2018

ACRP Design Competition -- Eagle Eye

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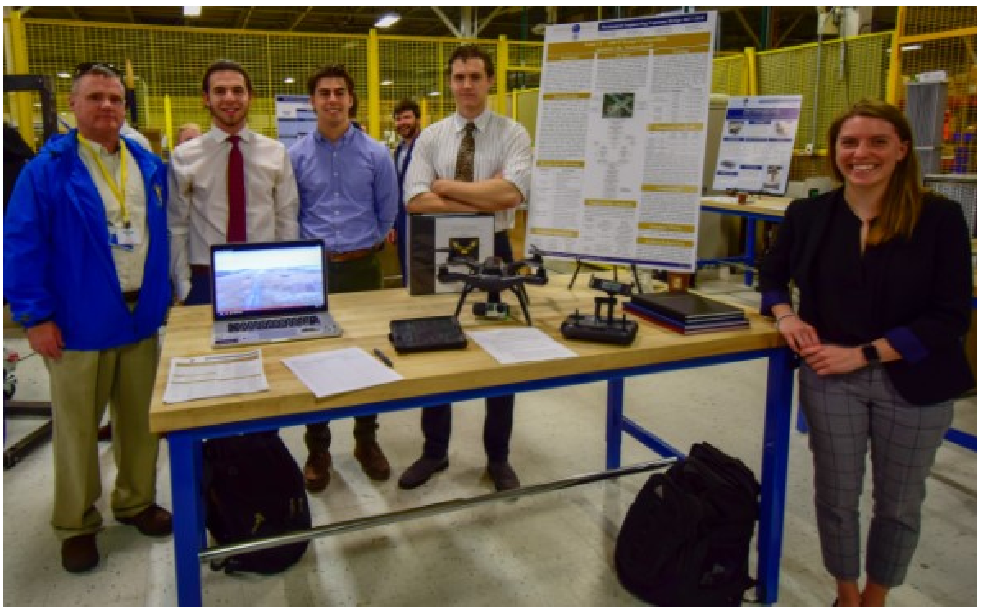
ACRP Design Competition

Team 11: Eagle Eye



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Abstract

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.

Capstone Design Team 11 was chosen to participate in the Airport Cooperative Research Program (ACRP) National Design Competition. The aim is to plan, design and create innovative approaches to resolve problems experienced by airports and the Federal Aviation Administration (FAA). The team was able to choose between four main categories in which to compete. 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

Nomenclature

Symbols & Units

$\frac{L}{b}$ . . Span Loading . . . . . $\frac{N}{m}$
C_L . Coefficient of Lift . . . . . –
D_i . Drag Force . . . . . N
K_T . Constant Dependent on Wing Geometry . . . . . –
L . . Lift Force . . . . . N
S . . Wing Area . . . . . m^2
V . . Aircraft Velocity . . . . . $\frac{m}{s}$
V_T . Tip Speed of the Rotor . . . . . $\frac{m}{s}$
W . Gross Weight of the Aircraft . . . . . N
$\frac{t}{c}$ . . Wing Thickness to Chord Ratio . . . . . –
f_c . . Allowable Direct Stress of Wing Material . . . . . $\frac{N}{m^2}$
p . . Disk Loading of the Rotor . . . . . $\frac{N}{m^2}$
q . . Aerodynamic Head . . . . . $\frac{N}{m^2}$
u . . Deflected Air Velocity . . . . . $\frac{m}{s}$
w . . Wing Loading . . . . . $\frac{N}{m^2}$
β_0 . . Coning Angle of the Rotor Blades . . . . . Rad
ρ . . Density of Air . . . . . $\frac{kg}{m^3}$
ρ_m . Density of the Wing Material . . . . . $\frac{kg}{m^3}$
σ . . Package Density Ratio . . . . . –

Acronyms

ACRP . . . . . Airport Cooperative Research Program
AR . . . . . Aspect Ratio
CAD . . . . . Computer Aided Design
FAA . . . . . Federal Aviation Administration
FAR . . . . . Federal Aviation Regulations
GA . . . . . General Aviation
NOTAM . . . . . Notice to Airman
QFD . . . . . Quality Function Deployment
RIAC . . . . . Rhode Island Airport Corporation
SMS . . . . . Safety Management System
SRM . . . . . Safety Risk Management
UAS . . . . . Unmanned Aircraft Sysetm
UAV . . . . . Unmanned Air Vehicle

List of Tables

List of Figures

1 Introduction

The Airport Cooperative Research Program (ACRP) sponsors a national competition for universities to plan, design and create innovative approaches to resolve problems experienced by airports and the Federal Aviation Administration (FAA). The FAA works to ensure the safety, security and efficiency of the nation's aviation system and encourages research to improve a wide variety of airports and the aviation community. The FAA manages the oversight of the ARCP as the program focuses on applied research on issues collectively faced by airport operation agencies that are not adequately addressed by existing federal research programs. The ARCP's goals include engaging university students pursuing a STEM major to contribute innovative solutions to problems faced by the nation's airports and FAA while increasing the students' interest and raising awareness to the importance of airports. The competition encourages individuals or teams of undergraduate and graduate students advised by faculty to design quality solutions directed towards areas including Airport and Operation Maintenance, Runway Safety and Runway Incursions and Excursions, Airport Environmental Interactions and Airport Management and Planning. The first technical design challenge, Airport Operation and Maintenance, entails the day to day responsibilities including record keeping, personnel turnover, maintenance of pavement, signs, and lights and emergency preparedness. This category focuses on designing innovative solutions that will increase the airport operations efficiency outside of the terminal and airport buildings. The second highlighted technical design category is Runway Safety and Runway Incursions and Excursions. The category focuses on enhancing the safety, efficiency and situational awareness of pilots and operators on the airfield and in the control tower. The third technical design category, Airport Environmental Interactions, works to improve airport operations with regards to environmental impact, air quality, energy supply, light and noise pollution, construction impacts and longevity of airports. The final technical design category, Airport Management and Planning, focuses on optimizing the use of existing airport resources and plan for upcoming functional needs. The competition is open from August 1, 2017 to April 27, 2018 and requires evidence of interaction with both airport operators and industry experts for feedback on the practicality of the proposed design and approach.

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 Project Planning

2.1 Fall Semester

In the beginning of the Fall semester, the team was chosen to participate in the ACRP Design Competition. In order for the team to stay organized and on track, a project plan with a Gantt Chart was created in the Microsoft Project. On the project plan, tasks were assigned with start dates and deadlines, along with initials for the team members completing these tasks. The full project plan Gantt Chart can be seen at the bottom of this section

The first task for the project was to decide on a project topic from the ACRP Design Competition booklet. The ACRP Design Competition was referenced to narrow down the project topics, and each group member listed topics of interest. The group used post-it notes to visually represent topics of interest, and to see where interests overlapped between group members. For clarity within this report and for archiving documents, this physical representation with colored post-it notes was then transfered into a digital copy as seen in Figure 1, with each row representing a different sub category from the ACRP Design Competition booklet.

Airport Operation Maintenance					
	1.a				1
	1.b	1.b		1.b	3
	1.c	1.c	1.c		3
		1.h	1.h		2
	1.i	1.i	1.i	1.i	4
	1.k				1
		1.l		1.l	2
Runway Safety/Runway Incursions/Runway Excursions					
	2.b	2.b	2.b		3
	2.c	2.c	2.c		3
	2.e	2.e			2
Airport Environmental Interactions					
	3.a	3.a	3.a	3.a	4
	3.b			3.b	2
	3.c	3.c		3.c	3
				3.d	1
Airport Management and Planning					
				4.1	1
				4.5	1
				4.6	1
	4.7				1
		4.8		4.8	2
		4.9	4.9		2
			4.11	4.11	2

Figure 1: Excel Representation of Top Topic Brainstorming Activity with Post-It Notes

All overlapping topics of interest were discussed and narrowed down to helping aging passengers, implementation of drones, managing excursions, improving baggage handling, improving security at non-towered airports, wildlife and vegetation management, and improving energy efficiency at the airport.

These top topics were then discussed in a first meeting with RIAC, represented by James Warcup and Dave Lucas. Discussion in the meeting lead to project ideas including: the design of a break wall for the Block Island Airport, designing a system for deicing liquid application at the hanger doors, and introducing a drone into the airport atmosphere for inspections or wildlife harassment.

In a separate meeting with Dr. Nassersharif, the project ideas discussed in the initial meeting with RIAC were further analyzed. Due to the national aspect of the ACRP competition, the break wall and deicing projects were eliminated, leaving the implementation of drones. This fits into the topic of Airport Management and Planning Challenges: Planning for the integration and mitigation of possible impacts of drones into the airport environment.

After meeting with Dr. Nassersharif, design specifications were set for the task, along with a QFD analysis to correlate customer requirements with engineering specifications, and then thirty concepts per group member were generated focusing on the implementation of drones for both inspections and the harassment of wildlife. The concept generation was aided by literature and patent searches that we conducted throughout the generation process.

Once initial concepts were generated, more research was conducted to better choose the final concept. This research included contacting Cloud City Drones, a drone store located across the street from T.F Green airport in Warwick, Rhode Island. Group members visited the store to talk to employees about possible use of drones within the airport atmosphere. More in depth literature and patent searches were conducted as well. These resulted in the discovery of the use of drones for construction mapping at the Hartsfield-Jackson International Airport in Atlanta. This proved to the team that airports would be ready and willing to use drones as a tool.

The literature search also showed that the harassment of wildlife with a drone would be extremely unpredictable and complex. This is because different types of animals would require different types of harassment techniques, and it is impossible to stop the animal from fleeing to a more dangerous location, or to stop them from returning. Because of this, the team decided to focus purely on the inspection of the airport.

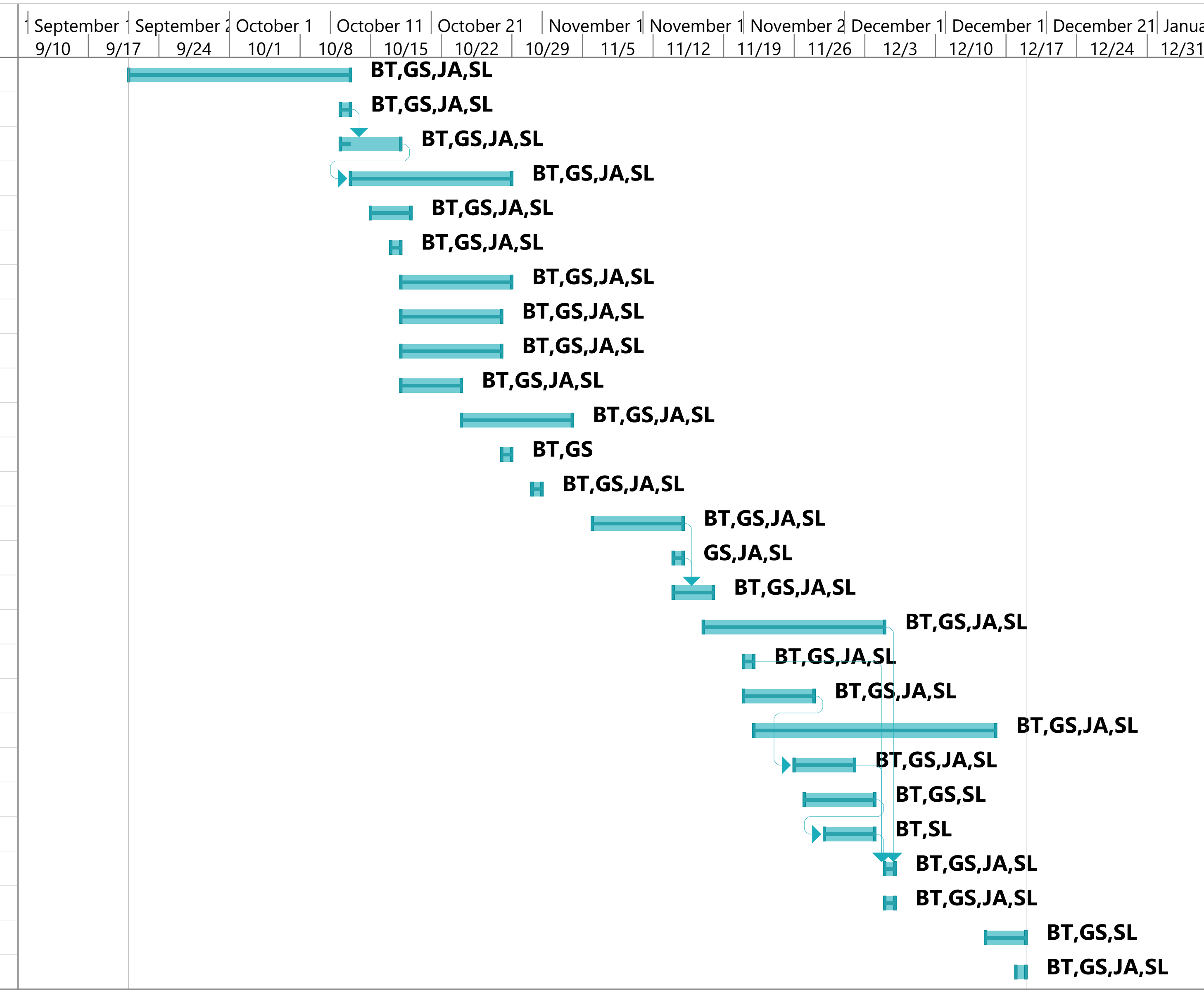
The group presented the design concept to Dr. Nassersharif and the rest of the class. After receiving feedback from both the class and Dr. Nassersharif, the group's next focus went to choosing an inspection check point to focus on, and an exact inspection process.

To narrow down the inspection checklist, the group visited Westerly State airport to meet with employees and the RIAC representatives, and to conduct an inspection of the airport to observe the current process. While there, the representatives expressed that archival videos of inspections would be the most beneficial to the airport. After the inspection, the group decided to focus on inspecting the runway and taxiway lights, and the perimeter of the airport.

After choosing inspection points, the group had to prove that a drone could, in fact, inspect the lights and perimeter. To do this the group downloaded Droid planner application on an android device to prove that the IRIS drone could fly preprogrammed missions. To prove that the drone would always be in range of the receiver, the group mapped out possible flight paths for the drone. The group used a different drone with a gimbal to prove that the video is clear and all inspection points can be seen at a range of speeds and heights. These speeds and heights prove that the drone can conduct a sufficient inspection within the time-frame set by the design specifications.

This proof of concept was presented to the rest of the class, Dr. Nassersharif, and James Warcup. After the proof of concept presentation, the group once again met with James Warcup to discuss the next steps in the project. After this, the team began to work on the preliminary design report with a due date of December 18, 2017.

ID		Task Mode	Task Name	Duration	Start	Finish	Predecesso	Resource Names
1	✓		Project Topic Discussion	16 days	Thu 9/21/17	Thu 10/12/17		BT,GS,JA,SL
2	✓		First Meeting with RIAC	1 day	Thu 10/12/17	Thu 10/12/17		BT,GS,JA,SL
27			Discussion of Projects Presented by	4 days	Thu 10/12/17	Tue 10/17/17	2	BT,GS,JA,SL
7	✓		Patent Search	12 days	Fri 10/13/17	Sat 10/28/17	27	BT,GS,JA,SL
3	✓		Research for Wildlife Management	4 days	Sun 10/15/17	Wed		BT,GS,JA,SL
6	✓		First Review Meeting with Dr.	1 day	Tue 10/17/17	Tue 10/17/17		BT,GS,JA,SL
4	✓		Preparing for Critical Design Review	9 days	Wed	Sat 10/28/17		BT,GS,JA,SL
10	✓		Design Specifications	8 days	Wed	Fri 10/27/17		BT,GS,JA,SL
11	✓		QFD	8 days	Wed 10/18/17	Fri 10/27/17		BT,GS,JA,SL
12	✓		30 Concept Generation	4 days	Wed	Mon		BT,GS,JA,SL
24	✓		Research for Inspection Techniques	9 days	Tue 10/24/17	Fri 11/3/17		BT,GS,JA,SL
9	✓		Visit Cloud City Drones	1 day	Sat 10/28/17	Sat 10/28/17		BT,GS
5	✓		Critical Design Review Presentation	1 day	Tue 10/31/17	Tue 10/31/17		BT,GS,JA,SL
13	✓		Inspection Checklist Review	7 days	Mon 11/6/17	Tue 11/14/17		BT,GS,JA,SL
8	✓		Inspection at Westerly Airport	1 day	Tue 11/14/17	Tue 11/14/17		GS,JA,SL
14	✓		Inspection Checkpoint Choice	4 days	Tue 11/14/17	Fri 11/17/17	13,8	BT,GS,JA,SL
21	✓		Work on Proof of Concept	12 days	Fri 11/17/17	Mon 12/4/17		BT,GS,JA,SL
15	✓		Second Review Meeting with Dr.	1 day	Tue 11/21/17	Tue 11/21/17		BT,GS,JA,SL
16	✓		Redefinition of Problem Definition	5 days	Tue 11/21/17	Mon		BT,GS,JA,SL
22	✓		Work on Final Report	18 days	Wed	Fri 12/15/17		BT,GS,JA,SL
17	✓		Update Design Specifications	6 days	Sun 11/26/17	Fri 12/1/17	16	BT,GS,JA,SL
19	✓		Drone Flight Practice	6 days	Mon	Sun 12/3/17		BT,GS,SL
20	✓		Flights for Proof of Concept	4 days	Wed	Sun 12/3/17	19	BT,SL
18	✓		Proof of Concept Presentation	1 day	Tue 12/5/17	Tue 12/5/17	20,17,21,1	BT,GS,JA,SL
25	✓		Meeting with James Warcup:	1 day	Tue 12/5/17	Tue 12/5/17		BT,GS,JA,SL
26	✓		Final Proof-Reading of Report	2 days	Fri 12/15/17	Mon		BT,GS,SL
23			Final Report Due	1 day	Mon	Mon		BT,GS,JA,SL



Project: Final Project Plan
Date: Tue 4/24/18

Task	Project Summary	Manual Task	Start-only	Deadline
Split	Inactive Task	Duration-only	Finish-only	Progress
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
Summary	Inactive Summary	Manual Summary	External Milestone	

2.2 Spring Semester

To begin the spring semester, the team met to review the fall semester's completed tasks and to create a list of vital tasks still to be completed. These tasks included the in-class lectures, design review meetings, ACRP University Design Competition due dates, process writing and process testing. The team decided that it would be also necessary to continue searching through literature and press releases as the drone market is a fast growing and moving market. The team wanted to stay up to date on the available technology and potential market competition throughout the second semester. The team created a project plan outline using the set dates for both the competition and the capstone class to structure the rest of the semester's schedule. The first inflexible deadline for the team was to send in the ACRP design competition notice of intent on January 27, 2018. The notice of intent required the team to define a clear project statement, and to categorize the project into one of the ACRP University Design Competition problem categories. This process allowed the team to assess the final goal of the project by focusing on the testing and verification of an automated inspection process using a drone. Once the notice of intent was completed and sent, the team continued to plan the semester based on a Build and Test presentation on April 6, 2018, a completed competition report and a Capstone Design Showcase date of April 27, 2018 and a final design report due May 7, 2018.

The team decided to focus on the building for the first half of the semester. Within this project, the build was split up into two sections; the building of a process, and the creation of the flight paths. The building of the automated process began with the team looking over the current inspection process. This required the team to experience and take notes on the way that the inspector must drive to difficult locations on the airport property, and how the inspector must always be looking to the surroundings while driving, creating potentially dangerous driving conditions. After taking these notes, the team created a list of all of the tasks needed to complete the inspection using the drone. This included everything from walking the drone to the home location, to clicking each button on the android app. The team then took these steps and created a flowchart to visually show the process.

The creation of the flight paths was a multi-step process that included analysis, testing and implementation. Because of the intertwining of testing and building, the team had to schedule many trips to Westerly State Airport in order to complete the build before the Build and Test presentation. These trips were facilitated through and with James Warcup, who provided necessary insight about the usability of the process.

One of the first steps in determining the flight paths was determining a viewable range for the video. To do this the team tested variables such as camera settings, altitude, distance from viewing target and the speed of the drone. In order to keep the test results organized, the team created a test matrix. Using this matrix, the team would vary one variable at a time to determine the optimal combination for the inspections. This was done separately for the runway and taxiway lights and the perimeter and security inspections. James Warcup, RIAC Chief Aeronautics Inspector confirmed that the optimal values chosen would create a usable and easily viewable inspection video. Once the optimal viewing values were chosen, the team wanted to confirm that the drone flight itself would be safe. To do this, the team used aerodynamic principles to mathematically show that the lift and drag experienced by the drone would be safe. After testing and analyzing the chosen values, the team created and saved the flight plans on the Tower android app to be used in further testing.

After the building portion of the semester, the team moved to further test and analyze their process and the flights themselves as well as redesign where necessary. The total inspection process was analyzed using critical path method. This method first gave the team a visual representation of how long each piece of the process would take. Once the critical path was found, the team could see which tasks in the process were creating the longest wait times for the rest of the process. From there, multiple steps were taken out. These steps included putting the drone together and taking it apart after each inspection. The team was then left with a streamlined and easy to follow inspection process to be implemented.

