traffic rate, and inaccessible areas that can be reached using a drone. GA airports generally have fewer resources to perform inspections which will cause the automation of the process to have a greater impact.

The current and only method for daily airport inspections is either driving or walking around the airport to manually check all of the inspection points. This is a very time consuming activity. Typical perimeter and security inspections and lighting inspections take approximately one hour to complete. The proposed automated inspection process can complete the inspections in under 20 minutes. Utilizing a GoPro on the drone, inspections have the ability to be logged on record for completion of the inspection tasks and can be used as evidence in a legal argument in the event of an incident, such as a casualty or crash. Along with this, the drone provides the ability to inspect inaccessible areas of airports that would otherwise not be inspected on a daily basis. The design allows for ease of use with a low learning curve to implement the automation process for different airports for the workers operating the system. Using the newly designed method, man-hours can be reduced and used for other activities in the airport, saving time and money. Also, if an anomaly is identified during an inspection in a hard to reach area, then the drone can be manually flown to the inaccessible area in the airport to be investigated.

The use of drones in and surrounding an airport within five miles of airspace is restricted by the FAR small Unmanned Aircraft System (UAS) Part 107, and requires authorization by both the state and the airport. Due to this restriction, the team was provided with two Operational Directives by the Rhode Island Airport Corporation, that granted the team permission to fly the drone used in this project in Westerly State Airport and Newport State Airport. In addition, other airports have been granted permission by the FAA to utilize drones for wildlife management and construction purposes. The Hartsfield Jackson Atlanta International Airport used a drone to 3D map a large construction site, and Bult Field, a general aviation airport in northeastern Illinois, is protecting the pilots and aircraft by deploying drones to harass and keep wildlife away from the airfield [1] [2]. These instances provided precedence and proof of the willingness of airport officials to invite drones into their airspace for official airport business.

The purpose of this design work is to utilize the advantages of a drone to decrease inspection time and airport operations, downtime while increasing the inspection accuracy and significantly reducing man hours, saving the airport money and increasing the visibility of inaccessible and hard to reach areas. Major airports could use the process to decrease runway shutdown time and optimize airport operations for the aircraft and passengers. The objective of the project is to demonstrate the usefulness of drones in a positive manner in airport operations to the FAA. With the increase in popularity of UAV's and improvements to the technology, drones need to be implemented into airport operations as the aviation community should be working with developing technologies, not against it.

2 Summary of Literature Review

2.1 Literature Search

Reading available literature kept the team up-to-date on the current drone market and status of problems at airports. The team read articles, books and reports relating to the use of drones in airport environments, new and old drone technology, and wildlife reports. Along with technical documents, the team made use of the press and media to survey current trends in the drone market.

The test drone first considered by the team was the IRIS, manufactured by 3DR. The IRIS is one of the most commonly known lower cost but high quality drones on the market. To learn more information on the technical aspects of the drone and its potential feasibility for use in the team's process, a number of external sources were researched. One article," Announcing Iris, a totally ready-to-fly UAV quad-copter with our next- gen autopilot" [3] was chosen as a valuable source. The article describes the press release announcing the mass market availability of the Iris drone while discussing some of its new-at-the- time features. These features include the full GPS-guided autonomous capabilities and the "out-of-the-box" flying experience. The announcement also boasts about the wide angle between the front arms to provide a clear view for the attached camera, and about the easily and inexpensively replaceable parts. The team used this press release as a tool to compare the Iris drone to other drones currently on the market. The article provided a quick and concise list of the higher-end features of the Iris drone. The team then later switched to the newer version of 3DR's drone, the 3DR Solo.

While it was not the main purpose of the automated inspection design process, wildlife harassment is a potential supplemental use of the drone system. Due to newly implemented use of a drone, research into wildlife harassment was also undertaken by the team, and a report was identified on drone usage to manage wildlife entitled "Bult Field Puts Drone Technology to the Test for Wildlife Management" [1]. This article describes the new use of drones as a tool for wildlife detection and harassment at the Bult Field (C56), a corporate/general aviation airport in northeastern Illinois. The article states that the airport has partnered on the project with Hanson Professional Services to alleviate some of the responsibilities placed upon the airport man- agers. The drone system includes a thermal imaging camera to help detect and identify wildlife based on their size and movement patterns. The article also includes a quote from William Viste, project coordinator, Illinois Aeronautics Division, stating," Drones can be valuable tools in many capacities from survey/mapping, infrastructure inspections, emergency response and visual assessments." The article goes on to describe a possible drawback of the drone system: the possibility that the wildlife will get used to the drone flying around. However, this drawback is not unique to drones. Wildlife also become accustomed to other methods of harassment. The article proved to the team that the FAA and general aviation airports are ready to welcome drones into their atmosphere. This article also proved to the team that focusing on the problem of the harassment of wildlife would not advance the field of drone integration into airport operations. This is because the Bult Field and Hanson Professional Services have more resources in both money and manpower, and therefore are better suited to continue the pioneering of using drones for this purpose.

In order to optimize drone safety during lower altitude inspections, the design team conducted an array of different flight tests and research to confirm the safest and optimal flying conditions for the drone. In addition to the testing, the team set values for drone input height, distance from inspection targets, and speed needed to support quantitative analysis. As a component of the preliminary necessary research for the analysis, the design team studied a series of articles detailing information about methods of generating and calculating optimal lift, ranges of values for wind gradients, drag coefficients, and lift coefficients as well as air density relative to humidity and partial air pressure. This allowed the team to identify the safest drone input height, speed, and distance from inspection target values and back our flight path system reasoning with quantitative analysis [4] [5] [6].

2.2 Patent Search

Any creative and practical product design requires research, brain storming, and accumulation and utilization of ample knowledge. Consequently patent searches are an absolute necessity in the creative process. As engineers it is important to know what has already been developed in order to understand the competition and to know how avoid copying a preexisting design. Patent searches also teach us about relevant subject matter and can assist immensely in the development process.

In the proposed design, much of the inspection process is reliant on clear and efficient video surveillance. Therefore patent research on various types of inspection systems and video surveillance became a necessity as the project progressed. One of the most useful patents found to date, Patent 20180103206 entitled "Mobile Camera and System With Automated Functions and Operational Modes" authored by Erlend Olson, detailed a devised system, device, and method for conducting surveillance of activities through autonomously captured video [7]. The patent further describes a detailed method of capturing and transmitting video that can then be configured to analyze the video in a variety of modes, including relayed streaming video and video/frame transmittance based on time intervals. This helped fortify the teams existing ideas and process design for drone-based video surveillance, combining previously devised process methods by the team with the time interval and live stream video capturing techniques described within the patent.

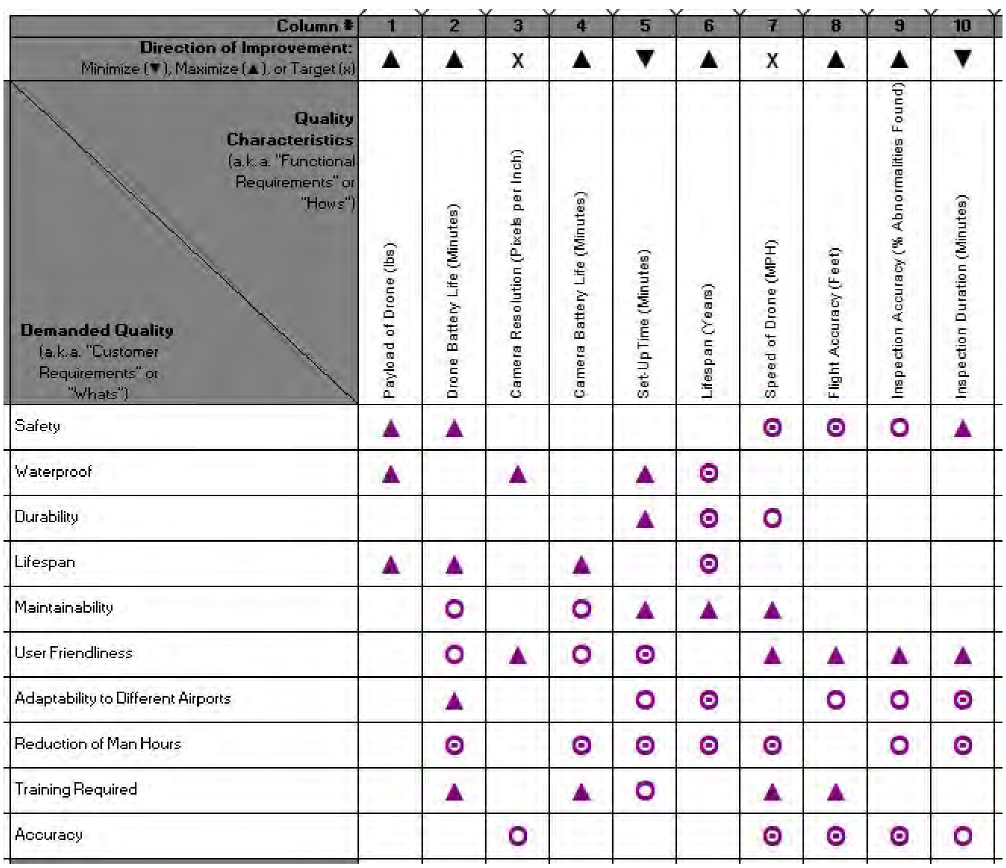
In conjunction with the aforementioned patent, additional research was also required on the combination of known methods of surveillance and video analysis with drone flight and path creation. As a prime example of a correlated drone implementation system, the EagleView drone-based property inspection process was heavily researched. EagleView is a rather well-known patent (patent 20170330207), that combines CAD, inspection, and building guideline data for analyzing building structures and the subsequent repair decisions that should be implemented based on the structural analysis provided by the drone inspection system [8]. The drone is able to automatically generate a flight path around a structure, and then captures visual data for future software analysis. This approach was one of the factors that inspired the design team to attempt a variation of an automated drone flight path and inspection, but within a different environment with greater ease of use and for lower cost. This helped lead to the streamlined automated drone-based inspection process that we devised, assigning a flight path relative to the relatively consistent geography of general aviation airports.

3 Team's Problem Solving Approach

3.1 Concept Generation and Selection

The team began the year by meeting with the Rhode Island Airport Corporation (RIAC) to discuss ideas that they believed would benefit airports. From this, the team decided to work with drones and chose the category of Airport Management and Planning with a focus on the challenge of planning for the integration and mitigation of possible impacts of drones into the airport environment. The team defined their problem as how to integrate drones into airports in a positive way. The process began the four team members each developing 30 design concepts. The concepts were thoroughly thought out and once completed the team reviewed the 120 concepts and created a final list of five designs that would provide the best possible solution and outcome to the team's problem definition. Once the best concept was chosen, the team defined their problem as how to automate daily inspections for runway and taxiway lighting and perimeter and security of a General Aviation (GA) airport using a drone, with the potential of extension to 139 airports.

The team then completed a Quality Function Deployment (QFD) Analysis to determine customer requirements and engineering characteristics of the design and their relationships to one another. The customer requirements chosen were safety, waterproof, durability, lifespan, maintainability, user friendliness, adaptability to different airports, reduction of man hours, training required, and accuracy. The engineering characteristics that were chosen were to maximize the payload of the drone, maximize the battery life of the drone, hit the target for the camera resolution, maximize the camera battery life, minimize the setup time of the system, maximize the lifespan of the system, hit the target for the speed of the drone, maximize the flight accuracy, maximize the inspection accuracy, and minimize the inspection duration. Figure 1 below shows the relationship between the customer requirements and the engineering characteristics. This helped the team identify which engineering characteristics best satisfied which customer requirements.



Column #	1	2	3	4	5	6	7	8	9	10
Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▲	x	▲	▼	▲	x	▲	▲	▼
Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Payload of Drone (lbs)	Drone Battery Life (Minutes)	Camera Resolution (Pixels per Inch)	Camera Battery Life (Minutes)	Set-Up Time (Minutes)	Lifespan (Years)	Speed of Drone (MPH)	Flight Accuracy (Feet)	Inspection Accuracy (% Abnormalities Found)	Inspection Duration (Minutes)
Safety	▲	▲					⊙	⊙	○	▲
Waterproof	▲		▲		▲	⊙				
Durability					▲	⊙	○			
Lifespan	▲	▲		▲		⊙				
Maintainability		○		○	▲	▲	▲			
User Friendliness		○	▲	○	⊙		▲	▲	▲	▲
Adaptability to Different Airports		▲			○	⊙		○	○	⊙
Reduction of Man Hours		⊙		⊙	⊙	⊙	⊙		○	⊙
Training Required		▲		▲	○		▲	▲		
Accuracy			○				⊙	⊙	⊙	○

Figure 1: Relationship between customer requirements and engineering characteristics

After the concept generation and QFD Analysis, the team created design specifications to be met to achieve a successful design. A shortened version can be seen below in Table 1. The team knew that there were certain customer requirements that must be met, such as following procedures for safety, creating a user-friendly system, creating a system that can adapt to other airports, reducing man hours used for inspection and designing a durable and maintainable system that is accurate. The drone that will be used is the 3DR Solo, with the GoPro Hero 4 Black camera attached. The system is operated with the use of the Tower app on a Samsung Galaxy tablet. This is where the flight paths are programmed and saved. The tablet will be connected to the drone and the saved flight paths can be opened and sent as a mission to the drone in order to conduct the inspections.

Table 1: Design specifications

Parameter	**Specification**
Hardware	- 3DR Solo Drone - GoPro Hero 4 Black Camera - Samsung Galaxy Tablet - Alfa WiFi Antennas
Software	- Tower App - 3DR Solo App - GoPro Quik App
Key Performance Targets	- Automation of inspection tasks - Complete inspection <20 min. - Little to no human involvement
Customer Requirements	- Ability to stop and land drone at anytime during inspection - Ability to log inspection videos - Clear videos to easily detect inspection items
Safety / Legal Requirements	- Only flown when Notice of Airmen (NOTAM) is issued - Abide by FAA UAS Part 107 - Operational Directive provided to team by RIAC

3.2 Design and Testing

There are two steps in the process design. The first step is defining the actual process that will be used for setting up the drone, conducting the inspections, bringing down the drone, and analyzing the video. The second step is designing the automated flight path that the drone will fly to complete the inspection.

The design of this process began by creating a brainstormed list of the most essential points of the process stemming from an extensive QFD analysis. These points were then organized in chronological order in terms of importance, and under each point subprocess points were generated to isolate the sections that could be optimized further to facilitate overall efficiency. These points were divided into four steps; setting up the drone, con- ducting the inspection, bringing down the drone, and analyzing the video from the inspection. As a component of optimizing the drone set up, the team reviewed the users' manual for the 3DR Solo drone and identified what information and drone functions were necessary and what ones could be eliminated. After much consideration as a result of analyzing the Critical Path Analysis, it was decided that a vast majority of the drone set-up steps could be completed before the first inspection in a preliminary fashion. As a result, the drone could be stored in its flight ready position to save significant time for all subsequent inspections. This then allows the first process point to be streamlined into a simplified two sub step method. This consists solely of the inspector bringing the drone outside to the designated take off point, and then attaching and turning on the battery and GoPro camera. After the Android tablet is turned on, the drone and tablet can be connected and the flight path for the perimeter or the flight path for the runway and taxiway lights can be chosen. Once the path is chosen, then the user selects "Auto Flight", and the drone flies through the path and once finished, it returns to its original takeoff location. When the drone has returned to the takeoff location, the inspector simply needs to turn off the drone equipment, and carry the equipment back inside for storage. Inside the main building, the battery from the drone and the GoPro may be removed and plugged in to be charged, and the micro SD card from the GoPro can be removed and plugged into the computer. When the SD card is in the computer, the "GoPro Quik" application can be launched and the videos can be uploaded and reviewed. These videos will automatically be logged by date and time on this application for future reference. After this task has been completed, the micro SD card can be removed and placed back into the GoPro for its next use. The updated flow chart after the critical path analysis is presented below in Figure 2.

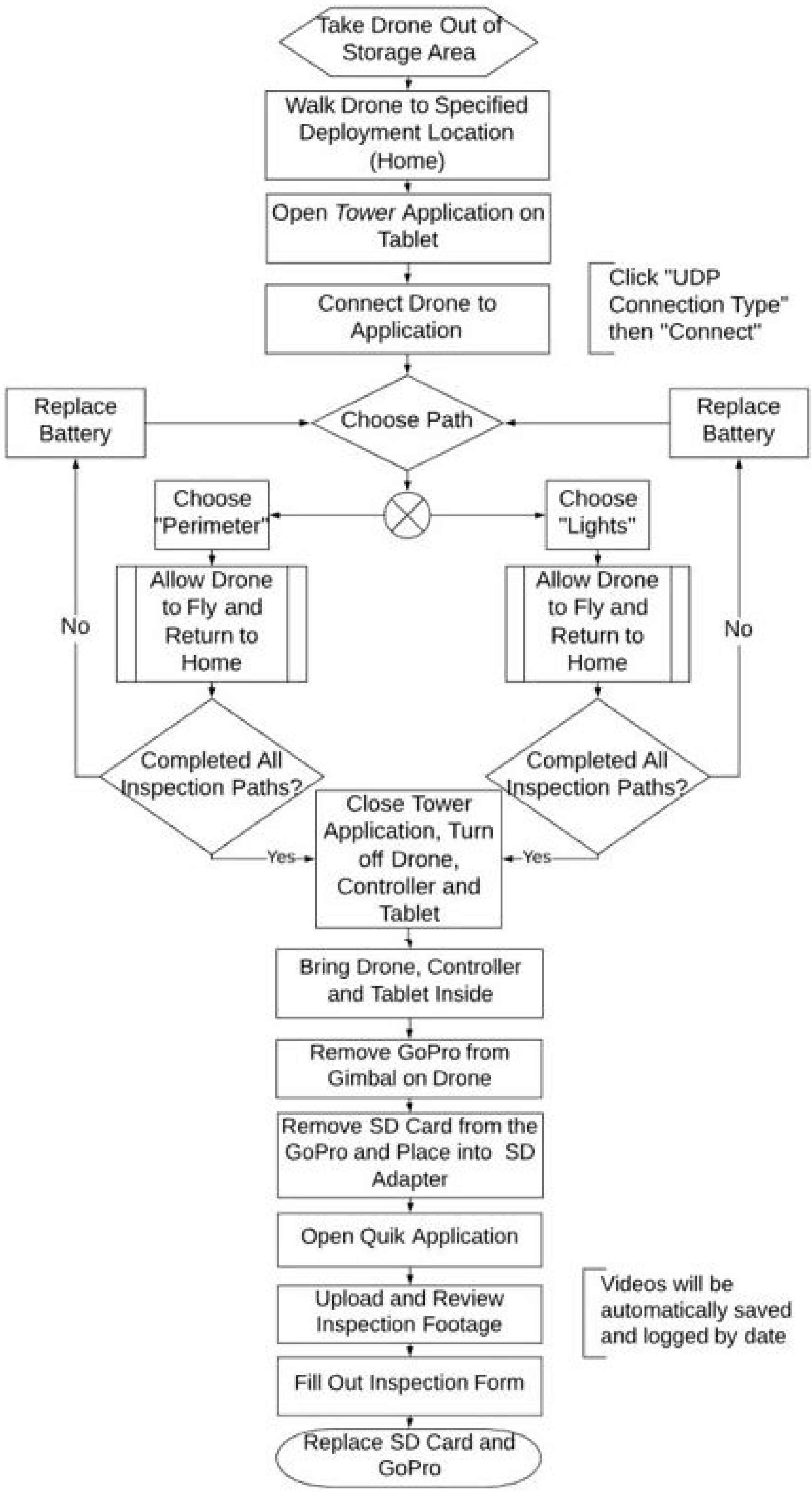


Figure 2: Updated process flow chart after Critical Path Analysis

The second step in the process is designing the automated flight path that the drone will fly to complete the inspection. This process began with proving the concept that the drone can clearly and visibly see what it will be inspecting at high speeds. The team proved this concept by flying the drone in a field along the tree line at various heights, speeds, and distances and all of the videos came out clear and the inspection points could all clearly be seen. In addition, the team used the equation speed is equal to distance divided by time to determine the time it will take the drone to complete the inspections. This calculated to under 15 minutes. These tests were completed with a 3DR Iris drone and a GoPro Hero 4 Black. The team practiced flying this drone and practiced flying autonomous flight paths using the Android Tower app. Once the team was comfortable using this, the teams faculty advisor Dr. Nassersharif, provided them with a more powerful drone to use, the 3DR Solo drone.