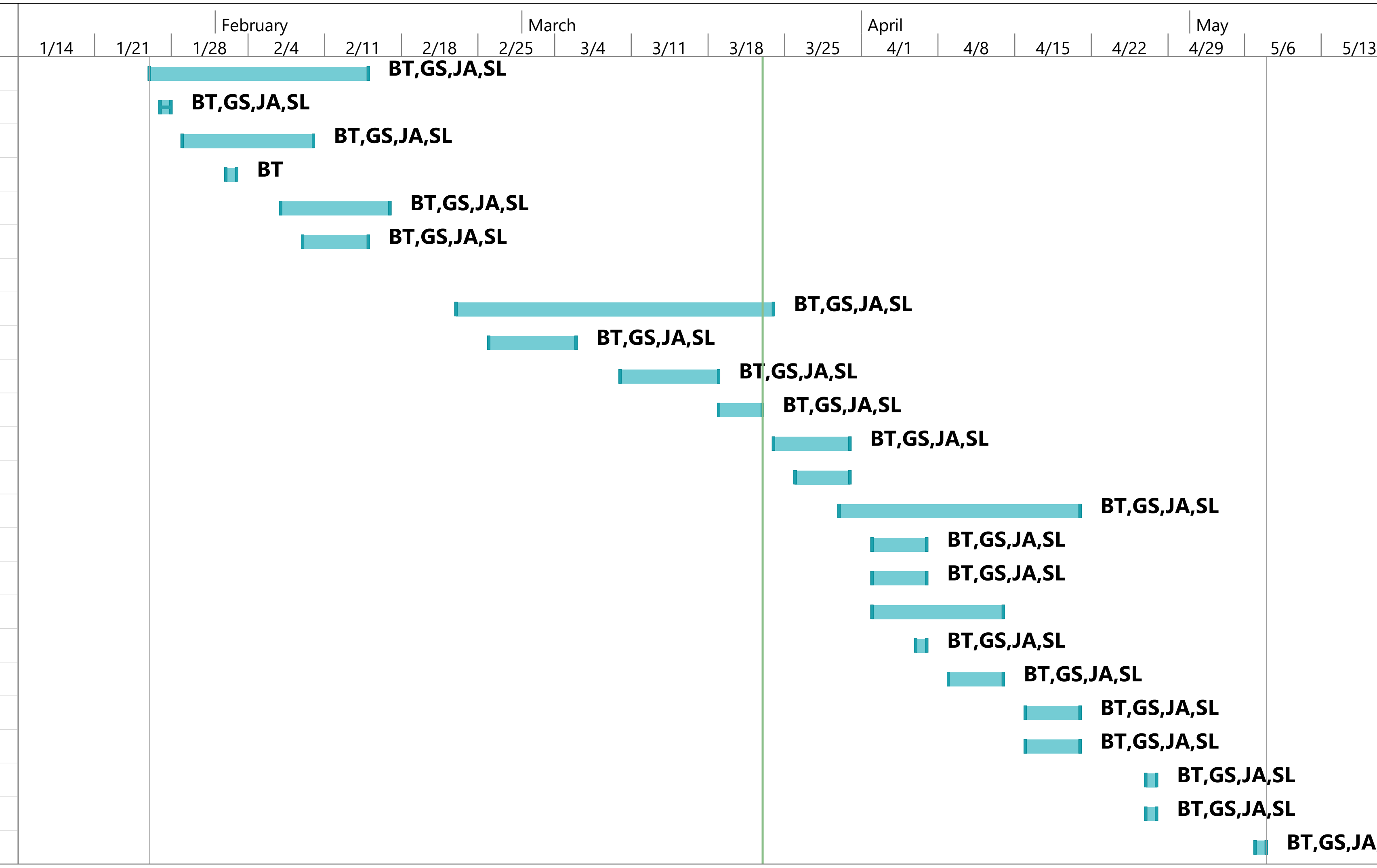
Per the Operational Directive that the team received, in order to test and analyze the flight paths, the team had to schedule a series of meetings with James Warcup so that the drone could be flown at the airport. Once the meetings were scheduled, the team used the previously saved paths, while also creating partial paths so that each portion of the flight could be analyzed on its own. While first testing the flight paths, the team noticed that the connection strength became low at far points of the inspection. Because of this, the team purchased WiFi range extenders for the drone controller. The team continued to test the paths and make small changes such as avoiding obstruction poles and creating more way-points so that the altitude of flight would be correct at each inspection point.

The team collected additional data in order to determine what reception the automated inspection would receive from airport professionals, and the user friendliness of the product itself. To determine the reception, the team created a survey for airport executives that included questions aimed to determine the time and money spent on current inspections and if the airport executive would be willing to use a drone within their airport. The team used test video to determine the user friendliness of the system itself. To do this the team used a 2 minute and 30 second video that showed 4 lights that were not on. The team then showed volunteers this video to see if they could point out where the defective lights were. Using the survey and the test video results, the team determined that the automated inspection process using a drone would be an effective and well-received addition to an airport management staff.

The next step in the team's project plan was to do final testing and implementation. This connected the process with the flight paths by going through the complete inspection at Westerly State Airport. After the successful run-through of the process in Westerly, the team tested the adaptability of the automated inspection process by creating flight paths for Newport State Airport and testing there.

To finalize the competition and the capstone project, the team collected all information and findings into multiple reports and a poster. The final competition report was completed, sent and received before the April 27 due date. The final poster was completed and showcased at the Mechanical Engineering Senior Capstone Design Showcase on April 27. The team also began work on the Final Design Report for the May 7, 2018 due date.

ID	Task Mode	Task Name	Duration	Start	Finish	Resource Names
1		Design Review Meeting 1	14 days	Fri 1/26/18	Wed 2/14/18	BT,GS,JA,SL
9		Notice of Intent Due	1 day	Sat 1/27/18	Sat 1/27/18	BT,GS,JA,SL
15		Write Survey Questions	10 days	Mon 1/29/18	Fri 2/9/18	BT,GS,JA,SL
16		Arrange Westerly State Airport	1 day	Fri 2/2/18	Fri 2/2/18	BT
10		Test Flight Paths	8 days	Wed 2/7/18	Fri 2/16/18	BT,GS,JA,SL
2		Lectures at Schneider	4 days	Fri 2/9/18	Wed 2/14/18	BT,GS,JA,SL
12		Write Detailed Process	21 days	Fri 2/9/18	Fri 3/9/18	BT,GS,JA,SL
3		Design Review Meeting 2	21 days	Fri 2/23/18	Fri 3/23/18	BT,GS,JA,SL
11		Test Flights at Westerly State	6 days	Mon 2/26/18	Mon 3/5/18	BT,GS,JA,SL
19		Spring Break	7 days	Sat 3/10/18	Sun 3/18/18	BT,GS,JA,SL
13		Test First Draft Process	4 days	Mon 3/19/18	Thu 3/22/18	BT,GS,JA,SL
17		Rewrite Process	6 days	Sat 3/24/18	Fri 3/30/18	BT,GS,JA,SL
23		Test Full Flight Path at Westerly	5 days	Mon 3/26/18	Fri 3/30/18	
5		Design Review Meeting 3	16 days	Fri 3/30/18	Fri 4/20/18	BT,GS,JA,SL
14		Test Revised Process at	5 days	Mon 4/2/18	Fri 4/6/18	BT,GS,JA,SL
20		Complete Presentation	5 days	Mon 4/2/18	Fri 4/6/18	BT,GS,JA,SL
24		Test Full Flight Path at Other	10 days	Mon 4/2/18	Fri 4/13/18	
4		Team Pesentations-Build and	1 day	Fri 4/6/18	Fri 4/6/18	BT,GS,JA,SL
21		Finalize Process	5 days	Mon 4/9/18	Fri 4/13/18	BT,GS,JA,SL
6		Adjust Process to fit General	5 days	Mon 4/16/18	Fri 4/20/18	BT,GS,JA,SL
22		Test Final Process at Westerly	5 days	Mon 4/16/18	Fri 4/20/18	BT,GS,JA,SL
7		Design Showcase	1 day	Fri 4/27/18	Fri 4/27/18	BT,GS,JA,SL
8		Competitions Submission Due	1 day	Fri 4/27/18	Fri 4/27/18	BT,GS,JA,SL
18		Final Report Due	1 day	Mon 5/7/18	Mon 5/7/18	BT,GS,JA,SL



Project: Updated Spring Project
Date: Fri 3/23/18

Task	Project Summary	Manual Task	Start-only	Deadline
Split	Inactive Task	Duration-only	Finish-only	Progress
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
Summary	Inactive Summary	Manual Summary	External Milestone	

3 Financial Analysis

3.1 Product Costs

In order to complete this project, the 3DR Solo drone and the Samsung Galaxy Tablet were provided by Dr. Nassersharif and the GoPro Hero 4 Black camera was provided by the team leader, Ben Travelyn. Along with this the team purchased Alfa WiFi Antennas, to boost the signal range of the drone. If all of these items were to be purchased, the prices can be seen in Table 1 below, totaling a cost of $1,017. The team was provided with a $1,000 budget, in which only the Alfa WiFi Antennas were purchased for $20.

Table 1: Costs for products used for project

Product	**Cost**
3DR Solo Drone	$585
GoPro Hero 4 Black	$292
Samsung Galaxy Tablet	$120
Alfa WiFi Antennas	$20
	$1,017

Currently the team is designing an automated inspection process of the perimeter and security and the runway and taxiway lights for GA airports, but the drone utilizes a versatile software system, this process could be implemented for other inspection items or functions at airports in the future. The team could create a consulting company where the airport would purchase the process, the preprogrammed routes, and all research and knowledge about the design, so all they need to do is purchase these products. This service of selling the whole design to an airport, would be used for daily airport inspections, which would significantly reduce man hours and yearly costs by airports.

3.2 Return on Investment

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 2 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 1, 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.

Table 2: Benefits of Drone-Based Inspection System

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

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.

Currently there is no company on the market that offers this proposed design and service, so the teams company would be in complete control of the market, being able to determine what the prices are. RIAC Chief Aeronautics Inspector James Warcup said that this would be a great help, causing a high demand, meaning airports would take advantage of this, forecasting a successful company.

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.

3.3 Human Resource Allocation

Throughout the year, various tasks were completed by each team member, Ben Travelyn, Scott Liguori, Julian Andriulli, and Grace Sanita. The total times for each task can be seen below in Table 3. These tables show the breakdown the full year consisting of tasks from Fall semester which are competition research, problem research, patent and literature search, market analysis, inspection research, design, drone flight and process, proof of concept, and preliminary design report. Then the Spring semester consisting of test drone flights, tests at airport, test form, survey, process, engineering analysis, video analysis, test plan report, capstone paper, poster and brochure, ACRP competition report, and the final report.

For the tasks completed during the Fall semester, the competition research was when the team was researching each category of the ACRP Design Competition and eventually choosing one of the categories. After this the problem research was conducted, where the team researched what exactly they could do for a project after choosing the category of "Integration and mitigation of drones in the airport environment". The team then chose to use the drone to automate the inspection process in the airport. Throughout this process, patent and literature searches were conducted to see if any of them related to the project and could help and also design specifications were set, thirty concepts per team member were generated and the team completed a QFD analysis. The team also completed a market analysis to determine what the current inspection method is and any other competing drones. After this, the team decided to inspect the perimeter and security and the runway and taxiway lights, the team had to learn the process for using the drone and conduct test flights in order to prove the concept. Then, the design was completed along with the proof of concept being worked on through conducting experiments with the drone and theoretical calculations using Google Maps. Lastly, the preliminary design report was worked on and completed.

For the tasks completed during the Spring semester, the test drone flights were when the team was familiarizing themselves with the new 3DR Solo drone and uploading flight paths from the Tower app. Then the tests at the airport consist of the tests to determine optimal values and the full flight paths at Westerly State Airport and Newport State Airport. Then, a survey was created to be sent to industry experts in order to gain feedback on the teams project. The next task was the process that the team created in for the airports to complete the inspection. The team completed various types of engineering analyses to verify the altitude chosen for the inspection, improve the process, and prove the lights can clearly be seen in the videos. After this, in order to verify that the videos are clear the team had to analyze the videos taken in the airport and edit them to cut out unneeded footage from the tests. After the tests, the team completed a test plan report to detail the various test completed. Next, the team completed a paper detailing the work completed on the project and the finalized design that has the potential to be published. Then, the team created a poster and brochure for the design showcase. After this the team completed the ACRP Design Competition report, which is the report detailing the full product design that was submitted to the ACRP Design Competition. Lastly, the team completed the final report, which outlines the overall design for the whole year.

Table 3: Breakdown of total hours for tasks by each team member

	Time Spent Per Team Member (Hours)			
Task	**Ben Travelyn**	**Scott Liguori**	**Julian Andriulli**	**Grace Sanita**
Competition Research	23	30	30	30
Problem Research	32	36	36	36
Patent and Literature Search	12	12	15	12
Market Analysis	19	15	15	21
Inspection Research	35	40	40	40
Design	20	20	20	20
Drone Flight and Process	25	15	9	10
Proof of Concept	35	29	29	29
Preliminary Design Report	80	40	40	40
Test Drone Flights	10	7	6	1
Tests at Airport	21	18	21	12
Test Form	4	1	6	1
Survey	4	6	4	4
Process	20	20	20	20
Engineering Analysis	10	10	30	25
Video Analysis	10	1	1	1
Test Plan Report	20	13	2	1
Capstone Paper	20	12	12	4
Poster and Brochure	10	5	1	1
ACRP Competition Report	55	38	25	12
Final Report	80	40	25	22
Total	545	408	387	342

A breakdown of these hours can be seen in Figures 4-7 below.

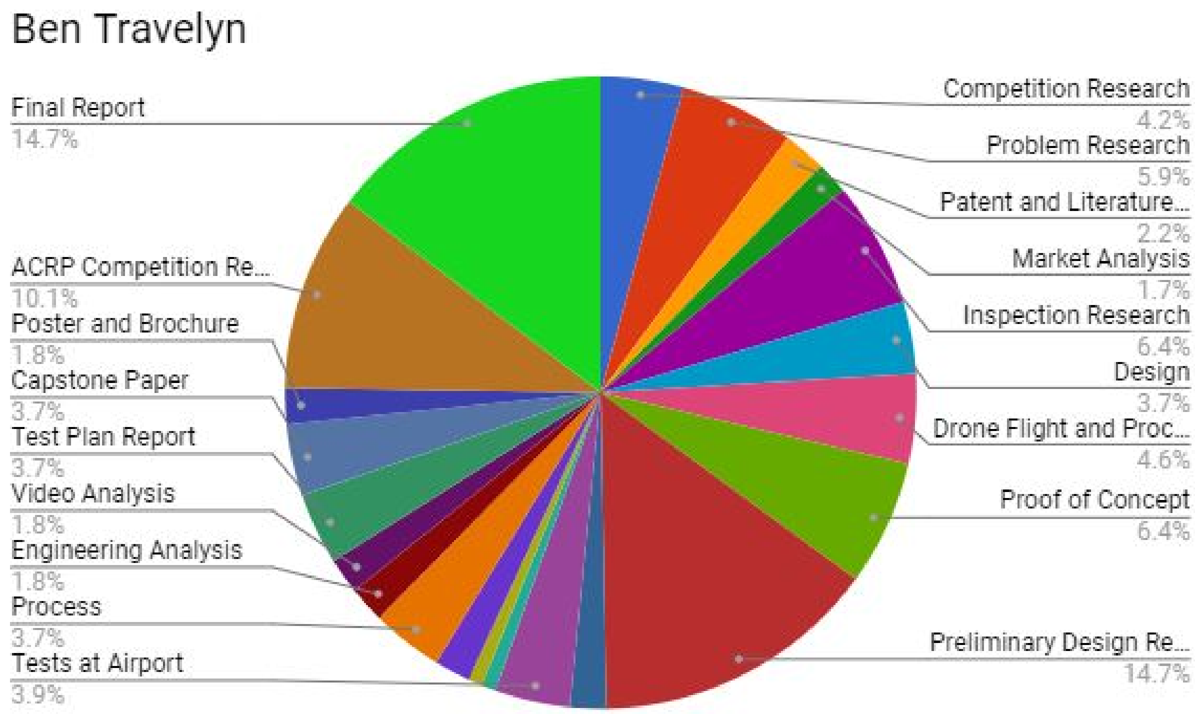


Figure 4: Breakdown of Ben Travelyn's time

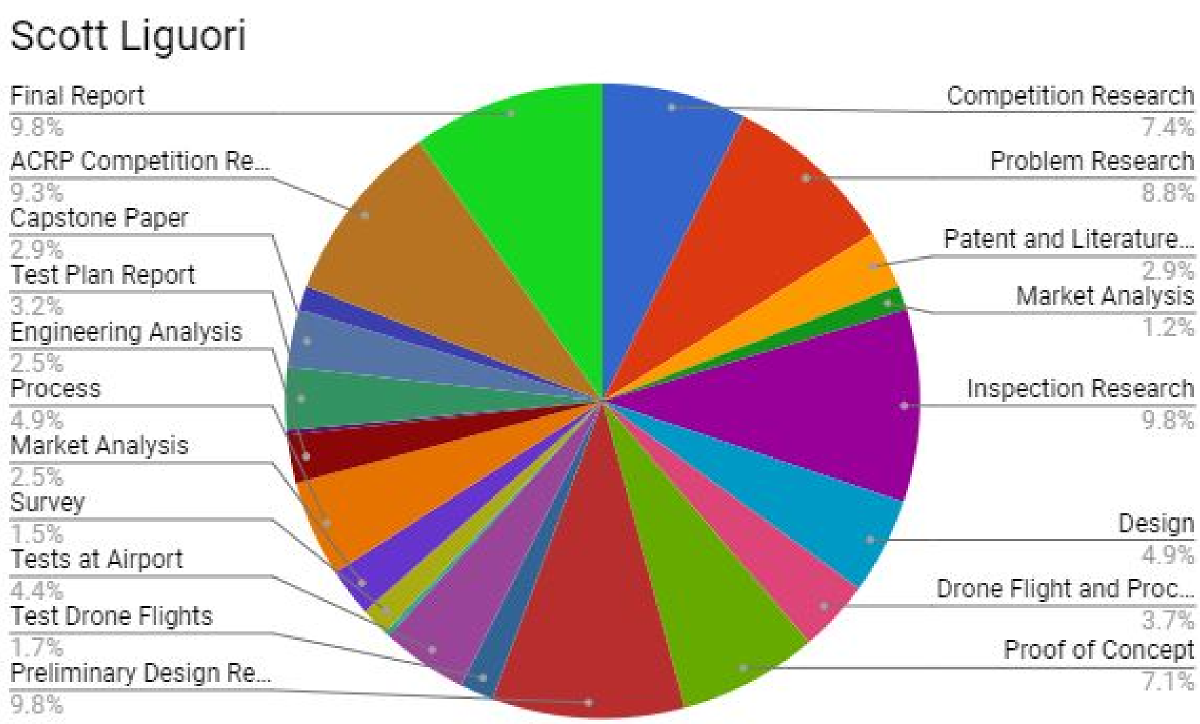


Figure 5: Breakdown of Scott Liguori's time

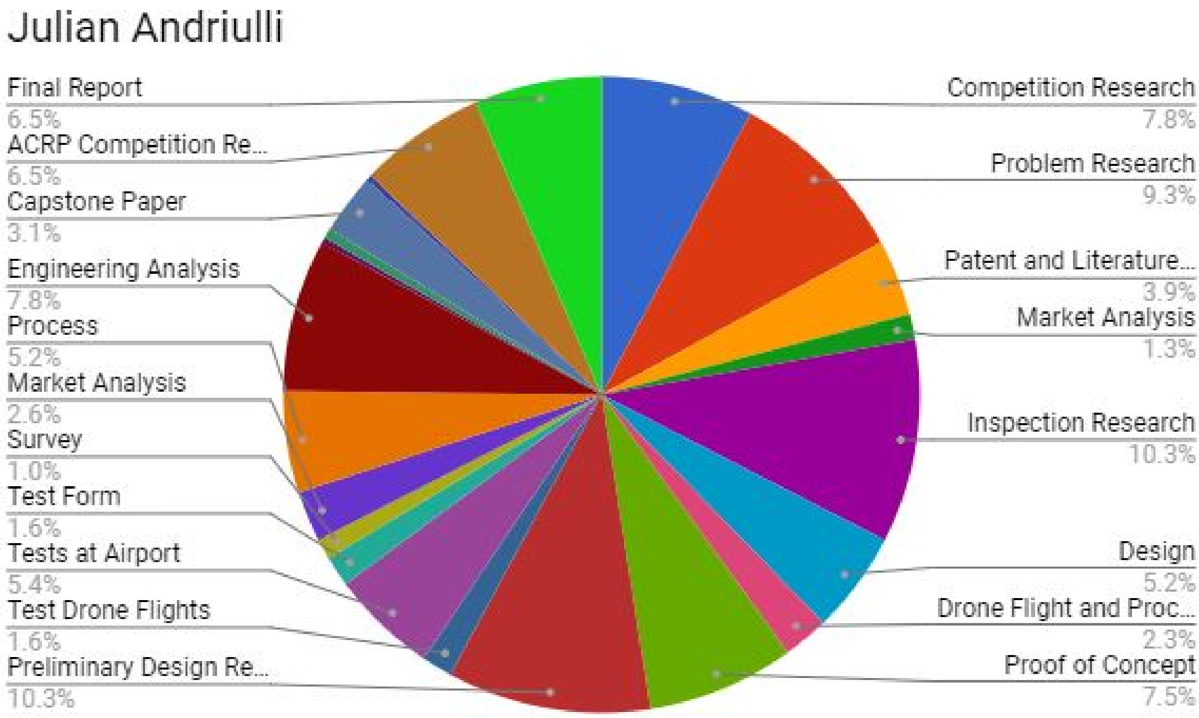


Figure 6: Breakdown of Julian Andriulli's time

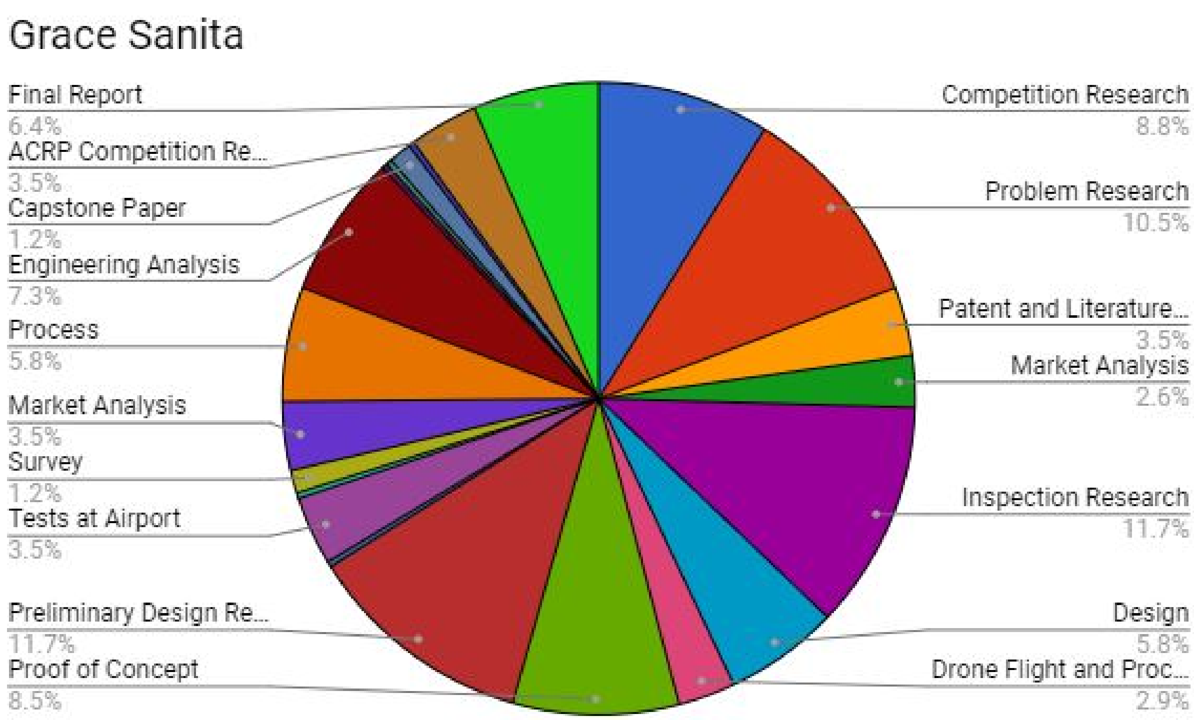


Figure 7: Breakdown of Grace Sanita's time

The team completed a total cumulative time of 1,682 hours. Along with this the team consulted with Dr. Nassersharif, Dr. Meyer, James Warcup from RIAC, and Dave Lucas from RIAC. The total time that the team consulted with Dr. Nassersharif is 15 hours, which includes design review meetings, presentation times, and questions asked. If he were to charge for his consultations, it would be valued at $150 per hour. The team also consulted with Dr. Meyer in regards to the preliminary design report for one hour, if she were to charge for the consultation, it would be valued at $150 per hour. James Warcup met with the team to discuss potential project choices, took the team on an inspection at Westerly State Airport, came to the teams proof of concept presentation and the teams build and test presentation, met with the team after to talk, and accompanied the team to Westerly State Airport and Newport State Airport each time the team conducted testing, which totaled to a time of 30 hours. Dave Lucas also met with the team to discuss potential project choices and took the team on an inspection at Westerly state airport, totaling a time of four hours. Dave and James consultation rate would be valued at $100 per hour. Below, Table 4 show the total cost for the team members time and each consultant for the project.

Table 4: Total cost of each team member and each consultant for the project

People	Time Spent	Hourly Cost	Total Cost
Ben Travelyn	545	$32.50	$15,080
Scott Liguori	408	$32.50	$11,960
Julian Andriulli	387	$32.50	$11,765
Grace Sanita	342	$32.50	$10,400
Dr. Nassersharif	15	$150	$2,250
Dr. Meyer	1	$150	$150
James Warcup	30	$100	$3,000
Dave Lucas	4	$100	$400
			$60,465

Overall, if hourly rates ($32.50) based on an entry level engineer with a $65,000 salary were applied to the project this semester and if rates from the consultants were charged, the labor for the project would be totaled at $60,465.

4 Literature and Patent Searches

4.1 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 atmospheres, new and old drone technology, and wildlife reports. Along with technical documents, the team made use of the press and media to watch current trends in the drone market.

Announcing Iris, a totally ready-to-fly UAV quad copter with our next-gen autopilot

Publication Date: August 19, 2013

Author(s): 3DR

Description: The press release announcing the mass market availability of the Iris drone discusses 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 [1].

Relevance: The team used this press release as a tool to compare the Iris drone to other drones currently out on the market. The article provided a quick and concise list of the higher-end features of the Iris drone .

Bult Field Puts Drone Technology to the Test for Wildlife Management

Publication Date: October, 2017

Author(s): Ronnie Garrett

Description: 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 managers. 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, saying, "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 setback of the drone system: the possibility that the wildlife will get used to the drone flying around. However, this setback would not be specific for drones. Wildlife also get used to the current forms of harassment [2].

Relevance: 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 have been a waste of time. 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.

How We Got Permission to Fly Drones at the Busiest Airport in the World

Publication Date: February 2, 2017

Author(s): 3DR

Description: This online press-release outlines the steps taken to allow Atkins to perform the survey mission that took place in 2017 at the Hartsfield-Jackson Atlanta International Airport. The articles also includes information about the mission itself. The press release states that the Atkins team performed a total of 7 flights, capturing over 700 nadir and oblique images, and covering an area of 40 acres. It also states that the pictures were then uploaded to the 3DR cloud where they are automatically processed into accurate 2D orthomosaics and 3D point clouds [3].

Relevance: This article inspired the team to look into different types of inspection techniques, including the 3D mapping technique that was used in Atlanta. The fact that a drone was used in an airport atmosphere proved to the team that the FAA, and individual airports are ready and willing to add drones to their toolbox. This article also pointed to the first step to get permission to fly a drone at an airport: the new FAA online portal.

Iris 3DR Drone User Manual

Description: The Iris 3DR Drone User Manual includes descriptions of and instructions for the Iris 3DR drone. These descriptions include details about the remote, batteries, charging, propellers and more [4].

Relevance: This manual was used by the team to accurately learn how to fly the Iris drone.

Unmanned Aircraft systems; UAV Design, Development and Deployment

Publication Date: 2010

Author(s): Reg Austin

Description: This book was written as part of an Aerospace Series published by John Wiley and Sons. The book includes design analysis of drones, as well as use instructions. The book also explains how drag and lift effect an unmanned areal vehicle [5].

Relevance: This book was used as a reference while completing the engineering analysis.

Wildlife Hazard Management at Airports: A Manual for Airport Personnel

Publication Date: July 2005

Author(s): Edward C. Cleary and Richard A. Dolbeer

Description: This manual includes a summary of the general wildlife strike problem, and more specifically wildlife strike records from 1990 to 2003. The manual breaks down the FAA National Strike Database for Civil Aviation. This database is broken down into data sets of strike frequency, types of wildlife involved, characteristics of strikes, aircraft components struck or damaged, and the effects of said wildlife strikes on aircraft and flights. Various agencies and organizations impacting wildlife hazard management on airports are looked into in this manual. The missions, authority, and roles and responsibilities are broken down for federal agencies, state agencies, airports, and the USA Bird Strike Committee. The federal agencies are more deeply investigated through their policies and regulations regarding wildlife management. Airport environments are investigated through the hazardous wildlife attractants on or near airports. The programs for wildlife management are explained as well as the training required for the employees to follow through with these programs. Importantly, the wildlife control strategies and techniques are laid out and explained in detail based on wildlife type and control outcome goals [6].

Relevance: This manual was originally found while the team was researching both wildlife management and the inspection of airports. It was used to research current techniques for wildlife harassment and management. It was also used to research the regulations that govern the harassment and management of wildlife. The wildlife manual became irrelevant to the team once the problem definition was set to focus on airport inspection.

Masdar Institute of Science and Technology: Autonomous Inductive Charging System for Battery-Operated Electric Drones

Publication Date: May 19th, 2017

Inventor(s): Khonji, Majid; Tseng, Chien-Ming; Alshehhi, Mohammed; Chau, Chi-Kin

Article Description: Electric drones have a wide range of applications due to the convenience and agility. One of the main hurdles for their wide deployment and full automation is the battery life limitation and the need for manual intervention for charging. In this work, they present a solar powered charging system capable of automatically charging battery powered drones in remote locations. They developed a tethered robotic rover equipped with a 2D Lidar sensor to detect and localize a drone, and a robotic arm equipped with an inductive charging pad. The charging pad senses current measurements from individual inductive coils, and adjusts accordingly the robotic arm position to maximize charging rate. Such system, in principal, can cater for arbitrary drone shapes and landing positions and is less susceptible to external lighting and environmental conditions by the use of Lidar and current sensors instead of computer vision. They remark that our system can be also applied to charging other small electric vehicles [7].

Relevance: Currently, one of the constraints on the implementation of drones for inspection usage in airports is their respective signal range as well as their battery life. As a possible future implementation into the design project, a drone and rover hybrid automated system may prove useful, both in terms of charging the drone and stretching the signal range area of the drone.

The Drag Coefficient,

Publication Date: May 05, 2015

Author(s): Nancy Hall

How does temperature and wind speed change as you go higher in elevation from sea-level

Publication Date: April 17, 2015

Author(s): Michael Barnard

How to Calculate Air Density

Publication Date: 2018

Author(s): Steve Griffin
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 [8] [9] [10].

4.2 Patent Search

As manifesting a creative and practical product design requires research, brain storming, and accumulation and utilization of ample knowledge, patent searches are an absolutely necessity in the creative process. As engineers it is important to know what has already been developed so that people may recognize the competition, know what has to be developed and what doesn't, and know how to not take excessively from a preexisting design. Stealing others ideas and patents is of course out of the question, but reading and learning about what other patents have to offer in order to teach us about relevant subject matter can assist immensely in the development process.

US 20170343665: Low Cost Apparatus and Method for Multi-Modal Sensor Fusion with Single Look Ghost-free 3D Target Association from Geographically Diverse Sensors

Publication Date: November 30, 2017

Inventor(s): Willey, Jefferson M.; Pavek, Richard E.

Patent Description: A system performs operations including receiving pairs of sensor signals indicative of imaging of an environment, each pair of sensor signals including (i) a first sensor signal received from a first sensor and including first spatial coordinates and a first signal characteristic and (ii) a second sensor signal including second spatial coordinates and a second signal characteristic. The operations include identifying valid pairs of sensor signals, including determining that an address including the first coordinates of the first sensor signal of a given pair and the second coordinates of the second sensor signal of the given pair corresponds to an admissible address in a set of admissible addresses stored in a data storage. The operations include identifying, from among the valid pairs of sensor signals, pairs of sensor signals that satisfy a threshold, including determining that a value based on a combination of the first signal characteristic of a given pair and the second signal characteristic of the given pair satisfies a threshold value. The operations include generating a representation of a target in the environment based on the identified pairs of sensor signals that satisfy the threshold [11].

Relevance: As the purpose of the teams design project is to conduct an inspection of airport perimeters as well as runway and taxiway lighting, This patent provides an extremely relevant method of imaging an environment with sensors and judging distances from given targets. As we looked extensively into image recognition software, lasers, and sensors to be used with a drone. The team initially thought that if sensor pairs were used, such as the ones proposed within this patent to locate the positioning of objects on a runway, but as further research was done with sensors, lasers, and RFID tags, it was determined that such distance measuring and location devices would not be necessary within a drone inspection.

US 20170344828: Pavement Marking Determination

Publication Date: November 30, 2017

Inventor(s): Akselrod, Ben Z.; Di Loreto, Anthony; McDuff, Steve; Robeson, Kyle D.

Patent Description: In an approach to determining pavement markings, a computer determines a location of a first computing device based on data received from one or more location devices associated with the first computing device. The computer then retrieves pavement marking data for one or more pavement markings for the location and determines whether one or more existing pavement markings are present at the location. Responsive to determining that one or more existing pavement markings are present at the location, the computer determines whether each of the one or more existing pavement markings meet one or more pre-determined thresholds for an acceptable pavement marking quality. Furthermore, responsive to determining each of the one or more existing pavement markings do not meet the one or more pre-determined thresholds for an acceptable pavement marking quality level, the computer provides pavement marking data to the first computing device [12].

Relevance: Holding much greater relevancy to the teams previous design problem, various methods of image processing/image recognition software were researched that could have been used to determine the overall quality and upkeep of inspection items. This patent detailed the computer software based image analysis of pavement markings, which the team contemplated heavily to implement into the project, but after discussion of the logistics and cost constraints with GA airport staff, it was determined that a more simple approach of utilizing unaltered standard HD video would suffice in assisting GA airport inspection efficiency.

US 20170352100: Image Segmentation System for Verification of Property Roof Damage

Publication Date: December 7, 2017

Inventor(s): Shreve, Matthew Adam; Bernal, Edgar A.; Howe, Richard L.

Patent Description: A system segments a set of images of a property to identify a type of damage to the property. The system receives, from an image capturing device, a digital image of a roof or other feature of the property. The system processes the image to identify a set of segments, in which each segment corresponds to a piece of the feature, such as a tab or tooth of a shingle on the roof. The system saves a result of the processing to a data file as a segmented image of the property, and it uses the segmented image to identify a type of damage to the property [13].

Relevance: Similar to the previously mentioned patent, this patent details another inspection method using image processing/recognition software to verify the amount of damage sustained by rooftops. Instead of using an image correlation method determining if markings within the image are above set thresholds, this method utilized a simpler software design implementing image sub feature segmentation, and analyzing the sub features to determine sub feature type and subsequent sub feature damages. This was also heavily contemplated, but was similarly determined to be a superfluous design to implement.

US 20170353229: Facilitating communication with a vehicle via a UAV

Publication Date: December 7, 2017

Inventor(s): Sham, Wellen

Patent Description: Embodiments are provided for facilitating communications with a vehicle through an unmanned aerial vehicle (UAV). The UAV can be configured to track vehicles traveling in an area covered by the UAV. An identification of the vehicle can be acquired after the vehicle is tracked by the UAV. The vehicle identification can be used to determine communication capability of the vehicle. Based on the determined communication capability of the vehicle, a communication request can be initiated by the UAV. The vehicle can determine whether to accept the communication request from the UAV or turn it down. If the vehicle accepts the communication request from the UAV, information intended for the vehicle, for example from another vehicle, can be forwarded to the vehicle by the UAV [14].

Relevance: This type of communicative technology was contemplated prior when discussing the type of inspection that the design team should pursue. The team concluded that this method would be most useful within the context of security measures by communicating with vehicles/pedestrians trying to enter airports without proper authorization. This could be a potentially feasible implementation of drone inspections within airports, but is less relevant to smaller General Aviation airports, as security tends to be a less pressing issue for them.

US 20180103206: MOBILE CAMERA AND SYSTEM WITH AUTOMATED FUNCTIONS AND OPERATIONAL MODES

Publication Date: December 26, 2017

Inventor(s): Olson; Erlend

Patent Description: 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. 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 [15].

Relevance: 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.

US 9,721,264: METHOD AND SYSTEM FOR PROPERTY DAMAGE ANALYSIS

Publication Date: July 28, 2017

Inventor(s): Labrie; Zachary

Patent Description: 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 9,721,264), 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. The drone is able to automatically generate a flight path around a structure, and then captures visual data for future software analysis [16].

Relevance: 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.

5 Evaluation of the Competition

The current and only inspection process at airports is to manually drive and walk around the airport. The teams proposed method of automating the inspection process can significantly reduce man hours and yearly costs for airports while also increasing the ability to inspect inaccessible parts of the airport that would not frequently be inspected.

As discussed in the Financial Analysis section, the team is planning to create a company that will sell the process created, the preprogrammed routes for their respective airport, and the knowledge behind the process and design and the airport will just have to purchase the products needed. 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 6, totaling $1,017. 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.

Currently, on the market there is no other company or anyone who offers this service, so the teams company has complete control on this market, so prices can be fully determined by the team. The only inspection competitor is the current inspection process of walking and driving around the airport to conduct the inspection. The team/company could expand their market by purchasing a drone with a larger range to inspect larger 139 airports, such as TF Green.

So, currently the teams company has complete market advantage and control of the inspection process using the drone. But, of course if the teams company does well and gains popularity, other companies will start forming to compete. The way to gain market advantage through this is to lower prices to attract more customers and further gain popularity. Also, since the team has a close relationship with the Rhode Island Airport Corporation

(RIAC), they could promote the company and airports that have used this inspection process can recommend the company, this would help other airport choose this company over competitors.

6 Specifications Definition

In the beginning of the year, the team decided on a problem definition of automating the inspection process at an airport. Once this was known, the team created design specifications that were later met to achieve a successful design. The design specifications can be seen below in Table 5. 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, the design must reduce man hours used for inspection, design a durable and maintainable system that is accurate. In order to meet all of these requirements, research needed to be completed.

The team determined the specifications of the 3DR Solo drone and the GoPro Hero 4 Black camera. The main specifications of the drone are it has manual or autonomous flying, it has a battery life of 20 to 25 minutes, a maximum speed of 55 mph, and has a maximum control distance of 2,640 ft. Since the constraints of the drone are now known, this can now be transcribed into engineering requirements. These engineering requirements are that since the minimum battery life is 20 minutes, the drone must complete the inspection in less than 20 minutes, which then determines the speed the drone must travel. The speed the drone must travel is less than 55 mph and greater than 15 mph, in order to complete the inspection in less than 20 minutes. The next constraint set is the maximum control distance of the drone is 2,640 ft, which means that the path of the drone in any direction must be under 2,640 ft. Another constraint set by the drone is a payload of 0.9 pounds, which is no problem because the only device attached to the drone is the GoPro camera which is about half of the maximum payload. A very important customer requirement is that the design must be adaptable to different airports, this can be achieved using the custom autopilot flight plan feature for the drone using the Tower app on the Samsung Galaxy tablet. The specification of the GoPro Hero 4 Black camera are, it has a maximum battery life of 50 minutes, which is well over the time needed to complete the inspection, the video resolution is 4k 30fps, which is a very high definition camera, and uses a micro SD card for memory, which is up to 256 GB. The customer requirements of the design being accurate, can be transcribed to the engineering requirement of camera resolution and inspection accuracy, which is 4k 30fps, since it is such a high definition camera, it will be able to clearly and accurately display everything in the inspection. Another customer requirement is user friendliness, which was transcribed into the engineering requirement of setup time, the set up time will be less than 5 minutes because all the user must do is connect the battery to the drone, the battery to the camera, and connect the camera to the drones gimbal. Another big customer requirement is maintainability of the design, which strongly relates to the engineering requirement of maximizing the lifespan, which the team is aiming to create a lifespan of three years before the technology on drones significantly increases. Another important customer requirement is safety, the design will abide by the FAR UAS Part 107 of not flying above 400 feet and a Notice to Airmen (NOTAM) will be issued to alert incoming planes to not land because there is a drone in the airport, but in the rare case of a plane disregarding this, the drone will always be in the users line of sight so he/she can press land and the drone will immediately land. One of the most important customer requirements and one of the main aims of the design is the reduction of man hours in the airport. Implementing the drone for inspections can completely replace an airport employee, saving the airport a lot of money, and reducing the man hours. Or, the employee can complete other tasks during the time they would have been conducting an inspection, also reducing man hours.

Table 5: Design Specifications

Specification	Description
Product Identification	
Product Name	–3DR Solo Drone –GoPro Hero 4 Black
Basic Function	Automation of daily airport inspections using an unmanned vehicle
Special Features	–Custom autopilot flight paths –Gimbal compatibility –Micro SD memory card can be increased to 256GB
Key Performance Targets	–Automation of inspection tasks –Little or no human element involved
Service Environment	–Outdoors –Good flying conditions
Training Required	–Training to fly drone

Inspection Information	–Inspection Duration: <20 min.
	–Maximum Distance Away: 5280ft
	–Inspection Occurrences
	  –1 required per day by FAA
	  –Multiple completed per day
	–Adaptable to various airports
	–Inspection Accuracy: 100%
	–Reduction of man hours in airport

Market Identification	
Current Customer / Market	Westerly State Airport & Newport State Airport
Long Term / Anticipated Market	General Aviation Airports around the country
Competing Products	–Current Inspection Process –Walk or drive around to conduct inspection
Branding Strategy	–ARCP Design Competition –Help from RIAC

Key Project Deadlines	
Deadlines	–Notice of intent for ACRP Competition: 1/27/2018 –Review Meeting 1: 2/14/2018 –Review Meeting 2: 3/23/2018 –Build-Test Presentation: 4/6/2018 –Review Meeting 3: 4/20/2018 –ARCP project submission deadline: April 27, 2018 –Final Report for Spring Semester: 5/7/2018
Time to Complete Project	Beginning of 2017 academic year- April 27, 2018
Physical Description	
Drone Specifications (3DR Solo)	–Manual or autonomous flying –Custom autopilot flight plans –Compatible with: –GoPro camera –Alfa Wifi Antennas –Battery Life: 20 to 25 min. –Max Control Distance: 2,640 ft –Max Speed: 55 mph –Payload of Drone: 0.9 lbs
GoPro Specifications (GoPro Hero 4 Black)	–Battery Life: 50 min –Video Resolution: 4k 30fps –Camera Resolution: 12 MP –Memory Space: Micro SD Card Required –8 to 256 GB
Operating Environment	–Good flying conditions –Potentially in rain and snow
Setup	–Setup time: <5 –Ease of setup
Financial Requirements	
Expected Costs	–Cost of 3DR Solo: $585 –Provided by Dr. Nassersharif –Cost of GoPro: $292 –Provided by Ben Travelyn –Cost of Samsung Galaxy Tablet: $120 –Provided by Dr. Nassersharif –Budget of $1,000 –To use for any additional costs
Reduction of Airport Spending	–Inspection automation should save money by reducing man hours
Lifecycle Targets	

Target Lifecycle	Minimum of 3 years
Maintenance Schedule	–Charging: –Drone and camera batteries charged after each inspection – 3DR Solo replacement parts –Four extra rotors (more can be ordered) –Two batteries (more can be ordered) –GoPro Hero 4 Black replacement parts –Four batteries (more can be ordered) – Three micro SD card (more can be ordered)
Social / Political / Legal Requirements	
FAA	–FAR UAS Part 107: Small UAS Rule –Cannot fly above 400 ft ceiling –Cannot operate within 5 mi of airport – RIAC provided team with Operational Direction
Safety	–Drone will always be in line of sight –Drone will only be flown when a NOTAM is issued –Will abide by FAR UAS Part 107 (below 400 ft)
Manufacturing Specifications	
Manufacturing Requirements	Potentially waterproofing drone, not currently necessary
Suppliers	Suppliers will be determined when needed

7 Conceptual Design

In the beginning of the Fall 2017 semester, each capstone student was assigned a project and once assigned a project each team member of that project had to generate thirty concepts each in order to choose a concept to develop into a product. Each of the four members concept generations can be seen in the following section. The four team members now have a total of 120 concepts, which was narrowed down to one for this project. Not every concept has a respective picture due to there being some concepts that do not need a picture to help understand the design. The concepts generated were for drones being used for inspection, a drone being used for harassing wildlife, drone waterproofing designs, and potential rover designs. However, in the end, the team decided to focus on the automation of the inspection process of a general aviation airport using a drone, focusing on inspecting the perimeter and security and runway and taxiway lights.