After the concept was proven, the team went to Westerly State Airport with Rhode Island Airport Corporation (RIAC) Chief Aeronautics Inspector James Warcup to conduct test flights at the airport. Currently, drone flight in an airport is restricted by FAR small Unmanned Aircraft System (UAS) Part 107, but the team was provided with two Operational Directives by RIAC which gives permission to fly the drone in Westerly State Airport and Newport State Airport. Once at the airport, the team needed to determine the optimal height, speed, and distance for the drone to be flown at for the perimeter and security and the runway and taxiway light inspections. To do this, the team manually flew the drone at various heights, speeds, and distances along the tree line perimeter, fence perimeter, and the runway and taxiway lights. The values that were tested are presented in Table 2. To ensure tests were successful, all variables but one were held constant to ensure the optimal test feature was chosen. Along with these, the camera field of view was tested for the perimeter and for the lighting. It was determined that a narrow field of view for the lights is best due to how small the lights are. It was also determined that a medium field of view for the perimeter would be used to optimize between narrow and wide, allowing for wide visibility but not being very narrow on an object. It was also determined that the GoPro will record in 1080p at 60 fps, for high definition quality but less storage space than higher definitions.

Table 2: Test Parameters

Inspection Item	**Parameter**	**Test Range**
Runway/ Taxiway Lighting	Altitude	3, 5, 10, 15, 20 ft
	Speed	10, 20, 25, 30 mph
	Distance	5, 10, 15, 20 ft
Perimeter (Fencing)	Altitude	10, 15, 20, 25 ft
	Speed	25, 30 mph
	Distance	5, 10, 15, 20 ft
Perimeter (Tree Line)	Altitude	40, 50, 60, 70 ft
	Speed	25, 30 mph

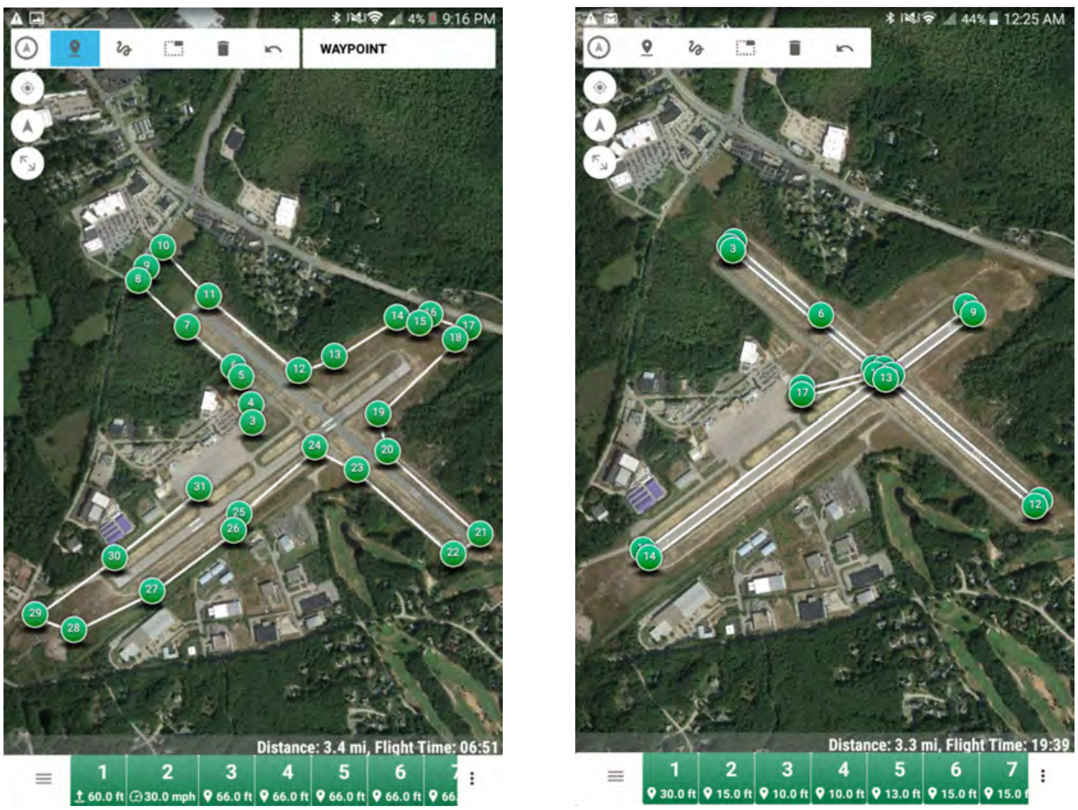
After these test flights were completed, the videos were analyzed and the optimum values were chosen based on visibility and room for variation of drone flight. Once the optimal parameters were chosen, each test and flight parameter was approved by James Warcup, to ensure and guarantee the quality of the inspection videos. The optimum values that were chosen for the altitude, speed, and distance from target are shown below in Table 3. While conducting the test flights for the runway and taxiway lights, the drone was being flown in 25 mph winds and was fluctuating in height by approximately three feet. Therefore, to verify that the drone would not crash into the ground while flying at seven feet, the team conducted a lift force analysis of the drone (this full analysis can be seen in the Description of Technical Aspects Section). The lift force analysis showed that the best height and speed to be flown at is 30 mph and between 5-12 feet, so the team chose seven feet because if the height does fluctuate by three feet then the runway and taxiway lights will never go out of frame. Along with this, the team had 20 peers watch a video of the runway and taxiway lights in which 20 were in the video and four were off. The team had each of the 20 peers watch the video and determine how many lights were off, the mean ended up being 4.056, which verifies that the inspection process is successful.

Table 3: Test Results

Inspection Item	**Parameter**	**Test Range**
Runway/ Taxiway Lighting	Altitude	7 ft
	Speed	30 mph
	Distance	10 ft
Perimeter (Fencing)	Altitude	20 ft
	Speed	30 mph
	Distance	15 ft
Perimeter (Tree Line)	Altitude	60 ft
	Speed	30 mph

Once these values were confirmed to be the optimum values, the team created partial flight paths at the airport to further test these values. The team used half of the runway to test the lighting, one full length fence, and various tree lines to test the perimeter. After conducting these flights and analyzing the video and again showing it to James Warcup, it was approved. The team then moved to the next stage which was programming the full flight paths for the perimeter, security and runway and taxiway lights. First, the team programmed the full flight path of the perimeter and security inspection. After conducting this test, the path was slightly redesigned due to the flight path being very close to obstructions in the airport, such as obstruction poles. The flight path was slightly moved from these obstructions to ensure no crashes. After redesign, the perimeter and security inspection paths allow for an altitude and distance from target tolerance, increasing the processes safety factor. Second, the team programmed the full flight path for the lighting. After conducting these flights, the altitude of the flight path was slightly adjusted. The reason it was adjusted was because the altitude set is based on the home location, so the altitude of parts of the runway is slightly higher than the home location so the altitude had to be increased to ensure that the drone will not crash into the ground. The new altitude still has 100% visibility of the lights on the runway and taxiway lights. After the design and testing process there were slight redesigns incorporated in the design process. During initial design and testing, a significant focus was placed on the connection range of the drone to the home location. The team has implemented a low-cost solution by using Alfa WiFi Antennas to boost the WiFi signal from the controller of the drone. This attachment cost $20, making it an inexpensive add-on.

The flight paths were created using the Tower Android application. The perimeter flight path for Westerly State Airport is seen in Figure 3a and the runway and taxiway light flight path is presented in Figure 3b. On this application, the drone flies to preset way points. At each way point, the drone's height and speed can be changed, so the flight paths were planned according to the optimal height and speed for each inspection. After these specifications were created, they were saved so they can instantly be opened and set for the drone to fly this path. When the inspection is scheduled, the drone will be brought outside, the application opened and connected to the drone, and the flight path will be chosen and sent to the drone.



(a) Flight path for perimeter inspection

(b) Flight path for light inspection

Figure 3: Flight paths at Westerly State Airport

After the flights were completed at Westerly State Airport, the team went to Newport State Airport to demonstrate the adaptability and versatility of the system. The team conducted full flight paths here as well, which were successful. The flight path for the perimeter of Newport State Airport can be seen below in Figure 4.

Figure 4: Perimeter flight path at Newport State Airport

On the following page Figure 5a and Figure 5c show runway lights that are off and Figure 5b and Figure 5d show runway lights that are on and the difference can clearly be seen. Figure 6a shows the fence line along the perimeter and the fence can clearly and visibly be seen. The tree line perimeter can clearly and visible be seen in Figure 6b. Another integral aspect to the design is that once an inspection is completed with the drone and the video is watched, if an anomaly is identified, the drone can manually be flown out to that point to determine what it is and if an individual has to drive to the point of investigation. This would then save the potential time that would be used to determine what the anomaly is. While conducting test flights the team demonstrated this feature by showing an open airport gate and inspecting a dead deer found on the airfield. Photos of these incidents these can be seen below in Figures 7a and b. Also, in many GA airports there are inaccessible and very hard to reach areas by car, but easy to reach with the drone as illustrated below in Figures 8a and b.