7.1 List of Concepts Generated

7.1.1 Benjamin Travelyn Concept List

1. A drone will have predetermined GPS coordinates programed throughout an airport, so a worker will have to just turn the drone and camera on and put it outside and press go and the drone will fly through each position conducting the inspection for

the airport worker. A live stream video from the attached GoPro will be watched by one worked and will check off each part of the inspection as the drone is flying. This will save man-hours from having workers walk around conducting the inspection. Relevancy: 10

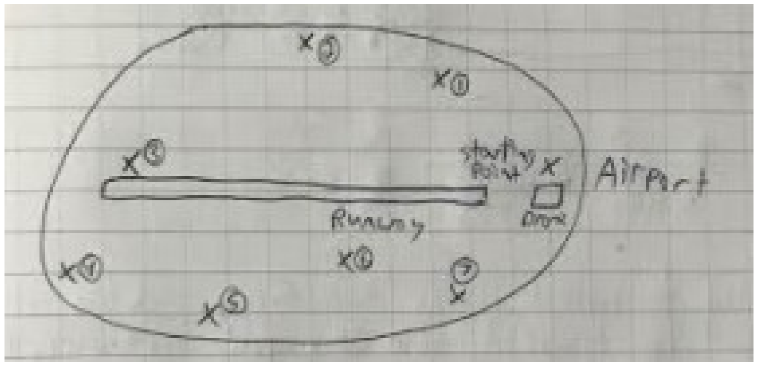


Figure 8: Ben Travelyn Concept 1

2. A drone will have predetermined GPS coordinates programed throughout an airport, so a worker will have to just turn the drone and camera on and put it outside and press go and the drone will fly through each position conducting the inspection for the airport worker. But instead of a worker watching the live stream, the video can be put into a video analysis software where a passing inspection was previously conducted and the new video will be compared to the passing video and it will see if the videos match, and if they do then the inspection will be passed. Relevancy: 8

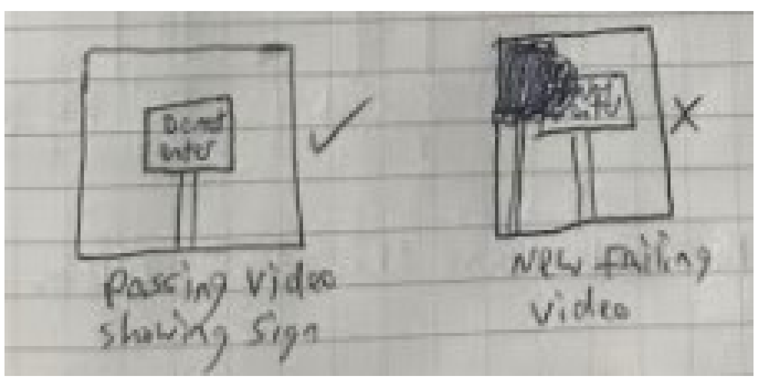


Figure 9: Ben Travelyn Concept 2

3. A drone will manually be flown by an airport worker and they will conduct the inspection, rather than programming the drones GPS. A live video will still be watched to conduct the inspection. Relevancy: 3

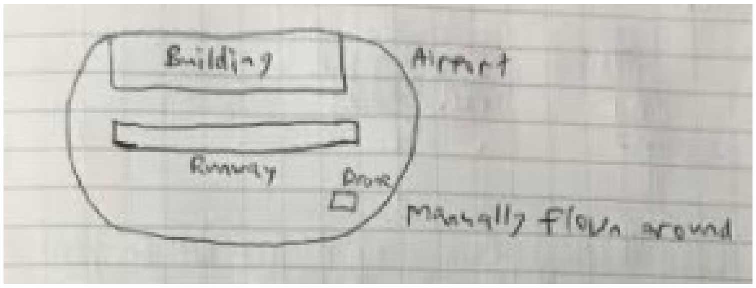


Figure 10: Ben Travelyn Concept 3

4. A drone will have predetermined GPS coordinates programed throughout an airport, so a worker will have to just turn the drone and camera on and put it outside and press go and the drone will fly through each position conducting the inspection for the airport worker. Instead of a live feed from the GoPro, when the drone is taken back inside the micro SD card will be removed and inserted in the computer and then the video will be inspected. Relevancy: 6

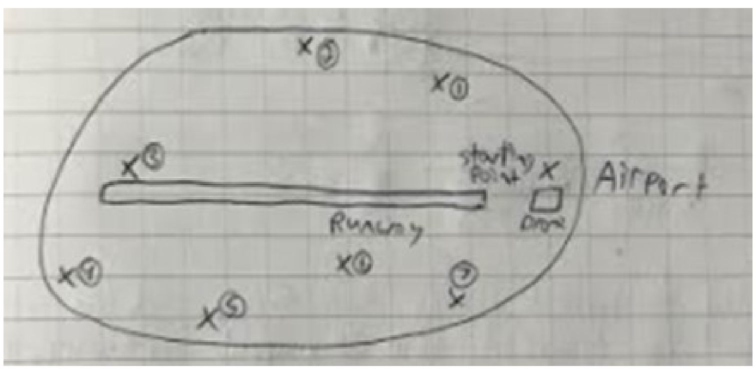


Figure 11: Ben Travelyn Concept 4

5. At each point of inspection, say for example the part when each sign is checked to make sure it is still there and visible. An RFID tag will be put on each sign and a reader will be attached to the drone and as the drone is set on its predetermined GPS coordinates programed throughout the airport as it passes by each sign a signal will be received by each RFID tag uniquely to show the drone did pass by each point. Relevancy: 8

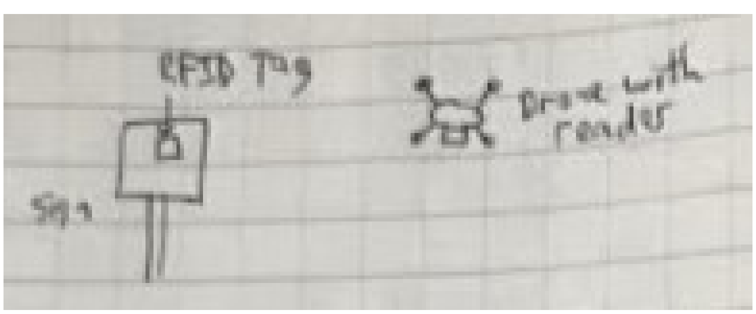


Figure 12: Ben Travelyn Concept 5

6. Similar to other concepts, the drone will be preprogrammed to be flown through GPS points, but for this the drone will but used for inspection of the runway. Rather than a GoPro being attached, a thermal imaging camera would be attached and would be able to show cracks on the runway due to temperature differences. Once the video is analyzed, either by live feed or by removing micro SD card, the cracks can be located and fixed. Relevancy: 7

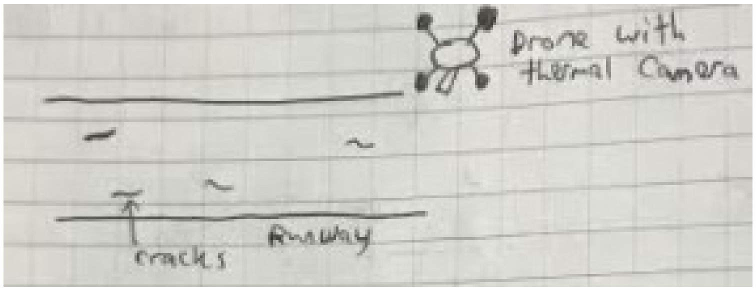


Figure 13: Ben Travelyn Concept 6

7. The drone will be flown over the runway with the camera pointed directly down at the ground and 3D mapping (topography) software, could be used to update the runway topography map and doing this can help find foreign debris or cracks. Relevancy: 7

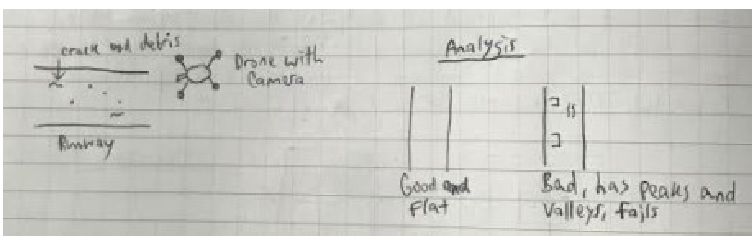


Figure 14: Ben Travelyn Concept 7

8. Drone process can be anything from concepts 1-7, but the drone will attempt to be waterproofed by creating some type of "wet-suit" that could be made to slip on covering the major components on the drone to keep the water off of the drone. The "wet-suit" will have to be a material that wont melt. Relevancy: 7

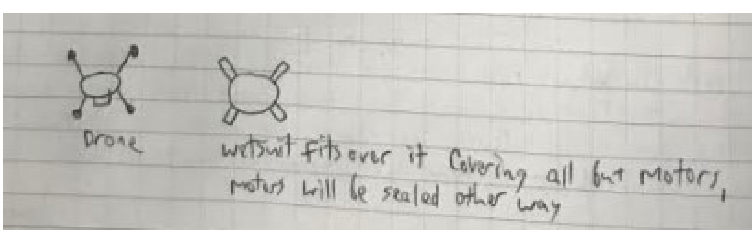


Figure 15: Ben Travelyn Concept 8

9. Drone process can be anything from concepts 1-7. The exposed parts of the internals of the drone will have a plastic casing built or 3D-printed to connect around it and all

of the cracks or openings will be covered. Then either some type of gasket or filling can be applied to the internals of the motor. A heat analysis of the motors will be conducted to see if the material will melt around the motors. Relevancy: 8

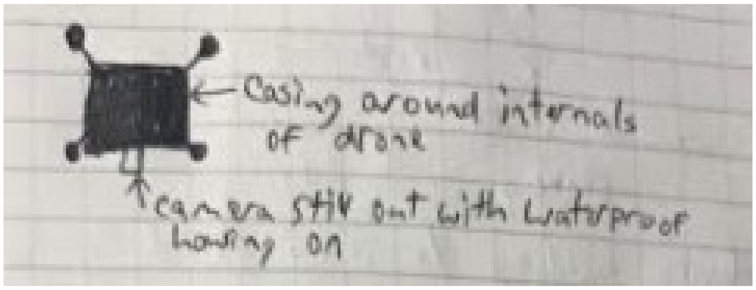


Figure 16: Ben Travelyn Concept 9

10. Drone process can be anything from concepts 1-7. Drone can be opened up and a waterproofing spray such as, "Corrosion-X Spray" can be applied to the electronic components to make them waterproof. Also, motors will be sealed like previous design. Relevancy: 6

11. Drone process can be anything from concepts 1-7. A bubble like umbrella could be attached to the top of the drone to keep water from getting on the drone, therefore making it waterproof. Relevancy: 3

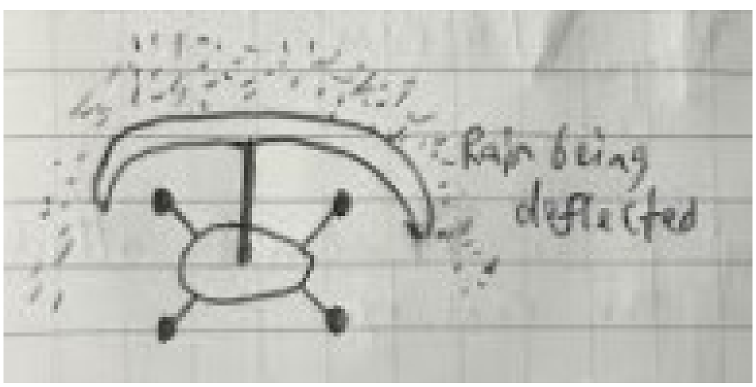


Figure 17: Ben Travelyn Concept 11

12. The drone could be used to help with the inspection of an airplane. When the inspections occur it is hard for an airport worker to get up to the top of bigger planes, so a drone could be used with a live feed from a camera so they can do the inspection that way so they can get to hard to reach places. Relevancy: 5

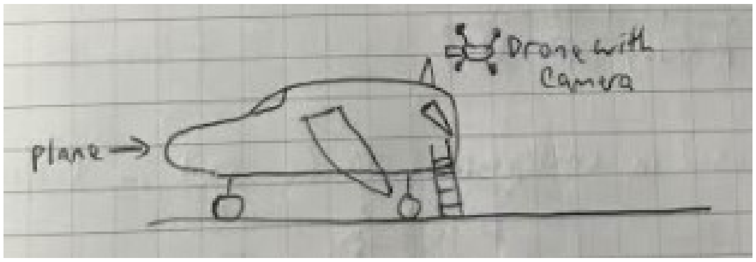


Figure 18: Ben Travelyn Concept 12

13. The drone will be programmed to fly through certain points in the airport as stated in previous examples, but rather than recording using video, the camera will be set to take photos at certain intervals so there will be a photo for each sign, light, or whatever the drone will be expected to inspect. Similar to the video comparing software, the photos will be compared side by side with pre-taken photos of the passing inspection. The photos will show that for example a sign isn't visible, isn't there or is visible and the software will be able to tell, and then the inspection will be passed or failed. Relevancy: 6

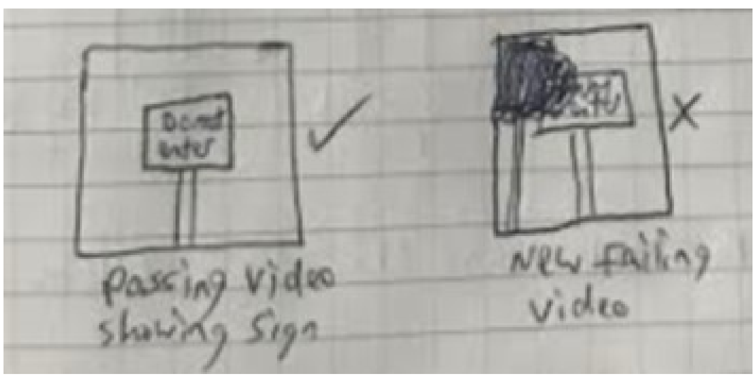


Figure 19: Ben Travelyn Concept 13

14. If a drone with a higher payload could be acquired, then a vacuum type device can be attached and the drone can be flown to inspect the runway. The drone can be flown up and down the runway and a live feed will be playing and if the drone operator sees any type of debris on the runway, then it can be lowered to the ground and the vacuum can suck in the debris. This would eliminate the need for multiple walkers to walk up and down the runway checking for debris. Relevancy: 6

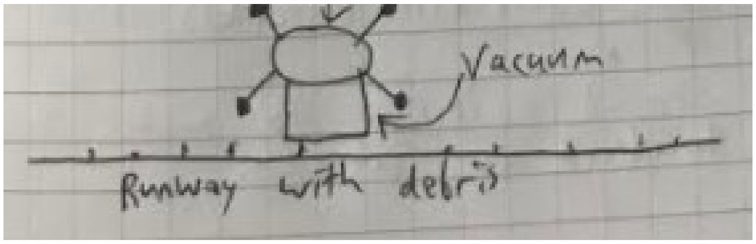


Figure 20: Ben Travelyn Concept 14

15. Quonset airport has a big problem with birds dropping shells on the runway and it always has to be swept off. This could be used there or anywhere that faces a problem with excess debris on the runway. A broom like sweeper could be attached to the drone and the drone can be flown low to the ground and sweep the shells to the side, this will eliminate a worked from having to go out and sweep them off of the runway. Relevancy: 4

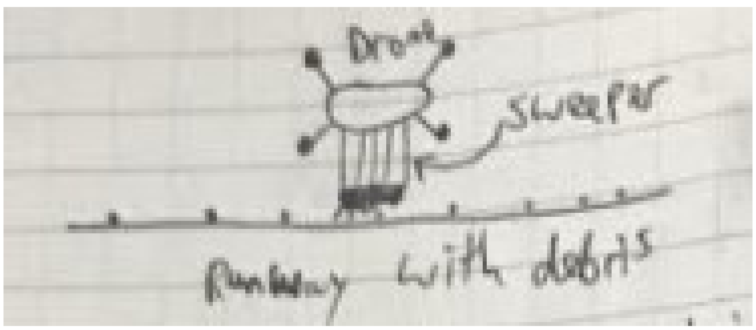


Figure 21: Ben Travelyn Concept 15

16. If a drone with a higher payload could be obtained then a device holding de-icing fluid could be attached to the drone and flown above an airplane to pour de-icing fluid on the drone, because that is a hard to reach place for people spraying the plane with de-icing fluid. Relevancy: 4

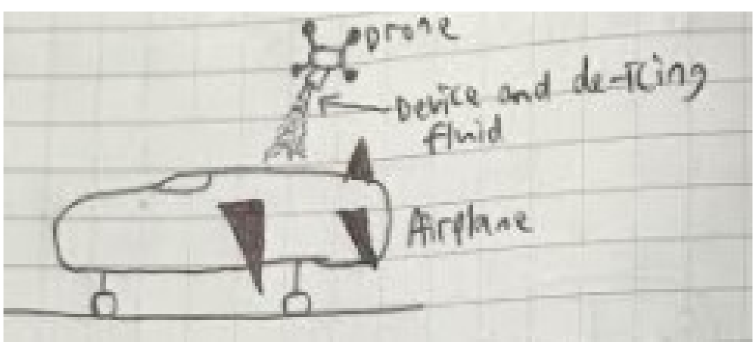


Figure 22: Ben Travelyn Concept 16

17. Some type of compressed air device with a remote trigger can be attached to the drone and the drone can be flown up and down the runway inspecting for foreign debris and

when the drone operator spots something then the drown will be flown to it and the compressed air will be sprayed on it and the debris will be pushed off of the runway. Relevancy:4

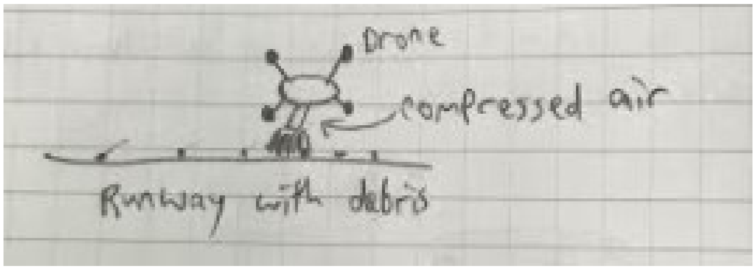


Figure 23: Ben Travelyn Concept 17

18. The drone could be implemented to be used in emergencies such as fires, emergency landings, or a crash. If something occurs, then the drone can be flown within a close proximity to get a better look before first responders are sent in. Relevancy: 5

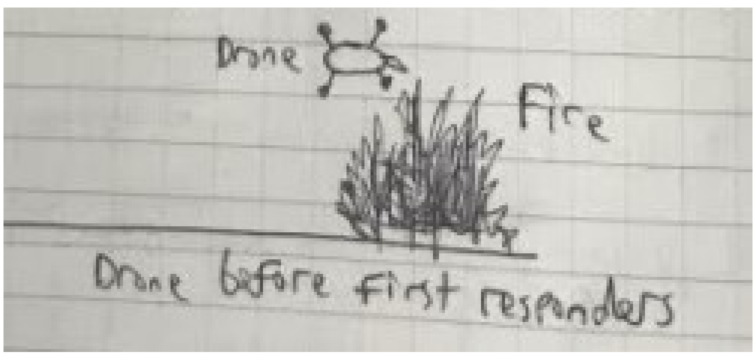


Figure 24: Ben Travelyn Concept 18

19. When an inspection occurs for the surrounding fences or any sort of suspicion of an intruder the drone can either autonomously be sent on a direct path above the fence or manually flown around the fence with a live stream so they can see if there is a breach of security rather than sending a worker out right away. Relevancy: 5

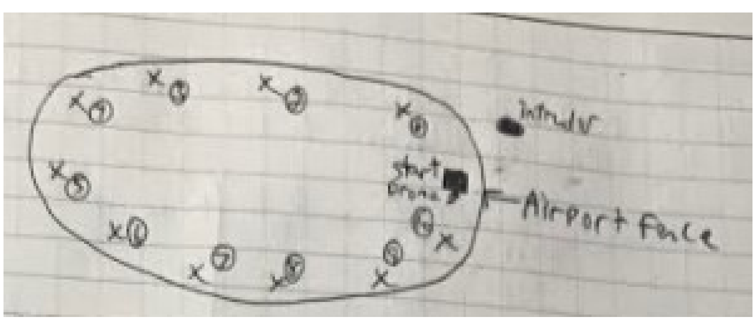


Figure 25: Ben Travelyn Concept 19

20. The Eye in the Sky project can be used to detect when a drone is in proximity of the airport and when the tower gets an alert that there is a drone then they can send their drone out that has a device attached to it that can disable a drone. This drone will be sent in the direction of the approaching drone and disable it so it cannot come into the airport. Relevancy: 7

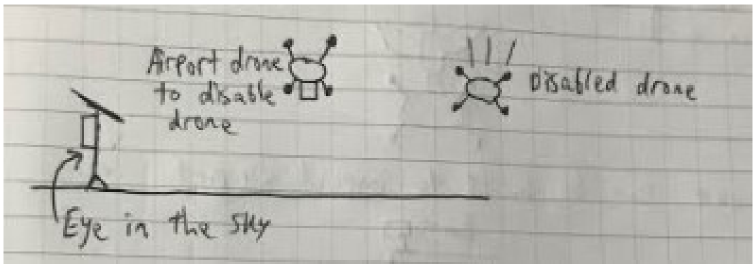


Figure 26: Ben Travelyn Concept 20

21. A drone with some type of arm with a claw attached to the bottom that can pick things up will be attached to the bottom of the drone. This can be flown to objects on the ground around the airport or to objects on the runway and used to pick them up, instead of airport workers walking around picking up trash. Relevancy: 5

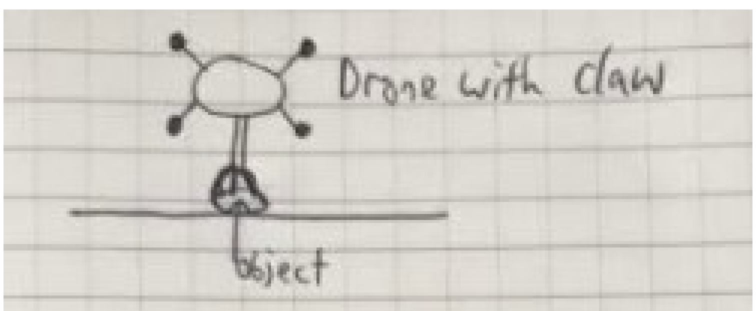


Figure 27: Ben Travelyn Concept 21

The concepts below will be for scaring birds out of an airport:

22. The drone will be equipped with a device that “screeches” loud sounds. So as the drone flies toward the birds they will be scared due to the sound of the drone and the screeching sounds. This will eliminate the current process of airport workers driving over to the birds and firing an air gun to scare the birds away. Relevancy: 5

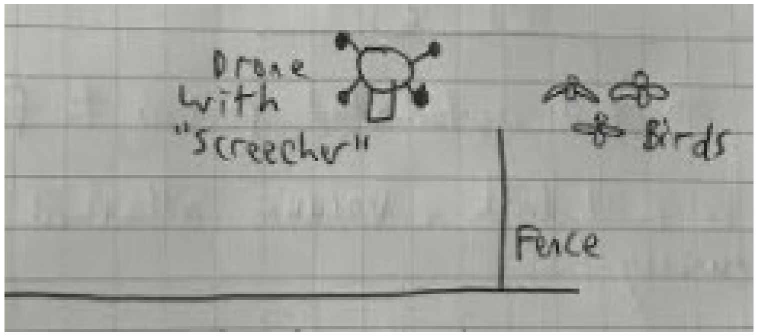


Figure 28: Ben Travelyn Concept 22

23. Same as previous concept, but also including a flashing strobe light with the "screecher" so the birds see that and the drone coming. This adds another component to keeping birds out. Relevancy: 6

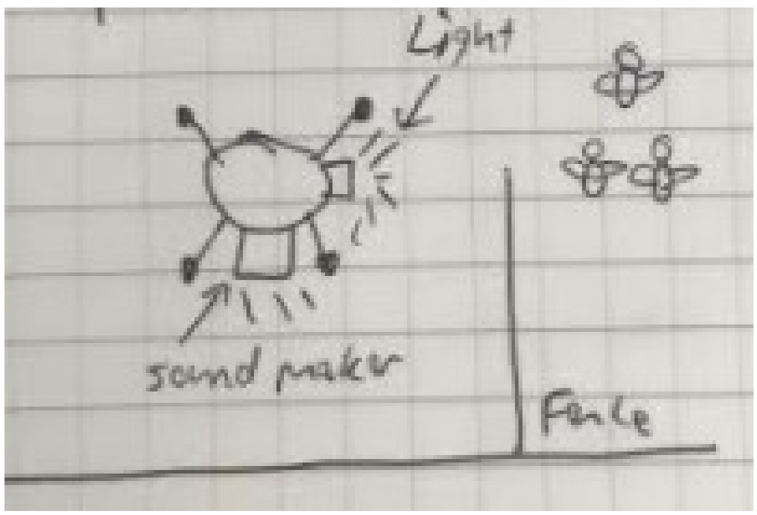


Figure 29: Ben Travelyn Concept 23

24. At TF Green they have a device that simulates a firework to scare the drone. This could be attached to the drone to be able to bring this device closer to the birds so it has a higher chance of scaring the birds away. Relevancy: 6

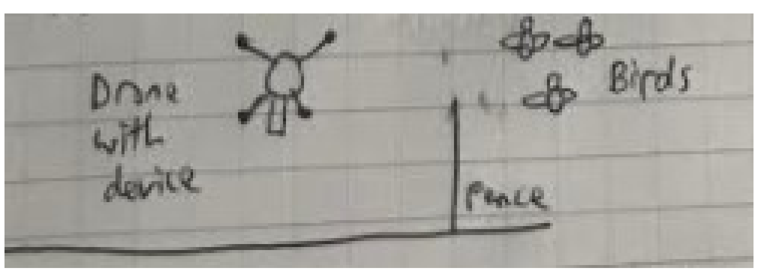


Figure 30: Ben Travelyn Concept 24

25. A release mechanism could be attached to the bottom of the drone to put a firecracker/firework like object that is safe but that creates a loud sound can be attached to the release mechanism. Once it is attached then the drone can be flown to the birds and when its target is reached the drone operator could press a release button and the object can be dropped and detonated without damaging the drone. Relevancy: 6

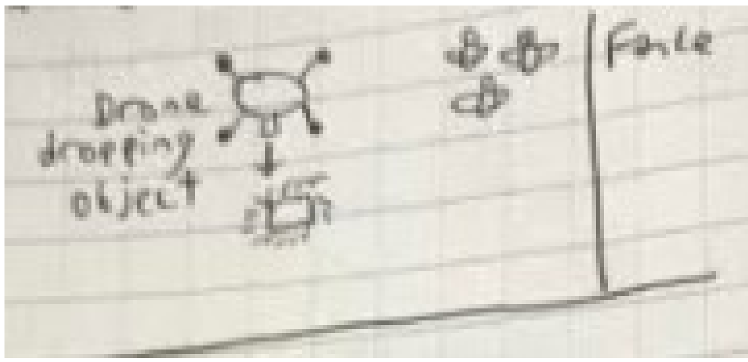


Figure 31: Ben Travelyn Concept 25

26. A fake predator bird can be attached to either the bottom or top of the drone and flown at the birds to scare them off. Currently airports put out fake animals to scare of the birds, but eventually they figure out it is fake. It is harder to find out this is fake when it is flying at the birds. Relevancy: 4

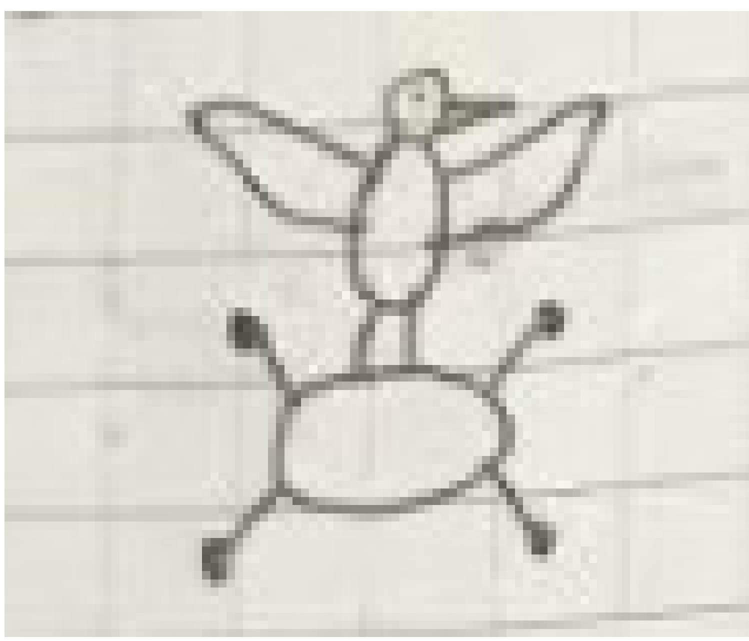


Figure 32: Ben Travelyn Concept 26

27. A drone with a remote trigger connected to an air horn or pop gun can be connected to the drone and flown to where birds are. One the drone is near the birds the trigger can

be activated and the loud sound will come out and scare the birds out of the airport. Relevancy: 4

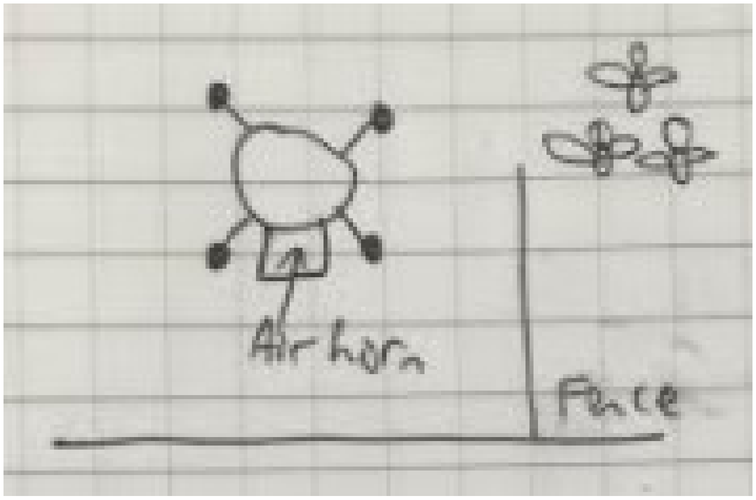


Figure 33: Ben Travelyn Concept 27

The concepts below are other concepts considered:

28. A rover could be built to travel on land rather than in the air, still with a mounted camera. This could be operated by an airport worker and driven to each spot in the inspection. Also, the rover would attempt to be waterproofed. Relevancy: 6

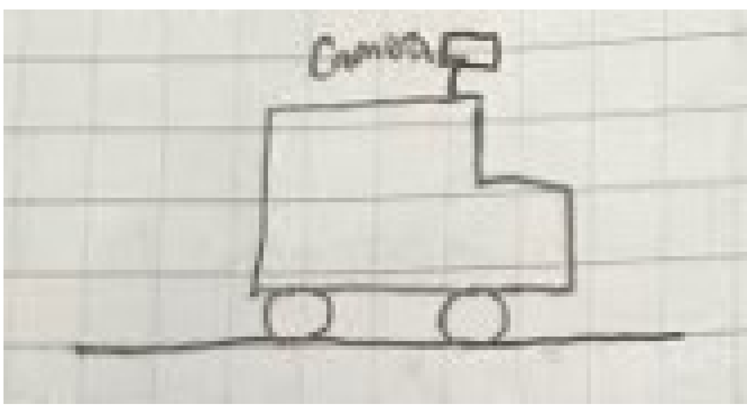


Figure 34: Ben Travelyn Concept 28

29. Same as previous concept except a special program will be written to program the drone to go to GPS coordinated like the drones talked about were programmed to do. If it is programmed then no airport worker would have to operate it, it would just have to be taken outside and turned on and press go. Relevancy: 7

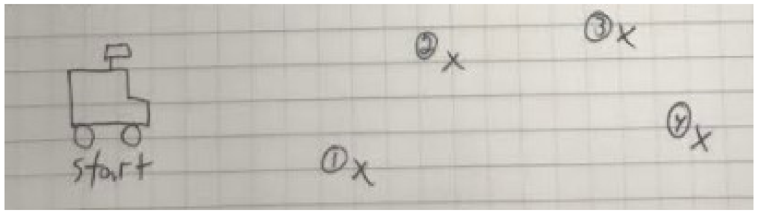


Figure 35: Ben Travelyn Concept 29

30. A rover will be built to specifically used for clearing debris off of a runway. It will have a vacuum or some type of device to suck up the debris on the bottom of the rover. It will be driven by an airport employee up and down the runway until all debris is gone Relevancy: 6

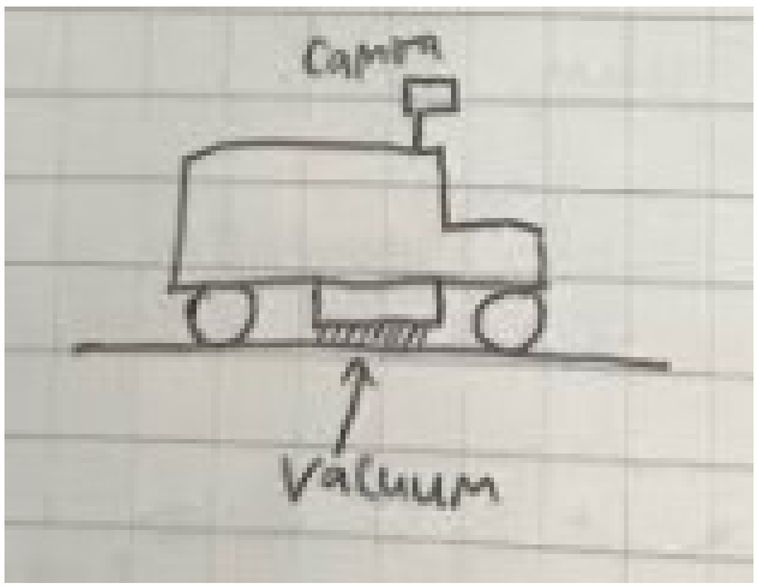


Figure 36: Ben Travelyn Concept 30

7.1.2 Scott Liguori Concept List

1. Airport worker manually flies a drone around the airport perimeter to conduct routine inspection tests with a live feed camera on drone. This concept allows the worker to manually operate the drone to allow for human discretion for inspection of airport parts, lights, signs etc. The positive in this design includes the operator having absolute control of the drone within the airfield. The only design would be determining the size of the drone and setting up the camera live feed. This design is more of a process than a design concept. Relevancy: 1

Figure 37: Scott Liguori Concept 1

2. Drone flies to predetermined, programmed spots on airfield with an attached camera with a live feed to the control tower or an airport worker. The programmed drone allows for autonomous flying which is a major highlight in the design. Dr. Nassersharif's drone allows for custom flight paths to be programmed and executed which would be designed for the specific airfield the inspection takes place (if allowed). The live feed camera (GoPro) provides real-time monitoring airfield and drone. This concept is very plausible as we have the resources (BN's drone) and would need to learn how to code and program the drone which may be tough with very limited programming skills in the group but extremely achievable. Relevancy: 8

Figure 38: Scott Liguori Concept 2

3. Same as Concept 2 but each predetermined spot has a signal whether or not the inspection of a light for instance is on/working properly that the drone reads. Once read, the drone will relay the signal to the control tower or worker. The project would require a lot of programming and sensors/ potentially strain gages to read a part of the light, maybe heat, and determine whether it is on or not which would be read by a code to relay whether or not the light is working. Could potentially use RFID tags as well. The project would be a great way to incorporate mechanical engineering design and experimentation into the project and allow for inspections to quickly happen and reduce man hours and save money. The drone would be able to fly continuously during the inspection, increasing the efficiency as it wouldn't have to stop at every inspection spot. Relevancy: 6

Figure 39: Scott Liguori Concept 3

4. Drone flies autonomously to predetermined, programmed spots with live feed camera and requires a human to manually hit "enter" or something similar to make the drone fly to the next inspection spot. This provides the autonomous feature that is very attractive to both airports and the ARCP competition. The inspection is more efficient integrating the drone into the inspection process while also allows the human element to control the outcome. The concept also allows a worker to visually determine if the inspection test passes or not with unlimited time to analyze the inspection. This is very plausible and would just need an in-depth knowledge of coding and programming which is very attainable with online / URI resources. Relevancy: 10

5. Same as Concept 4 but the drone hovers or circles the inspection spot for a predetermined amount of time (example 5 seconds) then proceeds to the next spot. This concept would not need a human input to go to the next spot which would simplify the inspection and decrease the total inspection time, allowing for the inspection time to be known before undertaken. The only cause for concern would be how long the pause would be and if the worker can determine if the inspection passes in time before the drone moves to the next target. Relevancy: 7

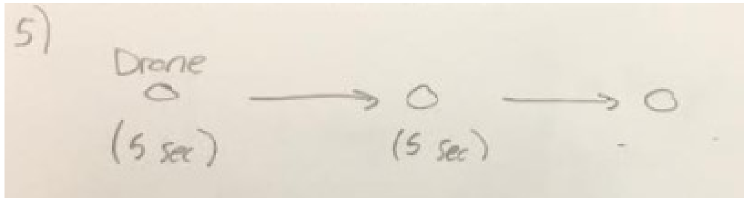


Figure 40: Scott Liguori Concept 5

6. Instead of drone, use an autonomous ground vehicle (4 wheels) to travel around airport and conduct inspection tests. The ground vehicle may be a better option than a drone as it would be able to operate in all weather conditions whereas the drone has limited flying conditions. The vehicle would have to use large, all terrain tires and spring system to allow mobility in mud, grass (wet and dry) and any holes in the ground or obstacles (branches, rocks). The vehicle would be better more overall option than the drone because it could operate in all-weather scenarios but is it a flashy enough design to win the competition? Do we have enough time to fully design, create and test the rover before competition end? Relevancy: 7

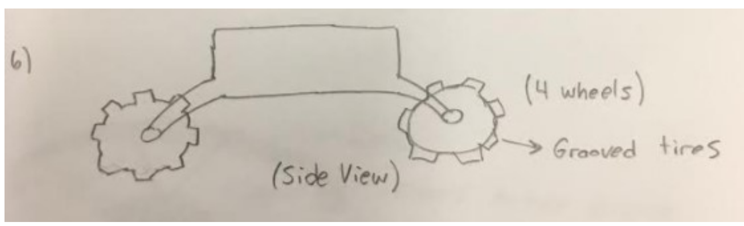


Figure 41: Scott Liguori Concept 6

7. Drone is attached with a rechargeable battery and is programmed to return to a charging tower (possibly solar panel) to self-charge. The solar panel would allow for continuous charging during flight, allowing for longer durations of inspections and being able to reach the farthest inspection spots within the airport perimeter. The only aspect of the concept that would make it not work is the lift capacity of the drone and weight of the panel. If too heavy, the panel would not be able to be attached to the drone. The added weight to the drone would decrease its top speed and possibly increase the inspection time with slower drone speeds. Relevancy: 7

Figure 42: Scott Liguori Concept 7

8. Ground vehicle is attached with a solar panel on it for continuous charging while in use. This design allows for the drone or ground vehicle to self-charge while performing duties and inspections. This continuous charge allows for longer, more in-depth inspections. The design would need to factor in the weight of the panel and the carrying capacity of the drone. The ground vehicle would be designed to carry any size panel. The added weight of the panel may reduce the speed of the rover. Relevancy: 7

Figure 43: Scott Liguori Concept 8

9. Same idea as concept 6 but the ground vehicle has tank tracks on it instead of wheels. The tank tracks on the ground vehicle would provide a tighter turn radius and provide

a more efficient device to perform routine tasks such as covering the runway to look for objects. The tracks may also provide better traction in variables such as mud, rain, snow etc. The tracks would be slightly more difficult to work with than just using wheels but could easily be accomplished. The tracks may hinder the speed of the vehicle which could slow the inspection and possible reduce its efficiency. Relevancy: 5

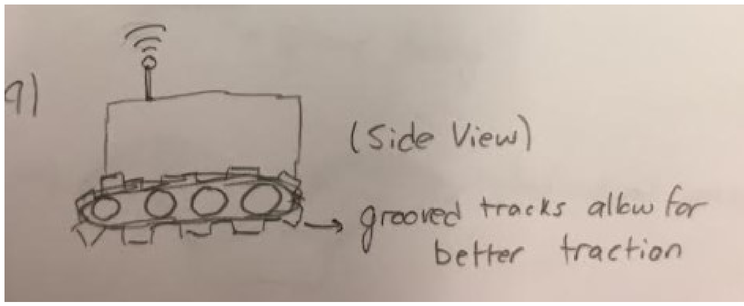


Figure 44: Scott Liguori Concept 9

10. Drone is attached with a vacuum to suck and contain foreign objects / debris (Shells) off the runway in Quonset / other airports near the bodies of water. The vacuum would be able to suck up and contain any shape object (Quonset: entire shells or small pieces) and remove it from the runway. The current method at Quonset is a cart with an angled scoop but the tarmac is grooved which causes problems with specific shapes of shells but the vacuum would be able to contain all shapes. The drone probably would not be able handle a large carrying capacity but the ground vehicle could be fitted to carry large loads. Relevancy: 6

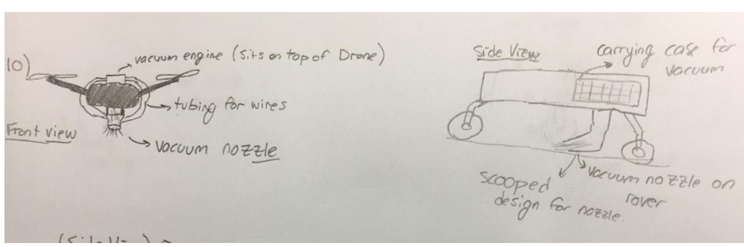


Figure 45: Scott Liguori Concept 10

11. Same as concept 9 but the drone / ground vehicle is attached with a blower device that uses air to remove debris / foreign objects from the tarmac. The blower device would be able to remove any shape object off the runway by blowing air with a leaf blower type device or with a canister of compressed air. The blower device may be difficult to control where the debris goes and could be inefficient in removing the foreign objects. The drone may be able to hold the compressed air canister and the ground vehicle would be able to handle the blower. Relevancy: 5

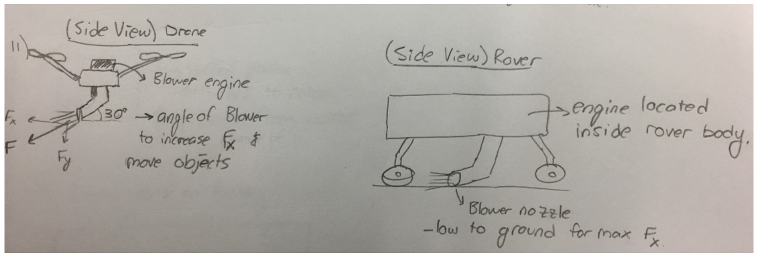


Figure 46: Scott Liguori Concept 11

12. Same as concept 9 but the drone / ground vehicle is attached with a grabbing device can grab and hold foreign objects / debris. The grabbing device (similar to a claw or gripper) would be able to grab large objects that the vacuum suction and blower couldn't remove from the airway. The device would most likely only work on a ground vehicle as the drone will have a relatively light carrying capacity. The gripper would be design for large objects which don't happen often and would require a manual remote operator of the vehicle. Relevancy: 1

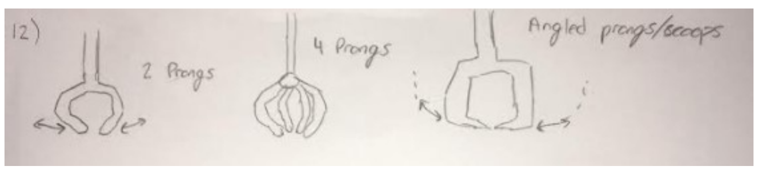


Figure 47: Scott Liguori Concept 12

13. Drone fitted with umbrella-like cover that encompasses the entirety of the drone and protects from weather elements such as rain or snow. The umbrella device would cover the entirety of the drone and protect the drone against rain and snow to allow inspection and wildlife removal in many levels of weather. The umbrella would protect the drone against vertical weather but may catch gust of winds and blow the drone off course or blow rain under the umbrella and may get into the engine. The umbrella covering the entirety of the drone may cause problems with the blades on the engine. Relevancy: 4

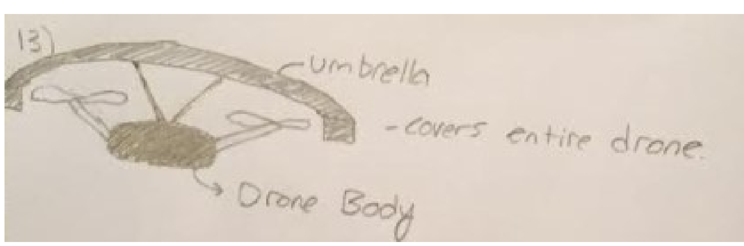


Figure 48: Scott Liguori Concept 13

14. Same idea as concept 12 but each engine has a mini umbrella for it. The individual umbrella would cover only the engines and as only the engines require protection from

the weather. The individual umbrellas would save costs on the material but may not fully protect the engine from the elements but would allow for better airflow to the blades of the engines. Relevancy: 4