(a) Red runway light off **(b)** Red runway light on **(c)** White runway light off **(d)** White runway light on

Figure 5: Examples of runway lights on and off

(a) Fence in perimeter inspection **(b)** Tree line in perimeter inspection

Figure 6: Example of fence and tree line in perimeter inspection

(a) Open gate **(b)** Dead deer in airfield

Figure 7: Example of failing inspection points

(a) Inaccessible area

(b) Second inaccessible area

Figure 8: Example of inaccessible areas during inspection

In addition to identifying the aforementioned instances of inspection and security breaches, the team used the drone to harass wildlife out of the airfield. The team harassed multiple flocks of birds out of the airfield and a pack of turkey vultures eating the deer.

4 Safety Risk Assessment

Every organization, including airports, has a Safety Management System (SMS). This formal process is how companies and organizations control safety risks and optimize safety risk mitigations [9]. Within an organization's SMS, safety management tools include assessing the risk and controlling risk [9]. The proposed design of automating the inspection process with the use of a UAV comes with inherent safety risks which are within an acceptable risk level with designed mitigations when necessary. The team has completed a Safety Risk Assessment (SRA), a formal process within a SMS to evaluate potential hazards using the risk matrix from the FAA's AC 150/5200-3 [10]. The first step in an SRA is to describe the system. The proposed design is to automate the inspection of the runway and taxiway lighting, and perimeter and security of a general aviation airport using a UAV. The second step is to identify hazards of the system. Risks include losing signal or control of the UAV and the potential of a collision with aircraft, poles or trees. The first mitigation taken to significantly reduce risk is to issue a Notice to Airmen (NOTAM) which will alert pilots that a drone is in the airport airspace and aircraft are prohibited from landing until the inspection is complete and the drone is secured. The NOTAM will be issued by the airport operator conducting the inspection or by the airport manager. The final design mitigation in place in the inspection process is to give the Airport Manager or Operator the discretion to stop or land the UAV when aircraft enter the Class E airspace within 5 miles of the airport. The combination of the design mitigations stated above serve to reduce the level of risk into acceptable levels with additional mitigations used to further minimize risks.

4.1 Loss of Signal

The first hazard of the system is if the UAV loses its signal connection during an inspection. The drone has a "Return to Home" feature which is activated when the signal is lost for any reason and the drone automatically returns and safely lands at the starting position determined by the airport operator. The likelihood of losing connection to the drone is low as the drone will always be flown within its signal range, as designed in the team's process. To boost the 3DR Solo range, Alfa WiFi Antennas were purchased to increase the range from 2,640 ft to 5,280 ft, ensuring the range is greater than the 3068 feet length of the farthest point from the airport base to the end of the farthest runway and perimeter point. The severity of this hazard is low as no planes will taking off or landing during the time of the inspection and the only risk is to the drone itself. This hazard falls within an acceptable level of risk with the designed mitigations. For future considerations, the team suggests airports should purchase and conducts inspections using a drone with acceptable flight ranges for their desired inspection areas.

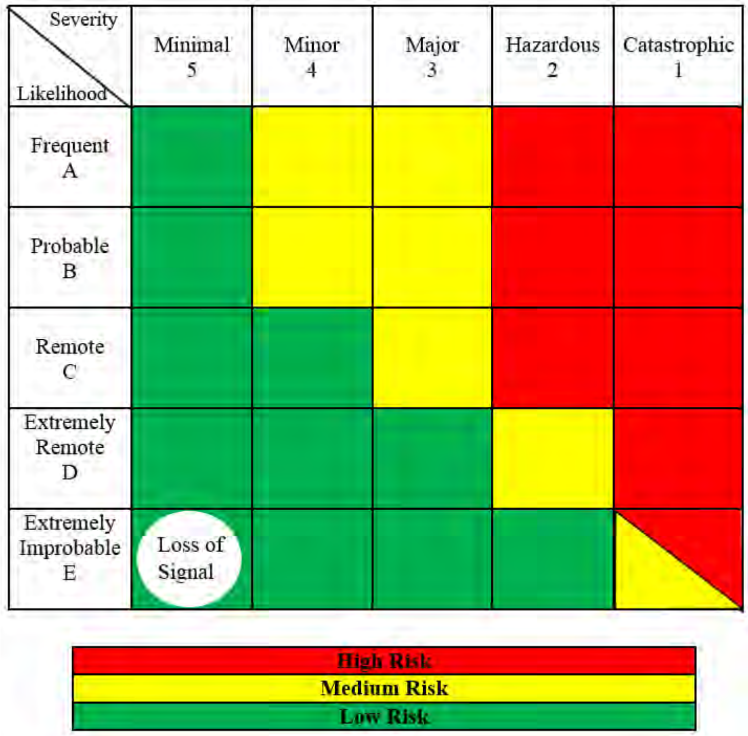


Figure 9: Risk Assessment Chart 1

4.2 Loss of Control of Drone

The second hazard is the potential risk of losing control of the drone and it flying outside of the programmed flight path. The likelihood of this happening is very low because the drone accuracy to follow the programmed flight path is extremely high. The severity is low because no aircraft will be in the airspace, and the drone will be in the eyesight of the operator at all times during the inspection. To control any risk if deviation does occur from the programmed path, the airport operator will be able to pause the drone flight and activate a "Pause" or "Land Safely" feature on the drone's app. Once the path has been stopped or drone has been landed, the operator can manually take control to fly the drone back to the start location or simply press the "Return to Home" button. The inspector can either restart the inspection from the beginning or continue where it left off.

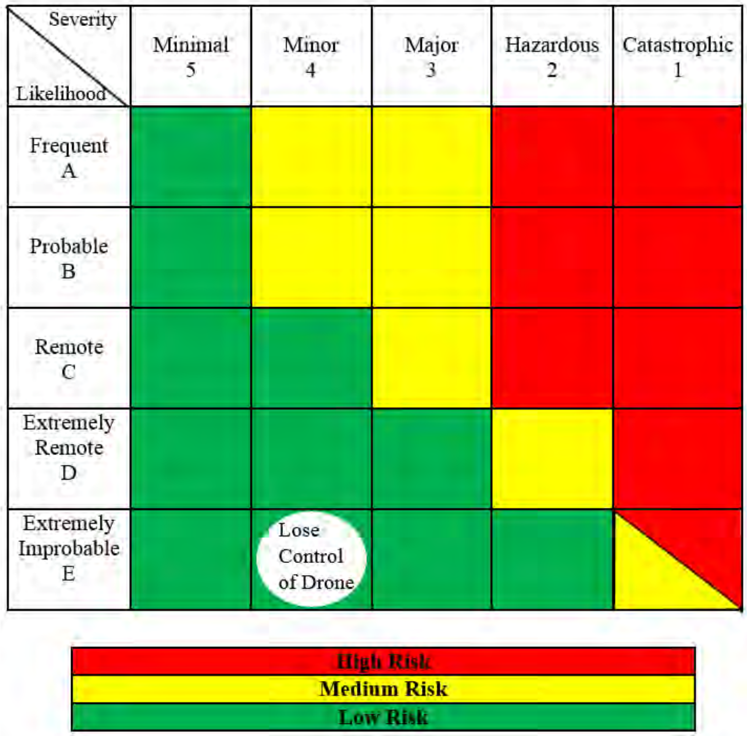


Figure 10: Risk Assessment Chart 2

4.3 Drone Crash

The third hazard is the potential risk of a drone crash. To control this risk to practical levels, there are several mitigations in place. Since the drone is a consumer product with already existing commercial safety tolerances in place, the likelihood of a crash event is significantly reduced. A NOTAM must be issued before any use of the drone to alert aircrafts of the presence of an UAV at the airport and the inspected runways and areas must be shut down to ensure absolutely zero air traffic volume will occur during inspections. In addition, the drone will also be in the airport operator's constant line of sight, who can visually inspect the surrounding airspace for aircraft, who must radio signal to alert other pilots and airport operators when they use the airport runway. The airport operator has full discretion and complete control to stop, land or return the drone back to the start position. The drone's app includes these safety feature to stop and land the drone at any point during the inspection. These designs mitigate the severity of a crash event and significantly reduce its likelihood of occurring. The highest risk for a crash event is that the drone hits a pole or tree while being manually controlled by the airport operator.

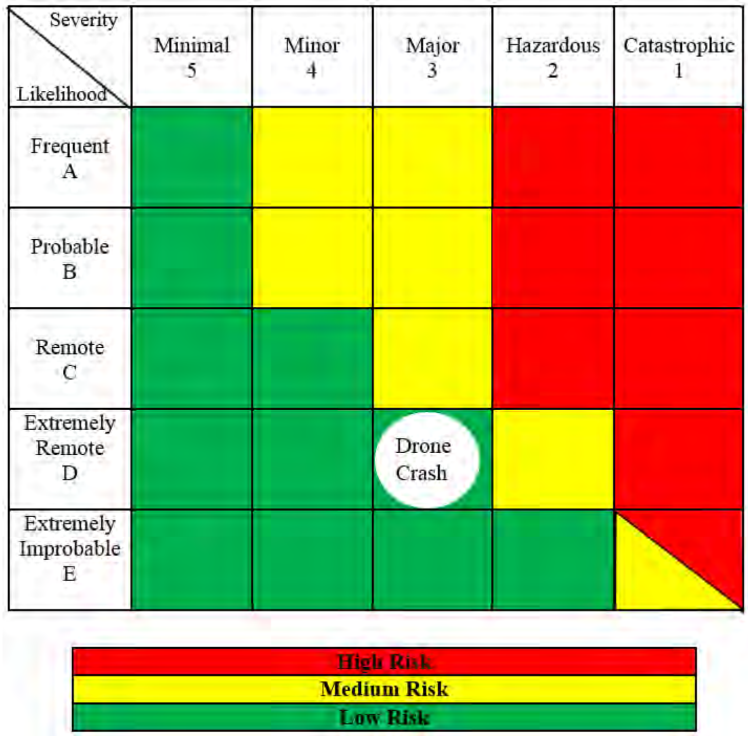


Figure 11: Risk Assessment Chart 3

After reviewing all safety hazards and completing a full Safety Risk Assessment, the automated inspection design using an UAV complies with the FAA's AC 150/5200-37, the Introduction to Safety Management Systems (SMS) for Airport Operators [10].