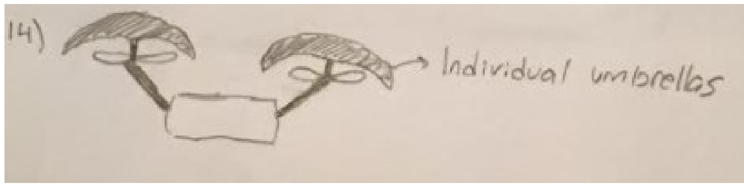


Figure 49: Scott Liguori Concept 14

15. Drone engines are sealed with a material that allows enough heat transfer out of the engine to protect from overheating but seals away water/snow from the engines. The material would need a high enough conductivity to allow for sufficient heat transfer out of the engine without overheating and increasing the risk of explosion or failure. The material would be able to be molded similar to silly putty. The material would have to be researched and tested to determine how long the engine could run without overheating, if such a material exists. The material totally sealing the drone may not be practical if the engine needs to "breath" to work or to cool itself. Relevancy: 5

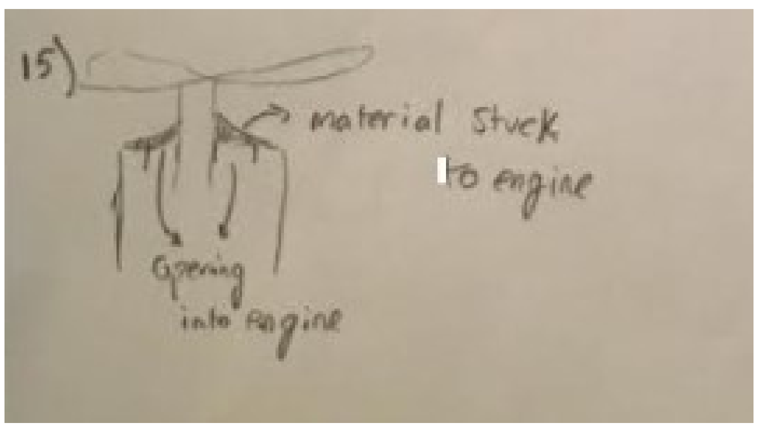


Figure 50: Scott Liguori Concept 15

16. Another seal concept would be a shelled plastic that attaches to the engines and simply covers the points of access that water could enter. This concept would just protect the access points to the engine while also allowing air to go circulate into the engine if needed. This idea I believe would best protect the engine from entering water while allowing the engine to "breathe" and not overheat. The shelled design would just need to be designed for the specific drone we use and how the engines are designed, specifically where the openings are. Relevancy: 7

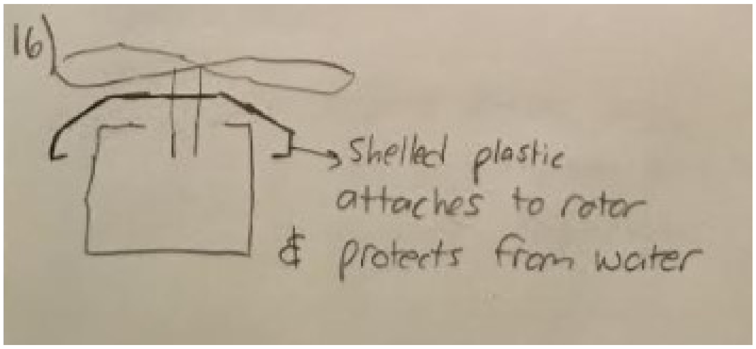


Figure 51: Scott Liguori Concept 16

17. When inspecting a runway for foreign objects, the drone would fly a programmed path with a video camera that a worker watches the live feed to see if there are any objects. This concept would be much faster than the current method of a line of men walking the runway as described in the group's meeting with RIAC. One man would be able to watch the feed and look for objects on the runway compared to many men. The video camera would have to have extremely high resolution and the drone would have to be able to go forward and backward on its path in case someone missed a second of the feed or wanted to double check something. Relevanacy: 5

18. Same idea as concept 17 but the drone has sensors on it that read the runway and detects objects. The drone would need to take a sample test of a clean runway and would compare the results of every inspection taken. The sensor would be a laser that would read the height of the beam and when flying over an object, the height discrepancy, if large enough, would be signaled the control tower. The sensors may be very expensive and from talks with RIAC, it seems that airports don't want to spend money unless they have to and try to get the FAA to pay for everything. Our group would need to conduct a cost analysis of whether or not the cost of the drone would save enough man hours and increase the number of aircraft landings for the airport to buy the drone. Relevancy: 8

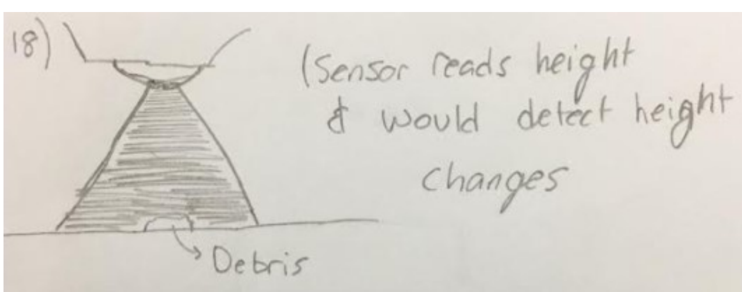


Figure 52: Scott Liguori Concept 18

19. Similar to concept 17 but the drone would drag a broom or similar device across a programmed path on the runway and would contain/sweep any debris off the runway. Any

objects that are not big enough to be swept off would not harm a plane and anything large enough would be taken off the runway. It may be difficult to contain all objects if many are on the runway, causing over spillage or over containment. Relevancy: 6

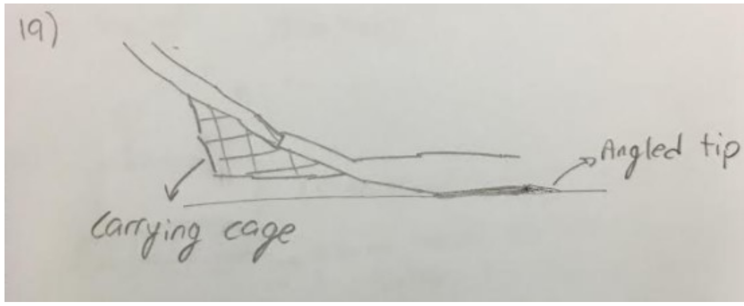


Figure 53: Scott Liguori Concept 19

20. Single camera that can rotate / translate up and down. The single camera would be able to rotate and translate if need be and controlled by the operator. This would allow for a single camera to view a full 360o for a full inspection. Putting an actuator or device to move the camera may significantly weigh down the drone and would need to be researched how lightweight the device could be. The human element to manually translate the camera may or may not be an ideal function if the inspection needs to be fully automated. Relevancy: 4

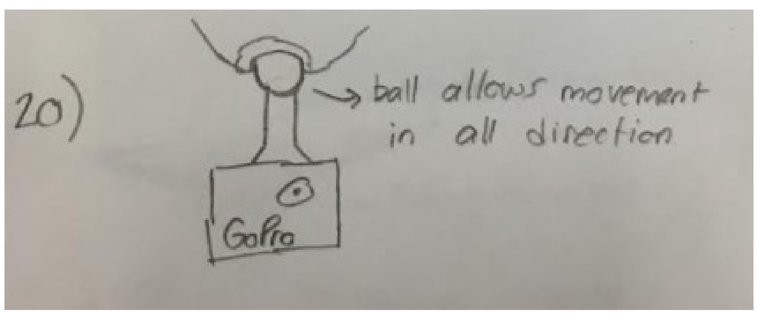


Figure 54: Scott Liguori Concept 20

21. Multiple cameras with pictures pieced together to create a single, coherent live feed. The combined videos to create a single feed would remove the need for the camera to be rotated and any human element as in concept 20. Obtaining four cameras or GoPros would be extremely expensive and probably not realistic if the project needs to be cost efficient and down the line trying to sell to airports. Relevancy: 4

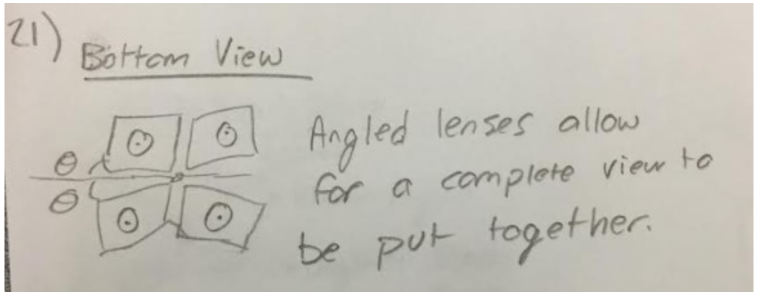


Figure 55: Scott Liguori Concept 21

22. Drone flown by an airport worker to scare wildlife, particularly birds, off the runways and landing strips. The drone being manually controlled would allow for the airport operator to determine which way the birds are scared off the runway to avoid the birds being scarred into the incoming or outgoing planes. The project would not need any engineering from the way I look at it but creating a plan to teach workers how to operate and fly a drone would be the project. More of a method and device than a physical mechanical project. Relevancy: 5

23. Drone with motion detector is triggered when birds land on runway and flies to scare them off. The motion detector located at strategic point, high bird volume, on the runway/airfield and once triggered, the drone would fly to the area and return to a programmed spot. The motion detector could either act as a trip wire when birds land or have weight sensors on parts of the runway that has high. I believe the motion detector would be tough to control for birds. It would have to be just right where it would not be triggered by stones or leafs. Relevancy: 4

24. Drone fitted with an owl / predatory bird costume to scare birds with recorder of predatory calls. The drone fitted with a predatory costume would work well to scare birds off the runway if flown at them and would work well to keep birds off the runways altogether if programmed to fly around the perimeter of the airfield. This would work to deter birds from entering the airfield would keeping the drone far enough away from the runways to avoid any collision hazards. The programming would be great to learn for the project but it may not be innovative enough to win the competition. Relevancy: 6

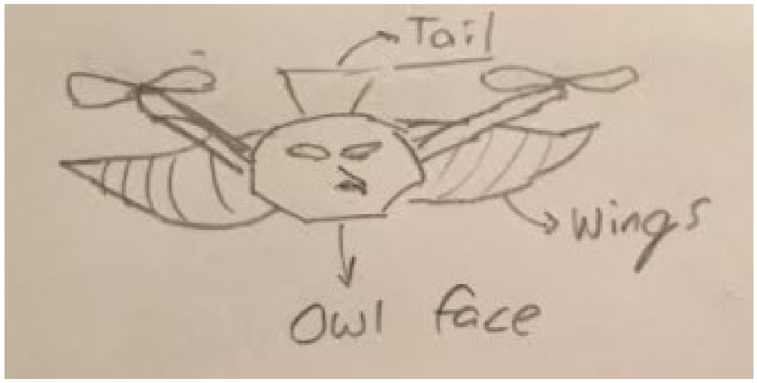


Figure 56: Scott Liguori Concept 24

25. Drone fitted with device to drop small explosive to scare birds off runway. The drone could be fitted with a release mechanism to simultaneously drop a small explosive device that produces enough light and noise to disturb the animals enough to cause them to flee. The small explosive (similar to a firecracker) would cause enough of a disturbance to the animals, especially birds, to cause them to fly off the runway. However, the idea of dropping firecrackers on the runway may cause a panic for passengers who don't know what's happening. Anything with firecrackers is a bad idea for an airport. Relevancy: 2

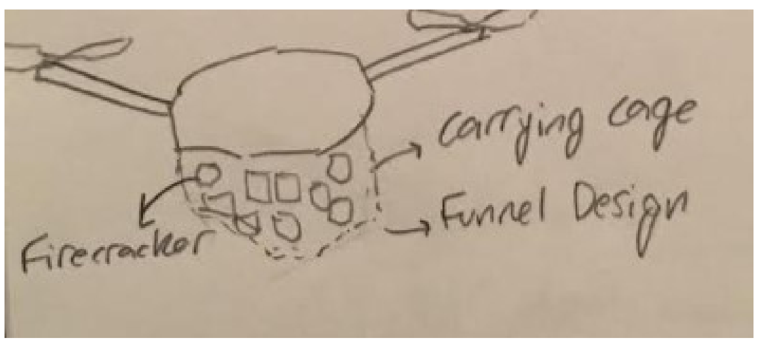


Figure 57: Scott Liguori Concept 25

26. Automated ground vehicle (4 wheels) remote controlled to manually operate the device to scare birds / other wildlife off runway. The ground vehicle would allow for an operator to control the ground vehicle in all-weather scenarios (rain/snow/ice) and allow the device to maneuver over all surfaces on an airfield (concrete/grass/tarmac/ pavement). This idea is very plausible as it allows for the airport to operate the device in all conditions compared to a drone can only fly good weather. Also vehicle is on the ground and avoids the implications of a drone flying around an airport including passenger safety and peace of mind and accidental collision with an aircraft. Relevancy: 6

27. When approaching the wildlife, specifically the birds on the runway, the drone would take a direct approach from any angle to scare them away. The direct approach from

the drone would scare the birds off in any direction the worker wanted to prevent causing the birds to fly away but in a direction towards another aircraft. The direct approach seems the most viable and easily programmed (if autonomous) compared to the next concepts. The direct approach may not be efficient enough though if the birds are in a large group compared to a single bird. Relevancy: 7

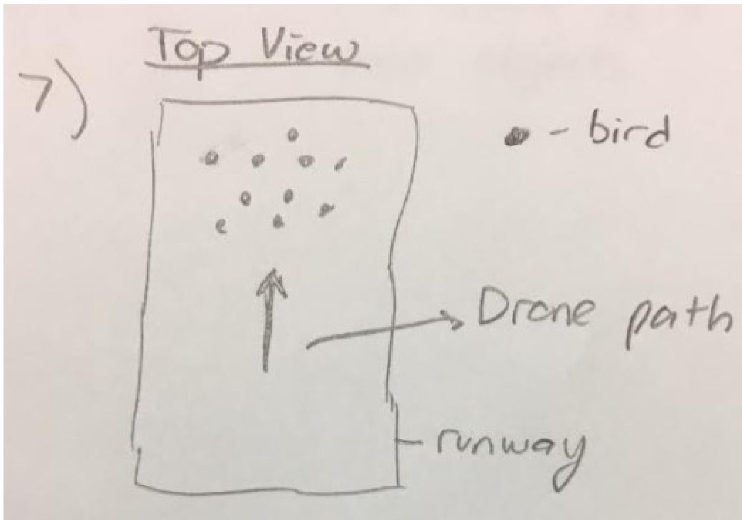


Figure 58: Scott Liguori Concept 27

28. Same as concept 7 but the drone would fly above the birds sitting on the tarmac and drop down into them from above to scare them away. The drop down method may be better concept to scare away birds as they would not see or expect the drone and may be a better way to surprise them. The drop down method may cause the birds to scatter in all directions which could be problematic if other aircraft are in the area as the removal of birds from the runway must be systematic and not random. Relevancy: 3

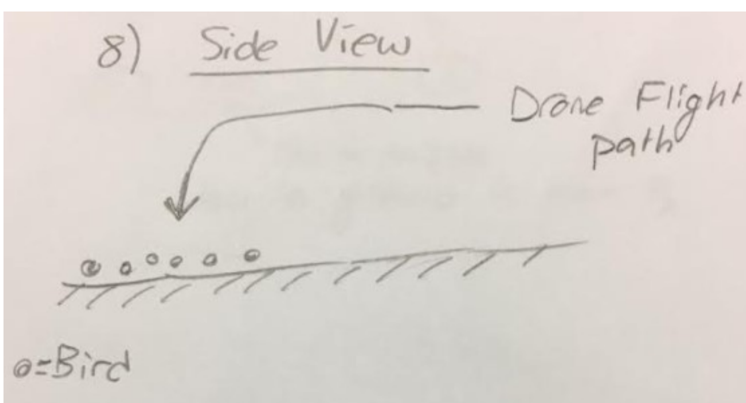


Figure 59: Scott Liguori Concept 28

29. Another concept to approach the birds on the runway would be to circle a large group

and approach with a spiral tactic. The spiral tactic may be a better approach to avoid birds from flying into different landing zones as it may cause the birds to fly upwards and out of the airfield. It is difficult to assume how birds would react to this tactic and could cause great help or harm depending on where the birds fly too. The bird's reaction is an important variable in the design process. Relevancy: 2

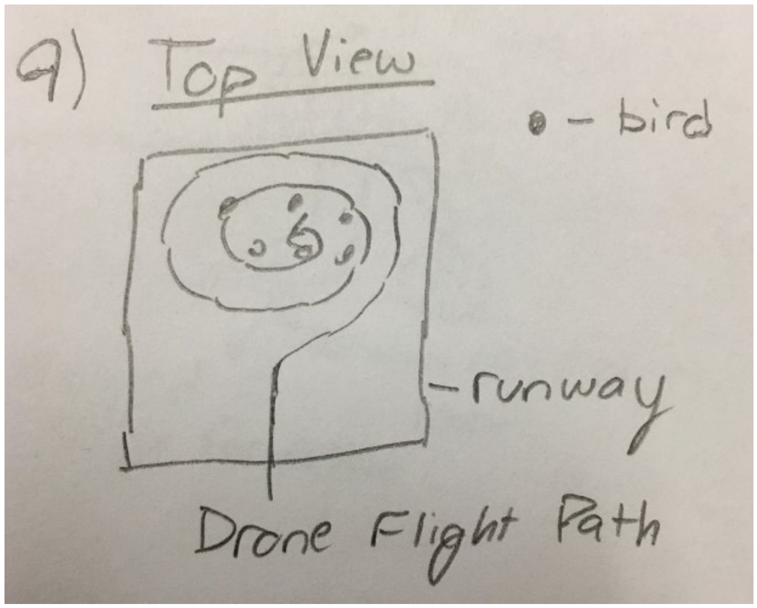


Figure 60: Scott Liguori Concept 29

30. Another concept to approach the birds may be in a zig-zag method. This approach may be more efficient for large groups of birds as the drone hits more surface area of the bird flock. Again, it is difficult to solidify exactly how birds will react but with enough research and testing, the best method of approach can be determined. Relevancy: 4

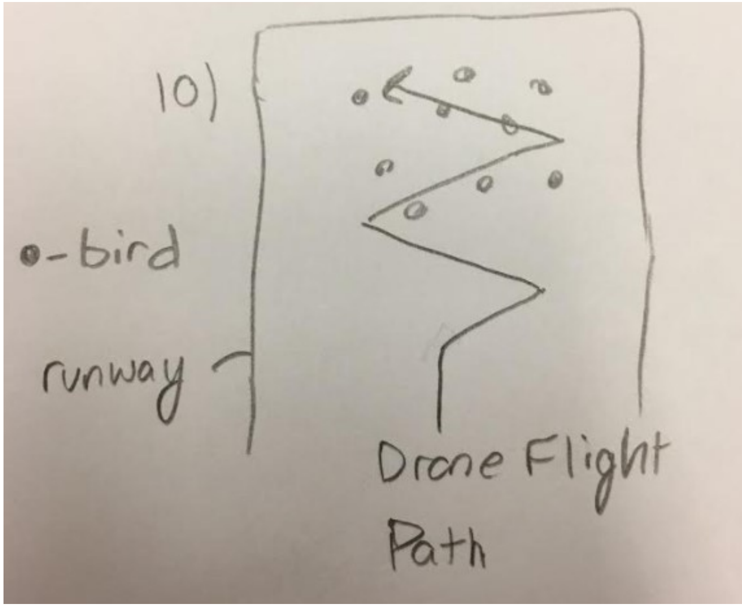


Figure 61: Scott Liguori Concept 30

7.1.3 Grace Sanita Concept List

1. Create a process in which the inspector will fly a drone with a camera pointed at the ground around the airport as an auxiliary inspection. The employee will be able to get a better overall view of the airport from the higher view of the drone. The employee will still have to actively watch and check off inspection points. This would be designing more of a process, not a device. Relevancy: 5

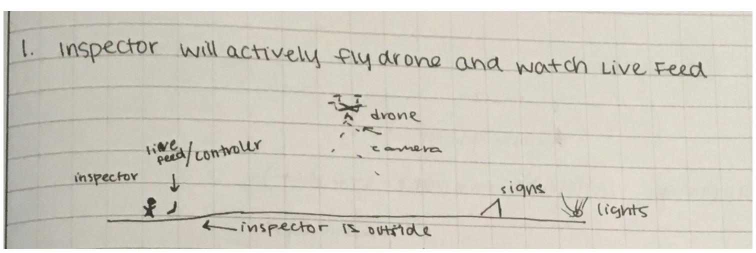


Figure 62: Grace Sanita Concept 1

2. Live Feed Drone with Automatic Flight Path: Create a process in which the inspector will watch a drone's flight path with a camera through an App/viewpoint around the airport as an auxiliary inspection. The employee will be able to get a better overall view of the airport from the higher view of the drone. Less training will be required because the employee will not be actively flying the drone. The employee will still have to actively watch and check off inspection points. This would be designing more of a process, not a device. Relevancy: 10

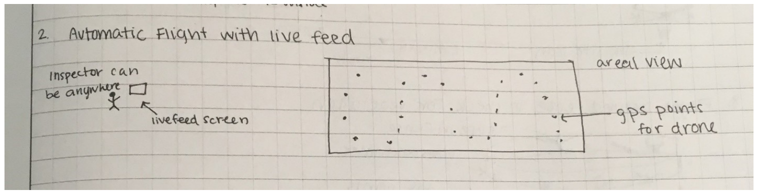


Figure 63: Grace Sanita Concept 2

3. Rover Used for Inspection: Create a process in which the inspector will drive a rover with a camera around the airport as an auxiliary inspection. The rover will be more easily weatherproofed than a drone. The Rover may be obstructed by foreign debris, therefore becoming foreign debris itself. The employee will still have to actively watch and check off inspection points. This would be designing more of a process, not a device. Relevancy: 5

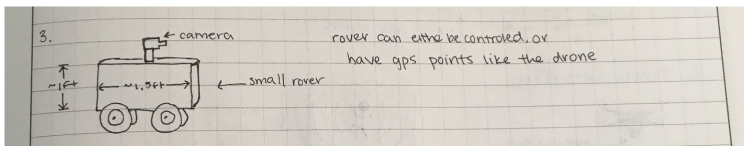


Figure 64: Grace Sanita Concept 3

4. Drone/Rover Used with RFID Chips: The drone would be equipped with an RFID reader. Each critical sign will be equipped with an RFID chip. When the drone passes each sign, it will confirm that the sign is still where it should be. This will save time for the employee. They will not have to actively check if each sign is where I should be during each inspection. The strength and range of the RFID chips would have to be specified to be able to check if they are in the correct spots. We would want it to be a somewhat weak signal so that chip is only read when the drone or rover gets very close. Relevancy: 10

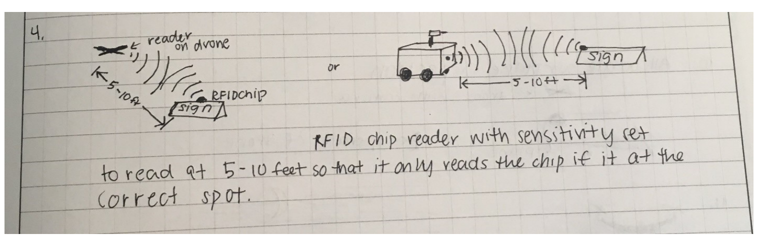


Figure 65: Grace Sanita Concept 4

5. Using Drone/Rover to Take Pictures to Check Contrast of Signs: Each sign is required to have enough of a contrast between the colors to be easily read. The rover or drone will be used to take still pictures of the signs along the runway, and the pictures will be used to test for the correct contrast. This will take the guesswork out of when to replace or repaint the signs. The pictures will need to be uploaded into a secondary system to be analyzed. Relevancy: 8

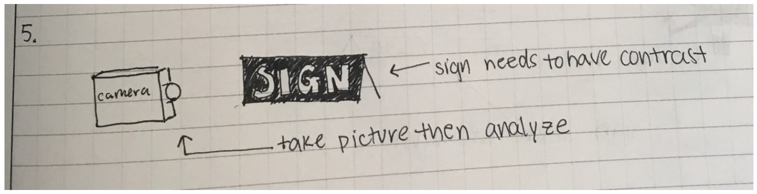


Figure 66: Grace Sanita Concept 5

6. Use Thermal Imaging to Check Lights: Flir Vue Pro is a thermal imaging camera that can be mounted using GoPro mounts on drones. This camera can be used to check if all the lights are on at night. This can also be used to determine road conditions. Flir has done this in the past in Finland. Thermal Imaging would give a more accurate representation of if the lights are on. This could also be used to detect the temperature difference between the pavement and cracks within the pavement. Thermal Imaging would not be able to inspect the contrast of signage. Relevancy: 8

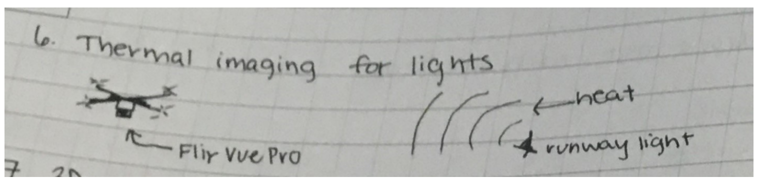


Figure 67: Grace Sanita Concept 6

7. Drone Used with 3D (Topography) Mapping: 3DR Site Scan can collect 3D maps of a site with quarter inch accuracy. This can be used with Sony R10C and DJI Phantom 4 Pro. The 3D maps, in conjunction with 'control' maps, can be used to find foreign objects on the runway along with cracks in the runway. This is expensive. Relevancy: 9

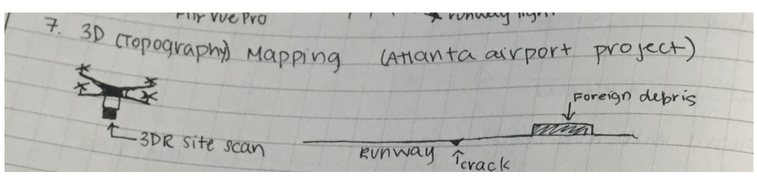


Figure 68: Grace Sanita Concept 7

8. Drone Used to Check Fence Stability: Drone flight path can be focused on the perimeter fence of the airport. It can take images of problem areas of the fence. The fence is subjected to a lot of vegetation overgrowth and this can help keep track of that. It will not actually fix the overgrowth, just monitor it. Relevancy: 3

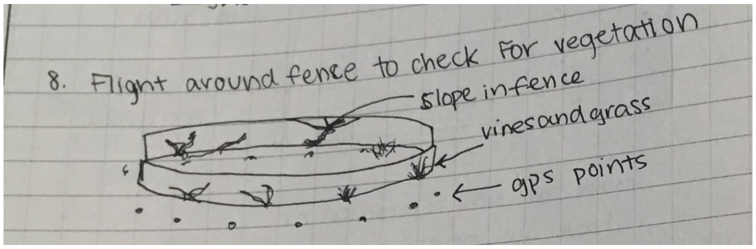


Figure 69: Grace Sanita Concept 8

9. Drone Used for Fence Security: A drone can be equipped with a thermal imaging camera to detect when a human is scaling the fence. The flight path will include weaker points of the fencing, or points where there is not fencing at all. Security is a large issue within the airport. The drone itself may scare away intruders. Drone may be overkill; well-placed cameras may be able to do the same thing. Relevancy: 1

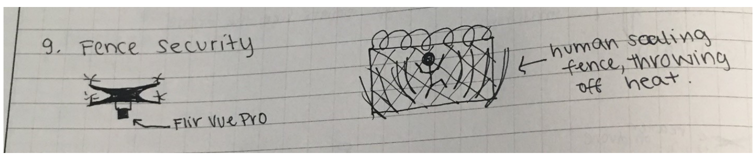


Figure 70: Grace Sanita Concept 9

10. Drone Used for Plane Inspection before Takeoff: An employee will use the life feed of a camera on a drone to fly over and inspect a plane before takeoff. This will afford the plane to get checked at all angles. If the drone falls on the plane, the plane would need another inspection before it can be cleared, therefore taking more time. Relevancy: 1

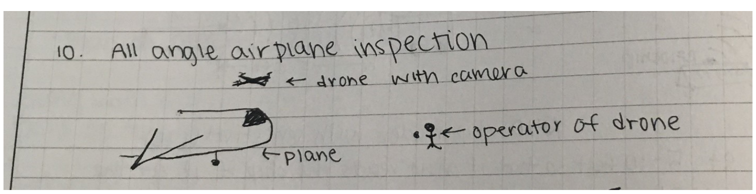


Figure 71: Grace Sanita Concept 10

11. Drone Equipped with Night Vision Camera: The camera can be switched to night vision at night. This can help see foreign debris in detail. The drone will be just as useful at night. Cons: Switching the camera will take extra time. Relevancy: 3

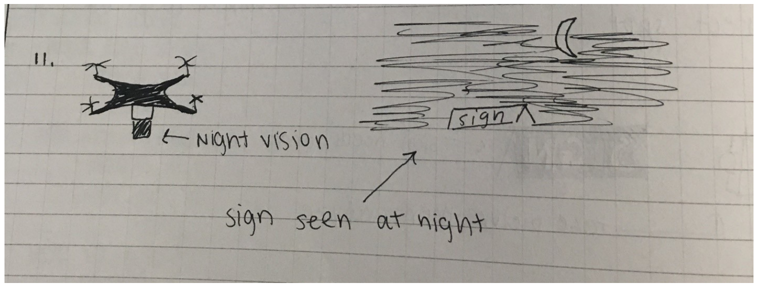


Figure 72: Grace Sanita Concept 11

12. Drone “Screamer”: Drone with constant noise maker while running to constantly be scaring birds.This requires no need to add motion sensor because the noise will be constant. This would be very loud and the birds may come back after the drone leaves the area. Relevancy: 2

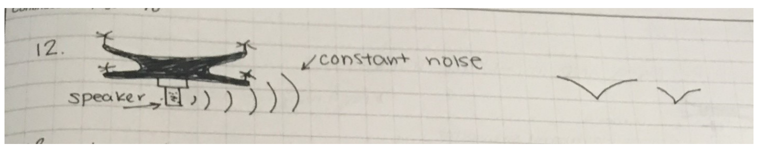


Figure 73: Grace Sanita Concept 12

13. “Scarecrow” for Drone: The drone will have a hanging ‘scarecrow’ feature. This can be made out of reflective streamers. The reflective material will scare away birds. This adds no excess noise. The reflective material may cause a distraction for pilots. This is also not very innovative. Relevancy: 4

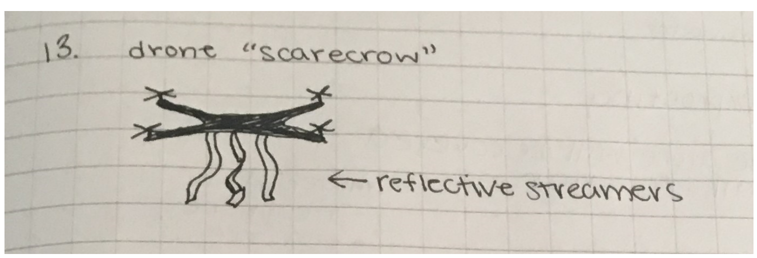


Figure 74: Grace Sanita Concept 13

14. Drone dropping actual flash bang: As the drone approaches an area that is heavily populates with birds, it will drop a small firework to scare away the flock. This will definitely scare the birds. Any explosion in an airport would have to be heavily monitored. Relevancy: 1

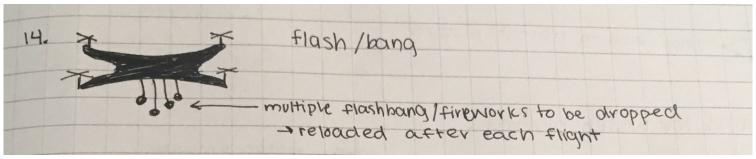


Figure 75: Grace Sanita Concept 14

15. Drone "Flashbang": Create a simulated flashbang on a drone to go off periodically while flying around. The airport. Flashbang will go off at set time intervals. This adds no need to add motion sensor because the noise will go off at set times. The birds may come back after the drone leaves the area. The flashbang simulator would have to be very light for the drone to carry it. Relevancy: 4

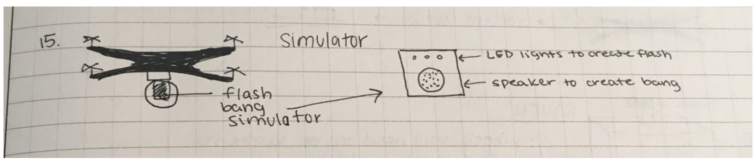


Figure 76: Grace Sanita Concept 15

16. Drone "Flashbang" with motion detector: This variation of the flashbang drone will be equipped with a motion detector so that the simulation will only go off when a bird flies past the device. This will save battery within the device, as it will not be constantly going off. The sensitivity of the motion detector will be a factor, as well as the response time of the device. If the bird has already flown away it will be useless. Relevancy: 4

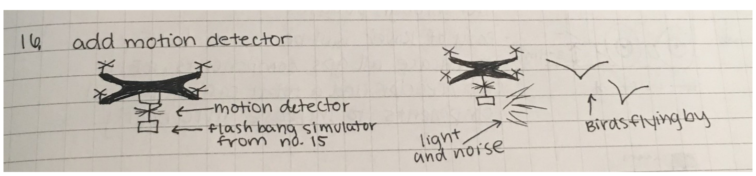


Figure 77: Grace Sanita Concept 16

17. Automatic Flight Path: Recorded Video for Biologists: Create a process in which a drone flies along a preset path and records video of the airport atmosphere. This video can be archived to be watched or reviewed at a later date to supplement wildlife reports of the airport. The Wildlife program will be supplemented by this data for the wildlife report. The only deterrent for the wildlife while the drone is flying would be the noise of the drone itself. It will take man hours to review the footage. Relevancy: 1

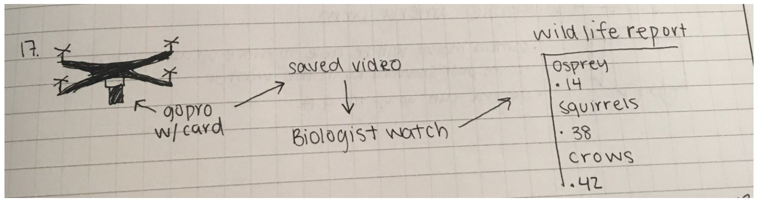


Figure 78: Grace Sanita Concept 17

18. Wildlife and Inspection Drone: This drone will be a two-in-one design with both the flash bang simulation and a camera for saving and inspecting footage. The footage can be archived for future use or for biologist. The drone will help get rid of the immediate problem with wildlife, as well as collecting data for future use. This will add weight and the flash may ruin the video. Relevancy: 5

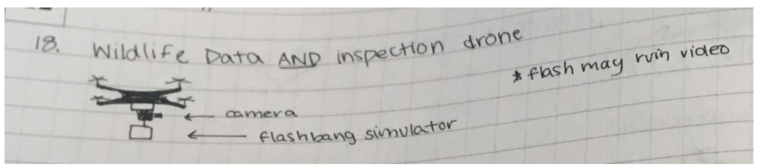


Figure 79: Grace Sanita Concept 18

19. Drone Waterproofing with Covering: The DJI Phantom 4 can become extremely water resistant through the use of its "wetsuit." The suit is made out of neoprene, and covers 75% of the drone. Most of this covering is focused on points on the body of the drone that water can enter through. The suit also creates a seal so batteries will also be protected. Neoprene O-rings are used to prevent water from entering through the motors. This system, adapted for our drone, will allow the drone to be used in the rain. This system is only for the Phantom 4. The system will add weight to the drone. Relevancy: 9

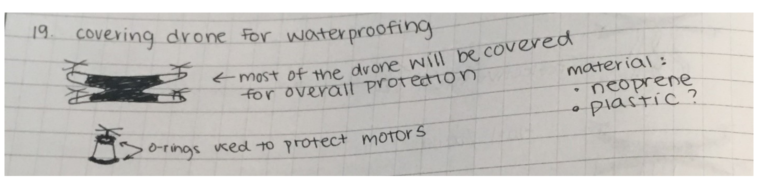


Figure 80: Grace Sanita Concept 19

20. Drone Waterproofing with Gels: Small drones have been waterproofed using gels and sprays to protect the electrical components. This would be a cheap way to waterproof. Gels and sprays are easily rubbed off; this may be an issue around the motors. Relevancy: 3

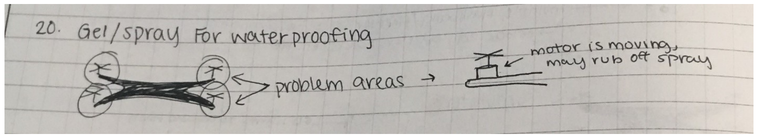


Figure 81: Grace Sanita Concept 20

21. Rover with Wheels: If a rover is created with wheels, the wheels will have to have a large diameter so that it can safely get through any puddles that may form after/during rain. A rover with wheels can be created with a kit for proof of concept. Wheels could lead to an unstable rover. Relevancy: 7

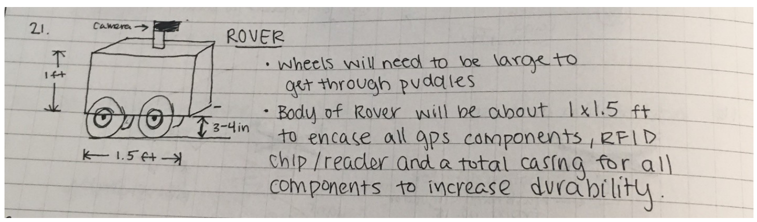


Figure 82: Grace Sanita Concept 21

22. Rover with Adjustable Camera: This modification of the rover design includes a camera mount that can move up and down. This will be used to get straight-on pictures of signs so that they can be properly analyzed for contrast. This can also help during the winter to get the camera over the snow banks. Exact camera angles can be replicated, and the camera can be raised to see over snow banks. An extra moving piece will complicate the design and add another potential spot for failure. Relevancy: 8

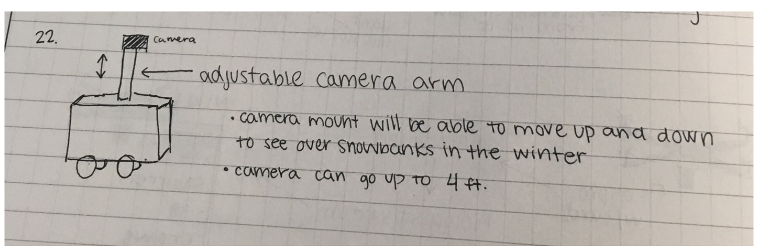


Figure 83: Grace Sanita Concept 22

23. Rover with Tracks: This variation of the Rover design will use a track system instead of wheels. This will help the rover overcome small obstructions in its path. This may cause the rover to be lower to the ground, therefore it may drive through puddles. Relevancy: 6

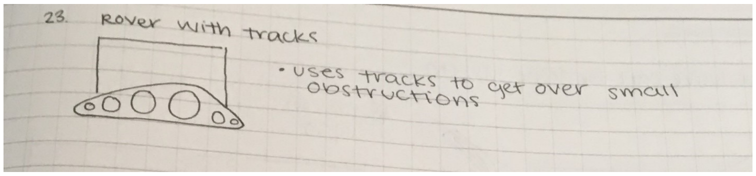


Figure 84: Grace Sanita Concept 23

24. Pinwheels on top of drones: The pinwheels can be used to scare away birds: birds do not like shiny moving material. The pinwheels also have the potential to be made into tiny turbines, to become a system for a rechargeable battery. This could extend the battery life of the drone or the camera. Weight and drag would be added. Relevancy: 1

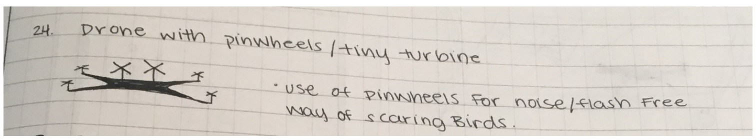


Figure 85: Grace Sanita Concept 24

25. Drone "home base" with Eye in the Sky project: The drone's home base will be near, or part of the existing eye in the sky solar panel base. This would create a space for batteries to be charged, and a URI Drone Kit for airports. This will create a chance to use the solar panels for charging batteries. The batteries will still need to be switched out. The drone's GPS system may not be accurate enough to get the drone home to the same spot each time. The drone would also then be left outside. Relevancy: 2

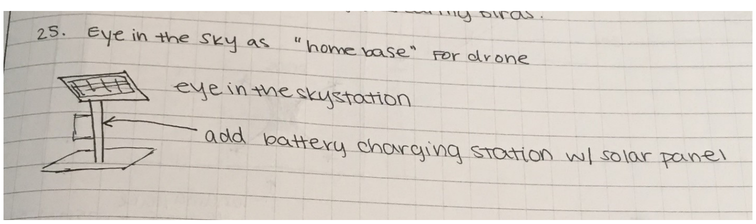


Figure 86: Grace Sanita Concept 25

26. Solar Panel on Rover: To make the Rover a complete system, a solar panel can be added so that it does not need an extra step of switching batteries. This would be a completely contained system.The solar panel will be slightly fragile, therefore bringing down the overall durability of the rover. Relevancy: 8

27. Solar Panel Added to Drone: A small flexible solar panel can be applied to the drone. This will make the battery last longer, therefore allowing the inspections to be more detailed. More detailed inspections can be done with a longer battery life. The solar panel may interfere with any waterproofing methods that may be used. Relevancy: 8

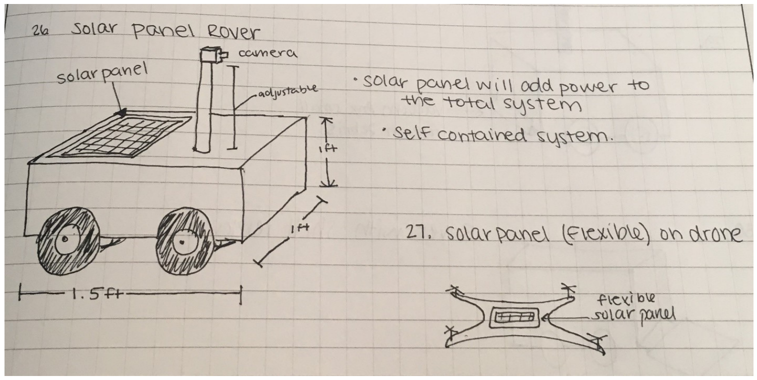


Figure 87: Grace Sanita Concepts 26 and 27

28. All-inclusive cart for drone system: This cart will be used to transport the drone from storage inside, to where it will take off outside. The cart will be 3ftx3ft with an area for the drone and extra batteries. This will make the transport of the drone safer, and the drone will be able to be stored inside. Extra storage space will be needed to fit the cart. Relevancy: 6

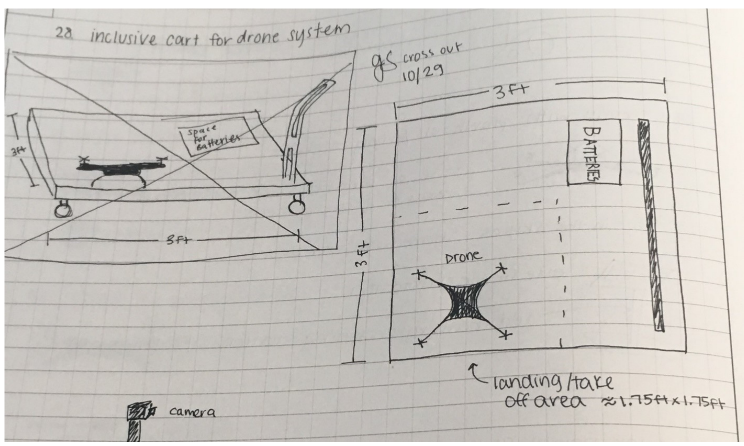


Figure 88: Grace Sanita Concept 28

29. Rover Vacuum: The rover will be equipped with a small vacuum that will have enough suction for small debris like shells and paperclips. When the rover spots this debris, it can vacuum it up on its next pass. This provides immediate removal of the found debris. The vacuum can get clogged, and it can fill up quickly. Relevancy: 1