5 Description of Technical Aspects

Throughout the design and testing process, various types of engineering analysis were used to optimize the design and to verify and prove the design is successful and optimized. First, the critical path method was used to optimize the full process and to eliminate unneeded process steps. Next, a lift force analysis of the drone was conducted to verify that the height and speed chosen for the lighting inspection is the safest and most optimal. Lastly, a statistical analysis for the lighting video was completed to verify that the method is validated and that the difference between a light that is on or off is accurately identified.

5.1 Critical Path Method

Some of the main concerns while building a process revolve around time. Time spent waiting, time spent actively working and time saved are integral and quantifiable values that affect the applicability of a new process. Critical Path Method (Critical Path Analysis) was used to indicate where bottlenecking and overlapping tasks could affect the amount of time that the total inspection process takes. Earliest start times and latest finish times were used. The analysis indicated that the set-up and take-down procedures in the original process were non-critical tasks that were taking too much time.

Per the design specifications, the total inspection process shall take no more than 20 minutes per inspection. The flight path times for the perimeter and lighting inspections were calculated to be definitive times at 5.9 and 5.13 minutes respectively. Once the total inspection flow chart was analyzed, it was clear that the set-up and take-down times were non-critical processes. The set-up and take-down times took an average of 2 minutes and 38 seconds, therefore adding over 5 minutes to the total inspection. This non-critical time created a waiting scenario before the critical process of bringing the drone to the designated home location could begin. This step was timed at an average of 1 minute and 11 seconds. To reduce time and raise efficiency, the team has changed the process to one that assumes that the drone will be set up, with propellers in place at all times. This means that during the preliminary set-up and training of the process, the drone will be fully assembled. This will also be part of the training so the inspector will be able to take apart the drone and put it back together in case parts need to be changed. The drone manufacturer's user manual will also be provided for additional assistance. This limits the day-to-day set-up and take-down times to the critical portions, including changing and charging batteries, and removal and replacement of the SD card. The updated process flow chart after the critical path analysis can be seen in Figure 2.

If and when the automated inspection process is adapted to a larger airport, the team can replicate this analysis to determine where shorter, partial inspections of runway and taxiway lights can be used throughout the day. These partial inspections can be used in larger (139) airports to limit runway shutdown time by fitting the inspections into the schedule of flights.

5.2 Drone Lift

One of the results that the design team found during testing was the UAVs susceptibility to altitude change during times of high wind speeds (25 mph). The team found that despite mostly horizontal wind currents acting on the drone, the drone did not actually have its position vary greatly in the horizontal direction, and inspection item visibility changes were negligible based on the horizontal position variation. However, variations in the vertical direction were much more severe, sometimes varying by three feet. As can be assumed from this observation, the variation of height from the original input altitude implies that the lift force allowing the drone to stay evenly suspended is also variable. In order to better understand the multi variable effects resulting in an insubstantial lift force, the magnitude of the lift force was studied as a function of the drone input speed and height. Lift is also a function of air density which is dependent on air temperature and the partial pressures of dry air and water vapor. To isolate these two key variables and avoid the usage of overly complex tensor matrices, air density was discretized for ambient conditions of dry air at 20 degrees Celsius with an atmospheric pressure of 101.325 kPa.

To achieve a better practical understanding of the resulting drone lift, the general lift equation was graphed with the drone input velocity and the drone input height (z) within a discretized range of 0-13.14 meters per second (0-30 mph) and 0-9.14 meters (0-30 feet) respectively.

The reactive lift force (L) acting on a UAV in the positive z axis direction is given by the following expression:

$$L = 1/2 * \rho * (V^2) S * C_L \tag{1}$$

Where ρ is the density of air, V is the aircraft velocity, and C_L the coefficient of lift that determines the ability of the wing of area (S) to deflect a given air stream. In tandem with the calculation of the lift force, calculations for the wind velocity gradient will be expressed by the following equation:

$$V_z = v_g * (z/z_g)^(1/\alpha), 0 < z < z_g \tag{2}$$

Where V_z is the speed of the wind at height z, v_g is the gradient wind at gradient height z_g, and α is the exponential coefficient. From these equations and the subsequent calculations, the results can be seen below in Figure 12.

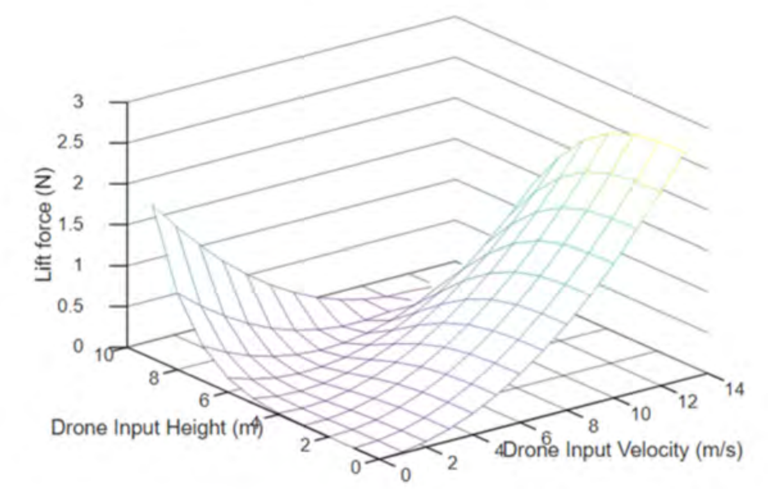


Figure 12: Plot used for drone lift

As can be clearly identified by the graph, there is a severe dip in the drone's lift force on a parabolic curve, indicating that the drone either needs to be at a high altitude with a low input velocity, or a lower altitude with a higher input velocity. By looking at the rightmost curve adjacent to the Drone Input Velocity axis, it can be seen that the lift force increases proportionally with the drone input velocity between the input heights of approximately 0-4 meters (0-13.12 feet). As discovered by the drone testing, dips of up to almost three feet may occur during periods of high intensity winds, forcing the optimal input height range to be from 2-4 meters (6.56-13.12 feet). As the lift force within this range due to altitude change is parabolic with 3 meters (approximately 10 feet) being the local maximum, the team chose this height as the most optimal input altitude for drone inspection. In addition, as the lift force increases proportionally with the drone input velocity, a max drone input velocity value of 13.41 meters per second (30 mph) was chosen. These settings will therefore allow for the inspections to be completed within the shortest amount of time, but with the largest factor of safety during periods of significant wind turbulence [4] [5] [6].

5.3 Statistical Analysis

In order to quantify the quality of a video-based inspection process, a test inspection video was created and shown to volunteers. Twenty volunteers watched the video while looking for lights that were off. The video that was used had a total of seventeen lights, of which four were off. After all of the volunteers watched the video, a statistical analysis was completed from the data. The mean, median, mode, and standard deviation were calculated based on the number of reported light outages by each observer. The results are presented below in Table 4.

Table 4: Results of Statistical Analysis

Mean	4.056
Median	4
Mode	4
Standard Deviation	0.639

The results for the median and mode were exactly four, which matched the number of lights that were off. The mean was 4.056 representing an error that was not statistically valid. Also, the standard deviation was 0.639, which quantifies successful results. If this system is implemented into an airport, then a trained airport inspector will be the one watching the videos. In this case, the inspector is far more knowledgeable with respect to what to look for in contrast to the volunteers watching the film with no prior training whatsoever. This shows that if someone with no prior training can determine if a light is off, a trained airport inspector will be able to do so without error.

6 Team Interactions with Airport Officials and Industry Experts

The team began the year by contacting RIAC officials to hold an initial meeting to discuss any outstanding inefficiencies concerning Rhode Island's airports. The team met with RIAC Chief Aeronautics Inspector James Warcup and Quonset Airport Manager Dave Lucas. Many ideas and concerns were discussed in the meeting using the ACRP University

Design Competition booklet as a facilitator of ideas. As a result, the team decided to pursue a project involving the integration of drones within an airport environment. From continued discussions with James Warcup and Dave Lucas, the team found that the most impact in improving the day-to-day management of an airport would be to facilitate and automate daily airport inspections using a drone. Mr. Lucas and Mr. Warcup provided the team with an inspection checklist and opinions about which inspection items would receive the most benefit from the automated process. With human factors in mind, including terrain hazards and task monotony causing complacency, it was decided that the automation would be best suited for the perimeter and security, and runway and taxiway lights inspections. The team defined the project as the automation of daily inspections for runway and taxiway lighting, and perimeter and security of a General Aviation (GA) airport using an unmanned vehicle.

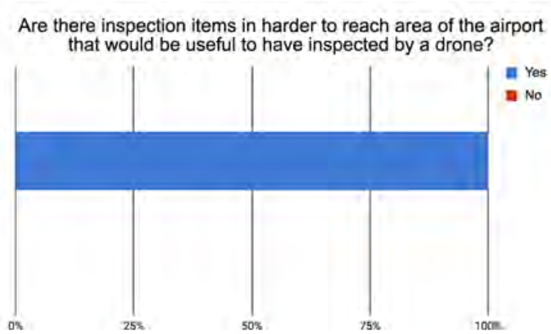
In addition to meeting with RIAC officials, the team was interested in speaking with drone experts and enthusiasts to hear their feedback about the practicability of using drones for an inspection. The team reached out to Cloud City Drones in Warwick, RI to meet with drone experts and technicians. The team met and spoke with Cloud City Drones employees, including Senior Technician Ian Schafron to present the project idea and to collect feedback and opinions. After introducing the team's idea of automating the inspection process, they agreed that is was potentially a transformative idea and said we should consider using a newer, more powerful drone if we planned to inspect larger airports such as TF Green Airport. This comment confirmed the team's decision to first focus on GA airports. The Cloud City employees also explained that fully waterproof drones with large ranges could be purchased if larger airports, or airports concerned about weather, decided to implement the automated inspection. The overall reception of the project was excellent, and the employees were excited to hear positive news about drones being welcomed into airports. Furthermore, the head of the corporate and educational division at Cloud City Drones, Christopher Williams, emailed the group offering training and guidance throughout the project's process.

To get better acquainted with the problem at hand, the team met with James Warcup and Westerly State Airport Operator Jim Cowley to tour Westerly State Airport. The team was escorted around the airfield and shown areal views of the property to better understand the obstructions and terrain that made many of the necessary inspections points inaccessible. Both Mr. Warcup and Mr. Cowley expressed how helpful it would be to fly the drone to these less-accessible points rather than driving around.

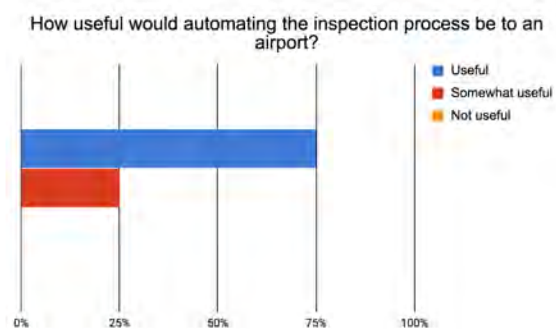
After the team proved that their concept was viable by proving mathematically that the drone could complete a flight path in well under 20 minutes, testing began. The team reached out to Mr. Warcup to facilitate on-site testing at Westerly State Airport, which is restricted by FAR small Unmanned Aircraft System (UAS) Part 107. The team was then provided with two Operational Directives, seen at the end of this section, which gave the team permission to fly the drone at Westerly State Airport and Newport State Airport. These directives gave the team the ability to conduct and complete full flight path tests, obtain test footage, and demonstrate the adaptability of the process across different airports.

Once testing was sanctioned, the team began their flights at Westerly State Airport, while always accompanied by Mr. Warcup and Mr. Cowley who provided the team guidance and advice. The team took advantage of the accompaniment by checking with the airport officials to get approval for the clarity and usability of the videos. After testing was completed at Westerly State Airport, the team began testing at Newport State Airport and were again accompanied by Mr. Warcup. The team was provided insight from Mr. Warcup about the helpfulness of digital, visual documentation in dealing with incidents. As Mr. Warcup said, the "snapshot in time" provided by the logged videos from the drone would be an integral addition to the airport management to show either change in conditions over time, or the conditions immediately before an incident.

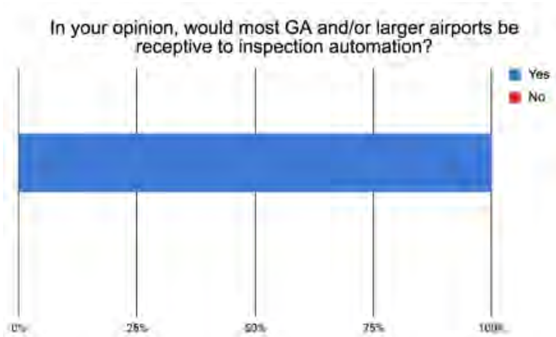
To get a wider range of feedback about the potential use of drones for automated inspections of an airport, the team created a survey that was sent out to various airport officials and executives, airport operations staff, and other airport employees. The purpose of this survey was to gain a better understanding of the current inspection process at airports, to gather feedback about the team's project and to determine if airport officials would be willing to implement the team's inspection process into their airports. The team worked very closely with RIAC, specifically alongside RIAC Senior Vice President of Operations and Maintenance, Alan Andrade who distributed the survey to various colleagues. The team remained in contact with him as he sent out the survey multiple times to different groups of colleagues. Figure 13a shows that 100% of the answers indicated that there are hard to reach areas in the airport that would be useful to have inspected by a drone. Next, Figure 13b shows that 75% of the answers indicated that automating the inspection process would be useful and 25% of answers said it would be somewhat useful, so 100% of the answers were positive. Lastly, Figure 13c shows that 100% of answers indicate that most airports would be receptive to inspection automation. These survey results demonstrate that most airport officials and executives, airport operations staff, and other airport employees believe the drone-based inspection system would be beneficial and useful.



(a) Survey question 1



(b) Survey question 2



(c) Survey question 3

Figure 13: Survey question answers

Rhode Island Airport Corporation

OPERATIONAL DIRECTIVE

Effective: January 1, 2018

SUBJECT: Procedures for Unmanned Aerial Systems (UAS) Operations at the Westerly State Airport (WST) for the University of Rhode Island (URI), Airport Cooperative Research Program (ACRP) competition team.

1. **PURPOSE:** To establish operating procedures for the use of a UAS at the Westerly State Airport for the URI Capstone ACRP Design Competition. This agreement fulfills the FAA notification requirement for UAS operations within 5 miles of an airport to establish mutually agrees procedures.

2. **CANCELLATION:** This Letter of Agreement will expire June 15, 2018.

3. **SCOPE:** The procedures outlines herein describe the authorization, use, and limitations of the use of a UAS to develop potential airport operation applications at General Aviation Airports. The potential applications will apply to runway inspections, perimeter inspections and wildlife control.

4. **RESPONSIBILITES:** Each Party to this agreement, and the personnel under their authority, are responsible for compliance with the provisions contained herein. The UAS operator will be responsible for ensuring all operations are in accordance with safety guidelines and rules established by the Federal Aviation Administration (FAA).

5. **PROCEDURES:**

   a. **GENERAL PROCEDURES:**

      1. Any request to operate a UAS at WST shall be made at least a week ahead of the proposed operation date(s). This request will be made to the Chief Aeronautics Inspector via Email and include a point of contact, dates, times, altitudes and a general description of the proposed UAS operation.

      2. The Chief Aeronautics Inspector along with the airport manager shall approve all UAS operations before any operation takes place.

      3. The Chief Aeronautics Inspector or Airport Manager will ensure any appropriate NOTAM(s) are issued before any proposed operation.

4. The Chief Aeronautics Inspector or Airport Manager shall accompany and escort the UAS operation around the airfield and ensure all radio calls on CTAF are accomplished.

5. The Chief Aeronautics Inspector or Airport Manager will ensure that any UAS operation ceases and the UAS grounded whenever an aircraft enters the class E airspace within 5 miles of the airfield.

6. The UAS operator will at all times adhere "See and Avoid" procedures as described in 14 Code of Federal Regulations, Part 107 rules and any additional restrictions impose by the Chief Aeronautics Inspector or Airport manager.

Rhode Island Airport Corporation

LETTER OF AGREEMENT

Effective: January 1, 2018

SUBJECT: Procedures for Unmanned Aerial Systems (UAS) Operations at the Newport State Airport (UUU) for the University of Rhode Island (URI), Airport Cooperative Research Program (ACRP) competition team.

1. **PURPOSE:** To establish operating procedures for the use of a UAS at the Newport State Airport for the URI Capstone ACRP Design Competition. This agreement fulfills the FAA notification requirement for UAS operations within 5 miles of an airport to establish mutually agrees procedures.

2. **CANCELLATION:** This Letter of Agreement will expire June 15, 2018.

3. **SCOPE:** The procedures outlines herein describe the authorization, use, and limitations of the use of a UAS to develop potential airport operation applications at General Aviation Airports. The potential applications will apply to runway inspections, perimeter inspections and wildlife control.

4. **RESPONSIBILITES:** Each Party to this agreement, and the personnel under their authority, are responsible for compliance with the provisions contained herein. The UAS operator will be responsible for ensuring all operations are in accordance with safety guidelines and rules established by the Federal Aviation Administration (FAA).

5. **PROCEDURES:**

   a. **GENERAL PROCEDURES:**

      1. Any request to operate a UAS at UUU shall be made at least a week ahead of the proposed operation date(s). This request will be made to the Chief Aeronautics Inspector via Email and include a point of contact, dates, times, altitudes and a general description of the proposed UAS operation.

      2. The Chief Aeronautics Inspector along with the airport manager shall approve all UAS operations before any operation takes place.

      3. The Chief Aeronautics Inspector or Airport Manager will ensure any appropriate NOTAM(s) are issued before any proposed operation.

4. The Chief Aeronautics Inspector or Airport Manager shall accompany and escort the UAS operation around the airfield and ensure all radio calls on CTAF are accomplished.

5. The Chief Aeronautics Inspector or Airport Manager will ensure that any UAS operation ceases and the UAS grounded whenever an aircraft enters the class E airspace within 5 miles of the airfield.

6. The UAS operator will at all times adhere "See and Avoid" procedures as described in 14 Code of Federal Regulations, Part 107 rules and any additional restrictions impose by the Chief Aeronautics Inspector or Airport manager.

7 Projected Impacts

7.1 Financial Analysis and Cost/Benefit Analysis

If the total labor costs for students, consultants, travel and materials were calculated, the total would be $58,507.48 [11] as presented below in Table 5. As previously discussed, the team sent out an industry survey with a number of questions. One of the questions was "how long does it take to conduct daily airport inspections and how many are conducted per day?" The answers were averaged and calculated to be 1 hour per inspection and 3 inspections per day. Another question was "how much does it cost daily to conduct inspections?" The answers were averaged and results show that costs are approximately $90 per day to conduct inspections for two employees. Viewing Table 6 below, the total inspections per year is 1,090 inspections (365 days times 3 per day). For man hours, with an inspection taking 1 hour for 1,090 inspections, a total of 1,090 hours per year of inspections are undertaken. With an hourly wage of $15 an hour ($30 for 2 employees) the total cost for the year is $32,700. With the drone, the number of employees used for the inspections can be reduced to one. Also, with the drone-based inspection system it will only take 20 minutes per inspection for 1,090 inspections totaling 363.3 hours per year and at an hourly wage for the one employee at $15 per hour, the total costs for the year equal $5,499.50. By implementing this inspection system, 40 minutes per inspection per day will be saved, totaling 726.7 hours per year, with a total cost savings of $27,250.50 per year. To implement the automated inspection system, the airport would buy the items needed as shown in Table 5, totaling $1,017. Finally, this means that in the first year, the airport will save $26,233.50 and $27,250.50 each year after that.

This automated inspection system has commercial potential. The team could form a company and sell the process and the implementation stages to airports. If an airport wants to implement this system they will have to purchase the equipment and receive permission from the state/FAA to fly the drone in the airport. Following, they purchase the process and the creation of the flight paths from the team. The team would use all testing, analysis, and prior knowledge to create the flight paths that the airport will be using and then provide training to the airport inspector. The team can charge $3,000 for the process and the time spent creating the flight paths for the airports. This presents a significant return for the team because the only costs involved would be traveling to the airport to conduct the tests and determine the flight path. This would also greatly help airports with spending the additional $3,000. With the $1,017 for the products, the airport would still save $23,233.5 the first year and then $27,250.5 each year after that.

Table 5: Total Tangible Costs for Year [11]

Item	**Rate**	**Quantity**	**Subtotal**	**Remarks**
Labor- ACRP Design Competition				
Student Efforts	$32.50/hr	1,648	$53,560	4 student - 412 hrs ea.
Faculty Advisor	$150/hr	12	$1,800	Consultancy with Dr. Nassersharif
Consultant	$150/hr	1	$150	Consultancy with Dr. Meyer
Industry Expert	$100/hr	24	$2,400	Consultancy with James Warcup
Airport Operator	$100/hr	4	$400	Consultancy with Dave Lucas
Consultant	$50/hr	1	$50	Let team fly drone for video
Travel	$0.54/mi	262	$141.48	Site Visits
Expenses				
Drone	$585	1	Provided	3DR Solo
Camera	$292	1	Provided	GoPro Hero 4 Black
Range Extender	$20	1	$20	Alfa WiFi Antennas
Tablet	$120	1	Provided	Samsung Galaxy Tablet
Subtotal			**$58,507.48**	

Table 6: Benefits of Drone-Based Inspection System [11]

Item	**Unit**	**Quantity**	**Total Hours**	**Hourly Wage**	**Total Costs**	**Remarks**
Cost						
Man Hours	60 min/insp.	1,090 inspections	1,090 hrs	$30/hr	$32,700	Year inspection cost (2 employees)
Drone Hours	20 min/insp.	1,090 inspections	363.3 hrs	$15/hr	$5,499.50	Year inspection cost (1 employee with drone)
Benefits	+40 min/insp.	-	+726.7 hrs	+$15/hr	+$27,250.50	Cost saved per year

Overall, the benefit of this drone-based inspection system is the reduction of man hours, resulting in a reduction in total costs per year. Over a 5-year period the airport will save a total of $132,235.50, this includes the cost to purchase the items needed and the inspection process from the team.

7.2 Economic Impact

The use of a UAV to automate the inspection process has the potential to greatly impact airports on an economic scale. As stated in section 7.1, the team's inspection process can significantly reduce the cost of labor for airports. The money saved yearly through the implementation of the automated inspection process can be allotted to other needs at the airport including fencing, runway and airfield maintenance, and upgraded equipment. Along with material improvements, airports can reduce costs of air travel and business operations to the public, increasing its competitiveness in the market. Airports are companies and must adapt to changing and evolving technologies to stay competitive in their respective market. For instance, Westerly State Airport is undermined by a rival aircraft fueling company which sells fuel for 50 cents less than Westerly Airport's price, therefore taking almost all potential fueling revenue from aircraft using the airport. By implementing the automated inspection process, Westerly can afford to lower gas prices and actively compete for the airport's aircraft fueling market. The same economic benefit and principles can be applied to 139 airports, along with general aviation airports. These 139 Airports, including TF Green Airport, employ over a dozen personnel that must shut down runways to conduct inspections. The use of a drone can reduce costs, allowing for the allocation of resources including man power and man hours for other important uses while also reducing runway shutdown time and thus increase the air traffic volume and profits of the airport.

7.3 Societal Impact

The automated inspection of runway and taxiway lighting and the perimeter and security of a general aviation airport using a drone will have a significant societal impact for airport management. General aviation airports typically do not have sufficient personnel or resources to inspect the entirety of the airfield and runways. These airports should be inspected daily with at least manual records kept of failed inspection items, weather and runway conditions, wildlife activity and more. The automated inspection process using a drone creates a logging system with video evidence of the inspection process and conditions of inspection items and runway conditions. The video logging system helps to provide an additional method to protect airports in casualty or crash incidents by providing evidence of the inspection process and airport conditions, with an emphasis on runway conditions. At both Newport and Westerly State Airports, aircraft crashes have occurred in past years where the pilots have attempted to blame the airport for the incident and threatened potential lawsuits. If the video logging system was in place, the airports would be protected by having evidence of runway conditions and showing reasonable doubt the pilot failed to correctly land or take off.

The main goal of the automated inspection process is to quickly and efficiently conduct inspections with clear video of tasked items. However, one of the byproducts of the inspection is wildlife harassment produced from the drone presence. Wildlife harassment is required by airport operators to deter birds and mammals from runways, airport property and airspace. The wildlife management process performed by airports should consist of an initial harassment of wildlife before any necessary shooting of animals is performed. GA airports lack the resources and personnel to sufficiently perform wildlife harassment and tend to allow wildlife presence or resort to shooting as the first line of defense. The use of the UAV performs the act of wildlife harassment. In three instances, the drone's presence caused a flock of small birds to fly out of the airport's airspace and caused four turkey vultures, twice the size of the 3DR Solo drone, to leave airport property.

7.4 Political Impact

The automation of the daily inspection process through the use of a UAV will greatly impact airports on a political scale. Currently, the FAA restricts the use of UAV's with specific restrictions and laws as stated in the FAA's Small UAS (Unmanned Aircraft Systems) Rule, part 107. Currently, no airport in the nation use UAVs on a daily basis, especially in the inspection process. There are only a handful of instances in which drones are being operated in airport airspace to aid personnel in specific situations, including construction surveying and wildlife harassment [1] [2]. These cases of drone usage have required several, necessary FAA directives, requirements and restrictions. Through the testing, completion and implementation of the automated inspection process with a UAV conducted by the team, the designed process will provide further evidence of the significant capabilities of acceptable drone usage in accordance to FAA's rules by airport operators on a daily basis. Drones can provide airports with increased security to protect the general public along with the airport itself. UAV capabilities and its market are exponentially growing and the FAA and airports must adapt and take advantage of the potential usage and benefits.

7.5 Ethical Consideration

One of the main ethical concerns that arise with the automation of daily airport inspection through the use of a drone is regarding the privacy of neighboring homes and buildings. Despite the drone never traveling outside of airport property, people living and working in the adjacent area surrounding airports, especially general aviation, could be recorded when the inspection process is being completed. Issues concerning intrusion and loss of privacy can be mitigated by only allowing approved airport operators to operate the drone and view inspection video logs. By only allowing approved personnel access to inspection videos, public privacy can be maintained and secured.

8 Conclusion

The team defined their problem as the design of an automated system for daily inspections of runway and taxiway lighting and perimeter and security of a general aviation airport with the potential of the system being extended to 139 larger airports. Throughout the design and testing this year, the team believes the design has been validated and optimized with respect to technical specifications and requirements. In conclusion, after reading the positive responses from the survey that was administered, the team believes that this process could definitely be implemented into airports and could greatly benefit airports from a a safety, economic and efficiency perspective.

9.2 Appendix B

University of Rhode Island

The University of Rhode Island is dedicated to being an institution of effective education that provides students with graduate and undergraduate opportunities in courses, work, and research that provide a deep sense of knowledge and an ability to apply that knowledge. The University of Rhode Island was founded in 1892, and in addition to having accreditation from the New England Association of Schools and Colleges, has not only a main 1,200 acre campus, but three additional campuses throughout the state of Rhode Island. These campuses are the Feinstein Providence Campus, Narragansett Bay Campus, and the W. Alton Jones Campus. At the University of Rhode Island, students can pursue 80 different majors from eight different colleges, being the colleges of Arts and Sciences, Business Administration, Continuing Education, Engineering, Environmental and Life Sciences, Human Science and Services, Nursing, and Pharmacy.

College of Engineering

At the University of Rhode Island, The College of Engineering leads a series of programs that prepare students to become effective members of the workforce that can be innovative, think critically, and apply passion to their work. Both the undergraduate and graduate programs cover the gamut of engineering, providing courses and research covering fields over a wide and diverse background such as mechanical, industrial & systems, ocean, computer, nuclear, electrical, biomedical, chemical, and civil engineering applications. The research centers at URI are state of the art and allow both students and faculty to interact and provide innovative interdisciplinary solutions that reach all corners of society. In addition to the cutting edge engineering research and courses available, The University of Rhode Island goes further by leading with an International Engineering Program that combines the benefits of engineering, foreign language, and study abroad experience into a five year dual degree. Along with this, the college is credited by the Accreditation Board for Engineering and Technology (ABET).

9.3 Appendix C

Rhode Island Airport Corporation

The Rhode Island Airport Corporation (RIAC) is a governmental agency of the State of Rhode Island that manages all publicy owned airports within the state. RIAC is a corporation founded in 1992 as a semi-autonomous subsidiary of the Rhode Island Port Authority headed by a seven-member board of directors that have developed a reputation for their service quality and high standards of safety and excellence. The airports that they are responsible include T.F. Green Airport and five other General Aviation (GA) airports: Quonset State Airport, North Central State Airport, Newport State airport, Westerly State Airport, and Block Island State Airport. RIAC not only manages, but also works to provide a vision and plan for these airports that optimize airport operations, increase overall performance and effectiveness, and increase overall value of each airport to the communities they serve.

9.4 Appendix D

The form can be seen on the following page.

9.5 Appendix E

Students:

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?

The Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airport Needs has provided a valuable learning experience for the team. While participating in the ACRP Design Competition as part of a URI mechanical engineering capstone design class, the team had a unique experience compared to other senior-level mechanical engineering students. While most peers were presented with predefined problem statements and design specifications, the Eagle Eye group had the opportunity to work state-wide with airport officials to discover and define a project. This step of finding and defining a problem gave the group the chance to look at the world in terms of what can be improved. Participating in the design competition displayed the amount of research, testing and redesign required to produce a helpful, user-friendly design. While conducting initial research, the team had the chance to learn about the management and operations needed to properly run an airport, a subject that the team may not have been exposed to otherwise. Every challenge and struggle provided an opportunity for the team to use the problem solving skills learned through previous years studying engineering.

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

The main challenge that the team faced was the restriction preventing drones from being able to fly within 5 miles of an airport. Once the team was able to prove to the Rhode Island Airport Corporation that the drone would add value to the airport by saving time, the team was provided with two Operational Directives allowing test flights at Westerly State Airport and Newport State Airport. Another challenge that the team encountered was the range of the drone not being large enough. This was resolved by changing the "home location" or takeoff location and purchasing the Alfa WiFi antennas which extend the signal of the drones controller. Some of the more engineering-focused challenges that the team had to face included optimizing the flight paths of the inspections, and making the complete inspection process as efficient as possible. The team expanded on knowledge previously learned in class by using engineering equations to find the optimum velocity and height for the drone. The most efficient process path for the inspection was found using Critical Path Method, an analysis tool that the team learned to use for this project.

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

The team began the year by meeting with the Rhode Island Airport Corporation (RIAC) to discuss ideas that they believe would benefit airports. In this initial meeting, the ACRP Design Competition booklet was used to facilitate discussion about potential projects that could improve airports in not only Rhode Island, but also the nation. From this, the team decided to work with drones and chose the category of Airport Management and Planning with a focus on the challenge of planning for the integration and mitigation of possible impacts of drones into the airport environment. After further discussions with RIAC Chief Aeronautics Inspector, James Warcup, and Quonset Airport Manager, Dave Lucas, it was decided that the management of airports could be most improved through streamlined methods of daily inspections. Dave Lucas provided the team with an inspection checklist with which the team narrowed down the critical inspection items to perimeter and security, and taxiway and runway lights. In order to freely brainstorm initial design concepts, each of the four team members developing 30 design concepts. The concepts were thoroughly thought out and once completed the team went through the 120 concepts and created a final list of five designs that would provide the best possible solution. Once the best concept was chosen, the team defined their problem as the automation of daily inspections for runway and taxiway lighting and perimeter and security of a General Aviation (GA) airport using a drone, with the potential of being extended to 139 airports.

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

Participation from industry experts was instrumental in the design and completion of the team's automated inspection process. James Warcup, chief Aeronautics Inspector for RIAC, consulted the team in aspects of the design process, aided in receiving both Operational Directives and approved test and completion video of the inspections. In an effort to gain as much feedback as possible, the team created and administered a survey for airport personnel. This survey included questions about willingness to include a drone into an airport's operational tools, current inspection times and the potential usefulness of an automated inspection. Alan Andrade, RIAC Senior Vice President of Operations and Maintenance, distributed the survey to colleagues for additional input. With this industry help, the team was able to successfully complete the project, network with important industry experts in RIAC, Westerly and Newport State Airports and understand the business, safety regulations and importance of general aviation airports. In addition to airport officials, the team reached out to local drone experts to gain insight into the emerging drone market. Cloud City Drones' employees, including including Senior Technician, Ian Schafron, and the head of the corporate and educational division at Cloud City Drones, Christopher Williams, provided the team with advice and enthusiasm about using drones in an airport atmosphere in a positive way. The insight, advice and guidance from airport officials and industry experts helped foster an innovative atmosphere based in the realities of the current world in which the team could create a project that can be implemented today.

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?

Throughout the process of hypothesizing, planning, designing, testing and implementing, the team has learned and applied new skills. To begin, the team learned how to plan and design a product/process starting from a problem definition up to its implementation stage.

On top of the hard skills such as learning about airport management, learning analysis methods for lift and process efficiencies, and how to fly drones, the team has also gained invaluable soft skills. Specifically, the team has learned and practiced how to speak and act professionally in a cross-disciplinary project while fostering new and innovative ideas. This soft-skill-set is extremely useful within the world of modern engineering, and therefore necessary as the team enters the workforce. Most careers and projects in the technological age heavily focus on bringing separate worlds together; like bringing drones into an airport atmosphere. Throughout the team's university studies, engineering skills have been taught and tested continuously. The ACRP University Design Competitions has provided a unique chance for the team to get a step ahead of peers through gaining experience with interpersonal relationships.

Faculty:

The answers to the faculty evaluation questions are on the following page.

THE
UNIVERSITY
OF RHODE ISLAND
COLLEGE OF
ENGINEERING

THINK BIG WE DO™

DEPARTMENT OF MECHANICAL, INDUSTRIAL AND SYSTEMS ENGINEERING
92 Upper College Rd, 203 Wales Hall, Kingston, RI 02881 USA p: 401.874.2524 f: 401.874.2355 mcise.uri.edu

April 26, 2018

To: Airport Cooperative Research Program -- University Design Competition for Addressing Airport Needs -- 2017 - 2018 Academic Year review panel

This is the eight year that our university and engineering program participates in this design competition. I selected this competition as one of the projects for my senior capstone design course in mechanical engineering because the program description and particularly timeline was an excellent match for my project requirements. Our senior capstone design sequence starts in the fall of the senior year and concludes in the following spring semester.

The value of the educational experience for students participating is absolutely outstanding. In particular, interactions with our local Rhode Island Airport Corporation (RIAC) were outstanding and we received tremendous support from the management and operational staff there. The students conducted a broad and comprehensive search through the problem space outlined by the design competition and identified a problem of significance to the airports and airlines that is also of significant interest nationally (and perhaps internationally).

The most significant challenge for the students at the beginning was to identify, define, and research the problem(s) of interest. This search was conducted over a period of two months, which delayed them somewhat during the fall semester. This delay was necessary because of the broad scope definition of problems provided by the design competition call and the necessary interaction time with the state airport corporation staff.

The student team has done an excellent job in thoroughly exploring their problem (*Eagle Eye*). They have designed a practical and very economical solution that is relatively inexpensive to implement. They have prototyped their process solution and have obtained excellent results to pursue the creation of a marketable service and process that should be of great interest to many airports. Their survey of airport operators, management, and airport executives shows high interest in this product. This is exactly the type of process and experience that we expect for our students on senior design projects.

I am very pleased with the competition process, project solicitation, and organization of the ACRP design competition for addressing airport needs. I will definitely use this competition again in the future. If you have any questions or need additional information, please contact me.

Sincerely,

Bahram Nassersharif

Bahram Nassersharif, Ph.D.
Distinguished University Professor

9.6 Appendix F

[1] Garret, R. "Bult Field Puts Drone Technology to the Test for Wildlife Management" airportimprovement.com, Airport Improvement, Oct. 2014, http://www.airportimprovement.com/article/bult-field-puts-drone-technology-test-wildlife-management

[2] 3DR. 2017 "How We Got Permission to Fly Drones At the Busiest Airport in the World" 3DR.com, 3DR, https://3dr.com/blog/how-we-got-permission-to-fly-drones-on-the-busiest-airport-in-the-world-bbcd037126c3/#

[3] 3DR "Announcing Iris, a totally ready-to-fly UAV quadcopter with our next-gen autopilot" , 3dr.com, 3DR, 19 Aug, 2013 https://3dr.com/blog/announcing-iris-a-totally-ready-to-fly-uav-quadcopter-with-our-next-gen-autopilot-53ac9d20558d/#

[4] Nancy Hall "The Drag Coefficient" May 05, 2015 National Aeronautics and Space Administration National Aeronautics and Space Administration April 15, 2018 https://www.grc.nasa.gov/www/k-12/airplane/dragco.html

[5] Michael Barnard "How does temperature and wind speed change as you go higher in elevation from sea-level?" April 17, 2015 Quora

April 15, 2018 https://www.quora.com/How-does-temperature-and-wind-speed-change-as-you-go-higher-in-elevation-from-sea-level

[6] Steve Griffin "How to Calculate Air Density" 2018 FLy Me To the Moon Brisbane Hot Air Balloon specialists April 15, 2018 https://www.brisbanehotairballooning.com.au/calculate-air-density/

[7] Olson; Erlend "MOBILE CAMERA AND SYSTEM WITH AUTOMATED FUNCTIONS AND OPERATIONAL MODES" Mobile video Corporation Patent application full text and database U.S. Patent and trademark office December 26, 2017

[8] Labrie; Zachary "METHOD AND SYSTEM FOR PROPERTY DAMAGE ANALYSIS " Mobile video Corporation Patent application full text and database U.S. Patent and trademark office, July 28, 2017 http://appft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=

[9] Wes Timmons. ARCP Design Competition. "Completing a Safety Risk Assessment" Youtube.com Airport Cooperative Research Program 29, Sept. 2016 https://www.youtube.com/watch?v=PX5GFC_RNYo&feature=youtu.be

[10] Federal Aviation Administration. "Introduction to Safety Management Systems (SMS) For Airport Operators" AC 150/5200-37. www.faa.gov U.S. Department of Transportation. 07, Feb. 2007 https://www.faa.gov/documentLibrary/media/advisory_circular/150-5200-37/150_5200_37.pdf

[11] Dave Byers. ARCP Design Competition. "Guidance for Preparing Benefit/Cost Analyses" Airport Cooperative Research Program 19, Oct. 2016 https://www.youtube.com/watch?v=J1yRM1uPpcc&feature=youtu.be