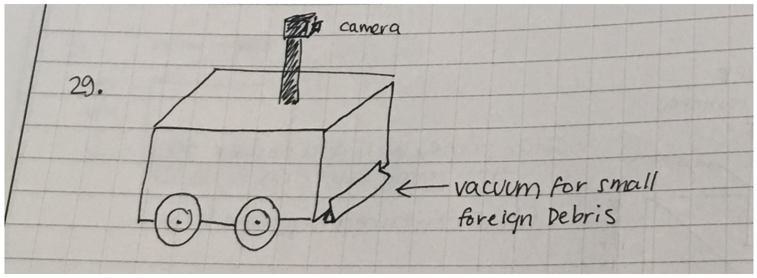


Figure 89: Grace Sanita Concept 29

30. Rover Zamboni: The rover can be equipped with a small version of the mat that is currently used to sweep up shells. As the rover makes its passes along the runway, it can also remove the shells. This provides immediate removal of shells. The shells will build up quickly. This can create even more of an obstruction. Relevancy: 3

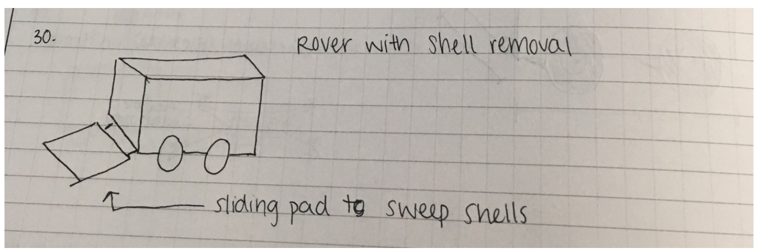


Figure 90: Grace Sanita Concept 30

7.1.4 Julian Andriulli Concept List

1. Bird/animal scaring rover: A rover designed to scare away animals from runways. This model has an extended wheel design with a metallic arm attached to each wheel and on each of the four corners of the rover. This metallic arm will be at a 45-degree angle to alleviate stresses on the axels on the main body of the rover. Front wheels will be able to rotate, 30 degrees, and the total length of the rover should be 2 meters. The device will be installed with a camera/motion sensor to detect any wildlife within proximity of the drone. In addition to the camera/motion sensor, a large speaker system that can output sound of close to 100 decibels, a lazer emitter/strobe flash light stunning system, and Helikite must be installed onto the rover to scare off any birds on the runway. The rover will also have a wide camera viewing range that can view a minimum of the runway width, and will enact its installed scare tactics (Flash, speaker) at approximately 8 meters. Relevance rating: 1

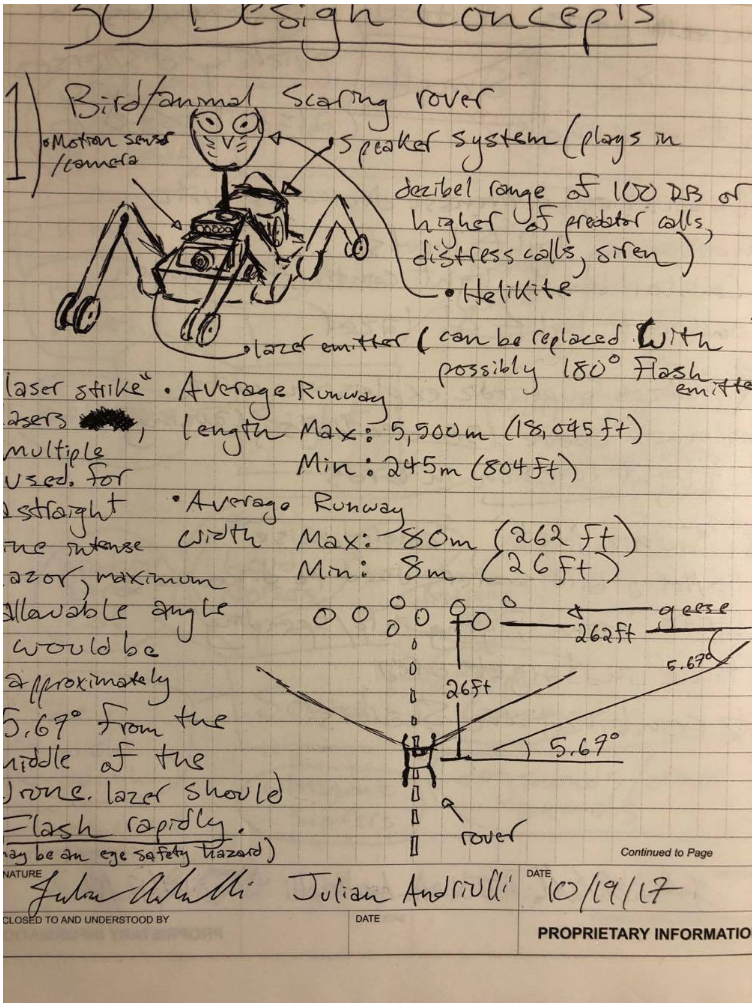


Figure 91: Julian Andriulli Concept 1

2. Bird/animal scaring rover; animated mechanical bird: This design will incorporate similar speakers and lazer emitters/ strobe flashlights to the previous design, but will instead sport a flat top and solar panels. If the solar panels are not feasible, then they will be removed, and only electric energy will be used from an outlet. The key feature with this design that makes it unique from the other rovers is the animated mechanical bird with mobile wings. The lazer emitter/strobe flash and speakers will be placed inside a realistically depicted mechanical predatory bird, and a small motor will be placed on the back of it to move the wings. This will create the illusion to flocks of waterfowl that it is a real predator, and the speakers will emit the bird call of a predatory species close to 100 decibels. For speed, the rover will use a small but powerful Saito engine with 200 Hp. Camera/ motion sensor would be placed at the front end of the rover. Relevance rating: 1

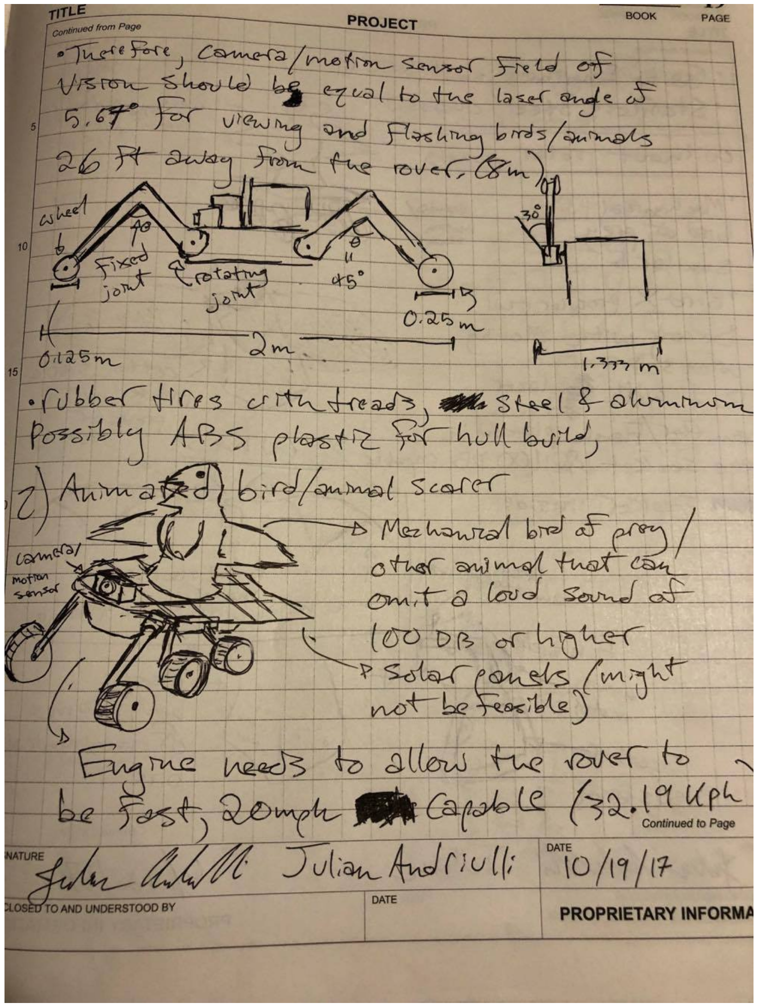


Figure 92: Julian Andriulli Concepts 1 and 2

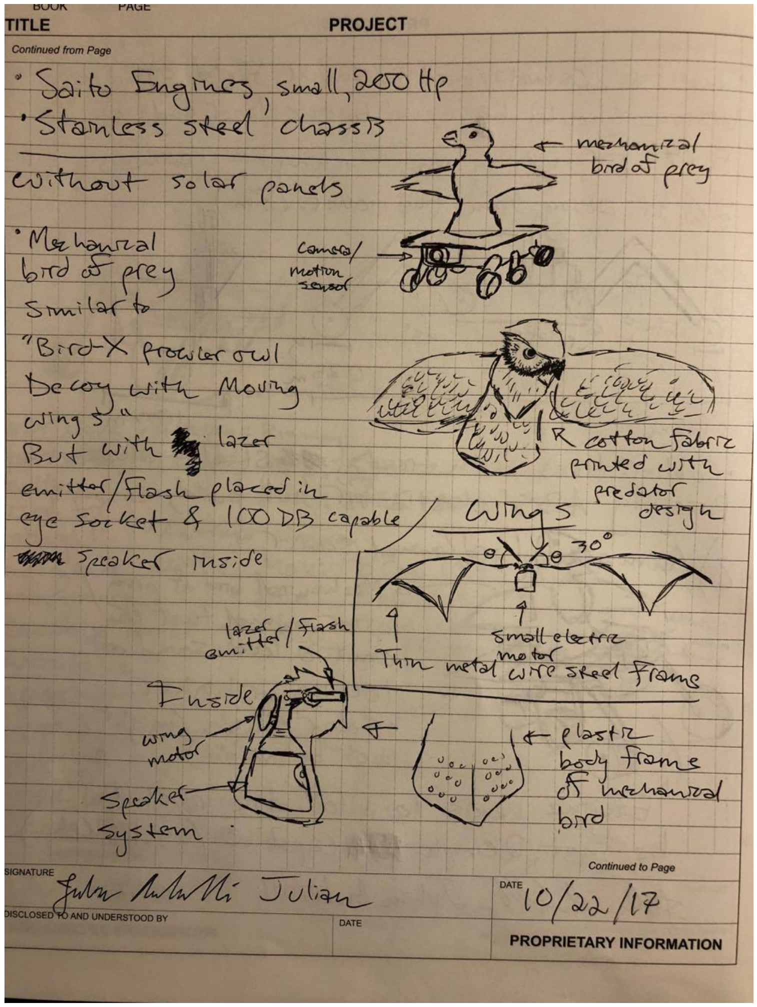


Figure 93: Julian Andriulli Concept 2

3. Animal scaring rover; bike design: Contrary to the typical four or six wheel rover design, this design is for a three wheel lightweight and mobile bike rover. The two large front wheels will be attached to a motor with all the motors torque running into the front most axel, and the Helikite design will be painted on a plastic attachable cover onto the firm steel chassis of the bike frame. Inside, the frame/chassis design will include a truss system for pressure and weight force distribution throughout the body, and large spring suspension will be placed on the front wheels for support. In addition, for the placement of the speaker, lazer emitters/ strobe flash and camera/motion sensor, a 2 cm thick tray will be placed laying inside of the frame. Will also include a Saito 200 Hp engine. Relevance rating: 1

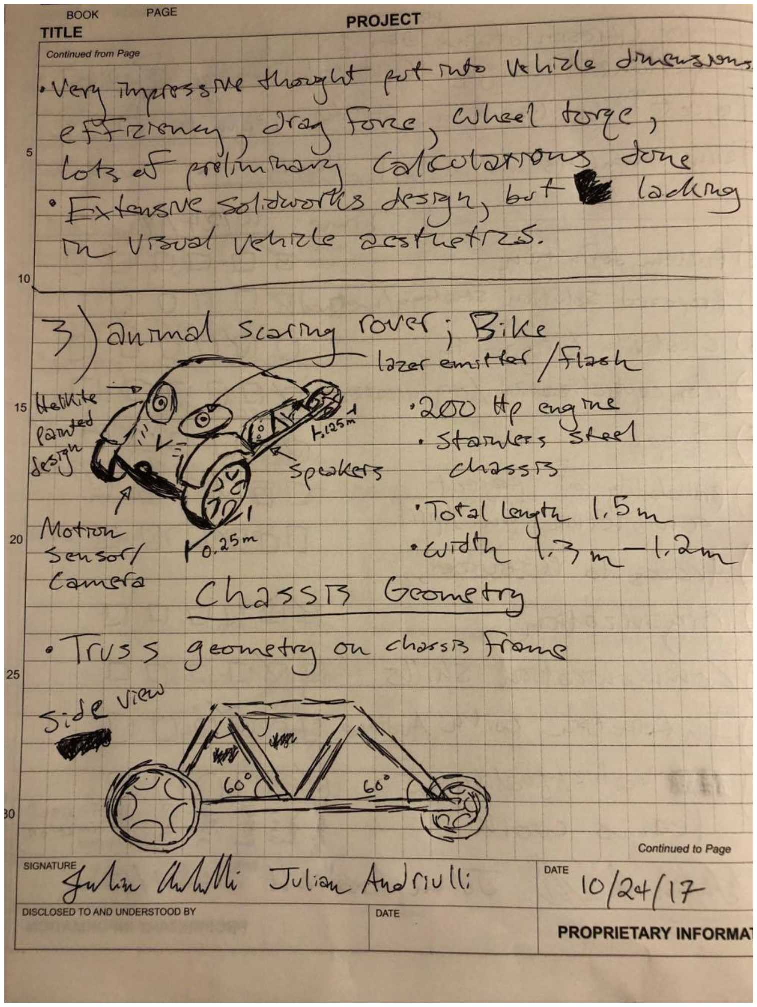


Figure 94: Julian Andriulli Concept 3a

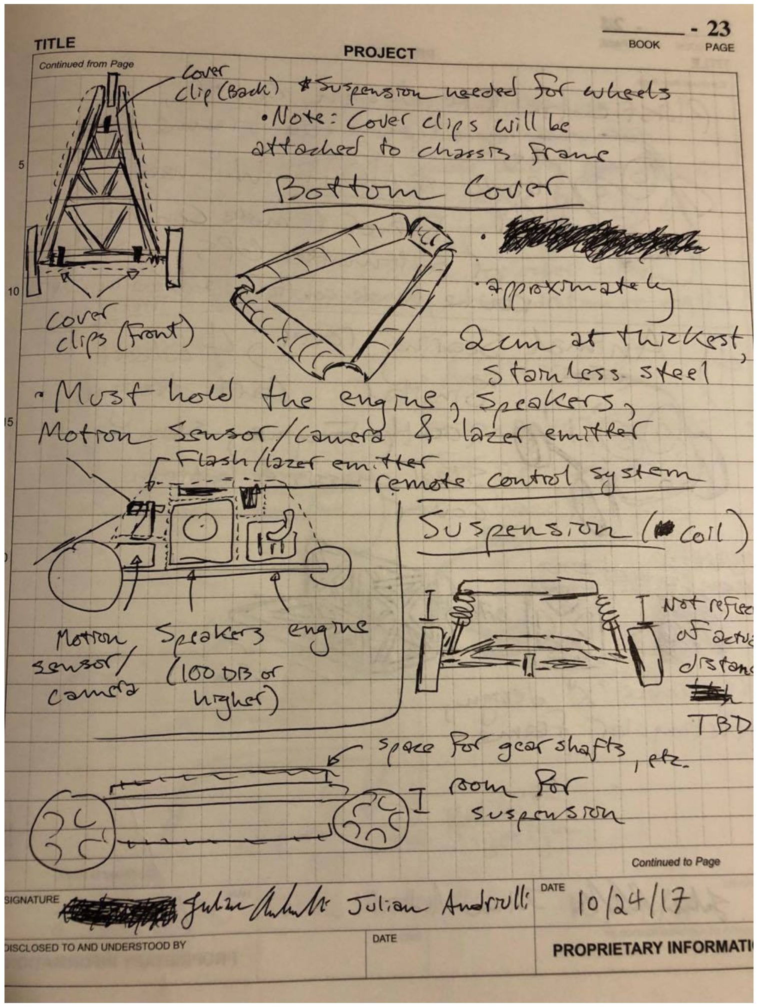


Figure 95: Julian Andriulli Concept 3b

4. Animal scaring rover; cart design: To increase frame stability and have an easily manufacturable frame, a cart rover may be a viable option. In concept, it would be similar to concept 3 using the same engine, clip on plastic Helikite cover, speaker, lazer emitter/strobe flash, camera/motion sensor and materials, but would place the engine motor at the far back and would distribute the motor torque to instead two different axels. The control board would be placed in the middle, and the entire control board, gear, motor, and mechanical system will be placed underneath in an ABS plastic cover. Above this, the speakers, camera, and lazer emitter will be placed. Relevance rating: 1

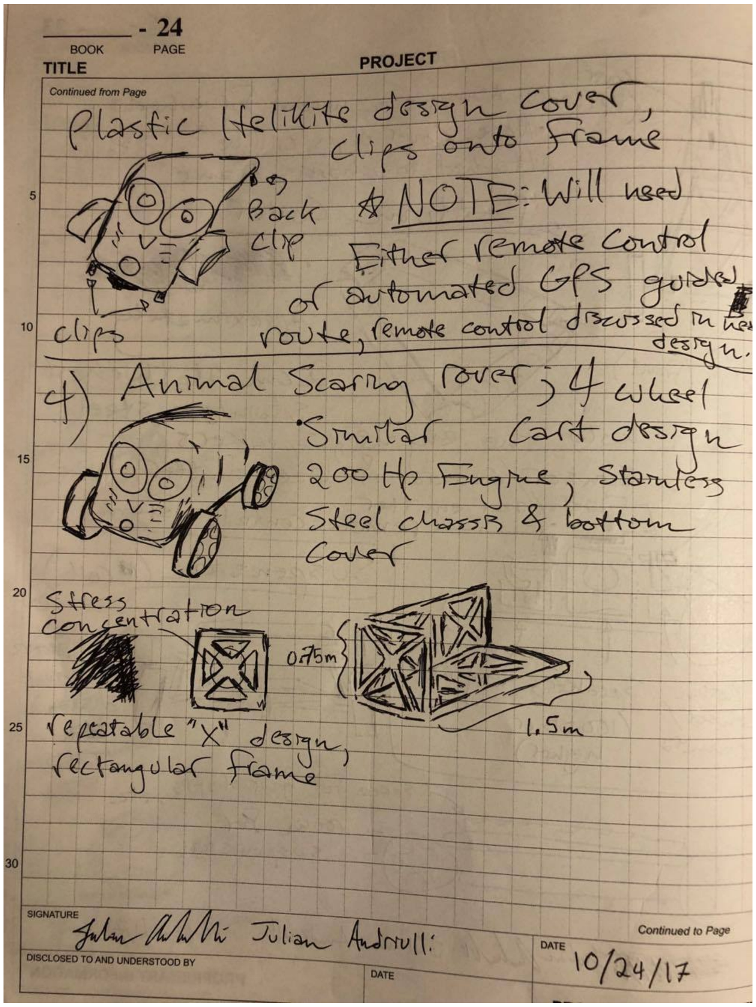


Figure 96: Julian Andriulli Concepts 3 and 4

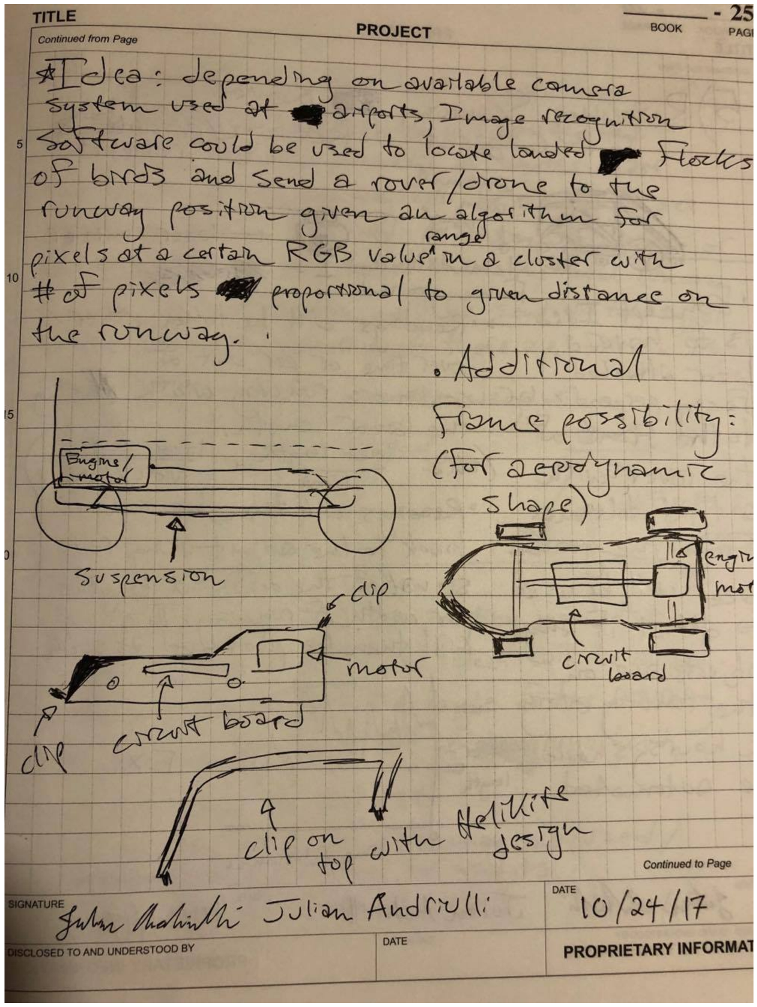


Figure 97: Julian Andriulli Concept 4a

5. Runway Scanning rover for object detection (Possible retrofit): As engines have an enormous amount of suction, it is necessary to make sure during an inspection that there is nothing on the runway, no matter how small. Therefore, a system would need to be put in place that could measure if there would be any obstructions whatsoever on the runway. To do this, two lazers could be placed on the front and middle of a rover. The front facing lazer pointing forward in the direction that the rover drives will be used to assure rover stability. The lazer attached to the front of the rover will be aligned with a reflector. If the reflected lazer creates an angle greater than 0 degrees with the initially emitted lazer, then the rover would not be aligned perpendicular to the runway. Once the rover is aligned so that it is facing perpendicular to the runway, the other lazer on the middle-bottom portion of the rover pointing parallel with the runway that is at ground level will be turned on. This lazer will then measure the runway distance over time or per unit width of runway. As runways are expected to be 1000 feet in length, if the lazer reads any of the distances as being less than 1000 feet, the runway will be deemed as containing obstructions. Relevance rating: 5

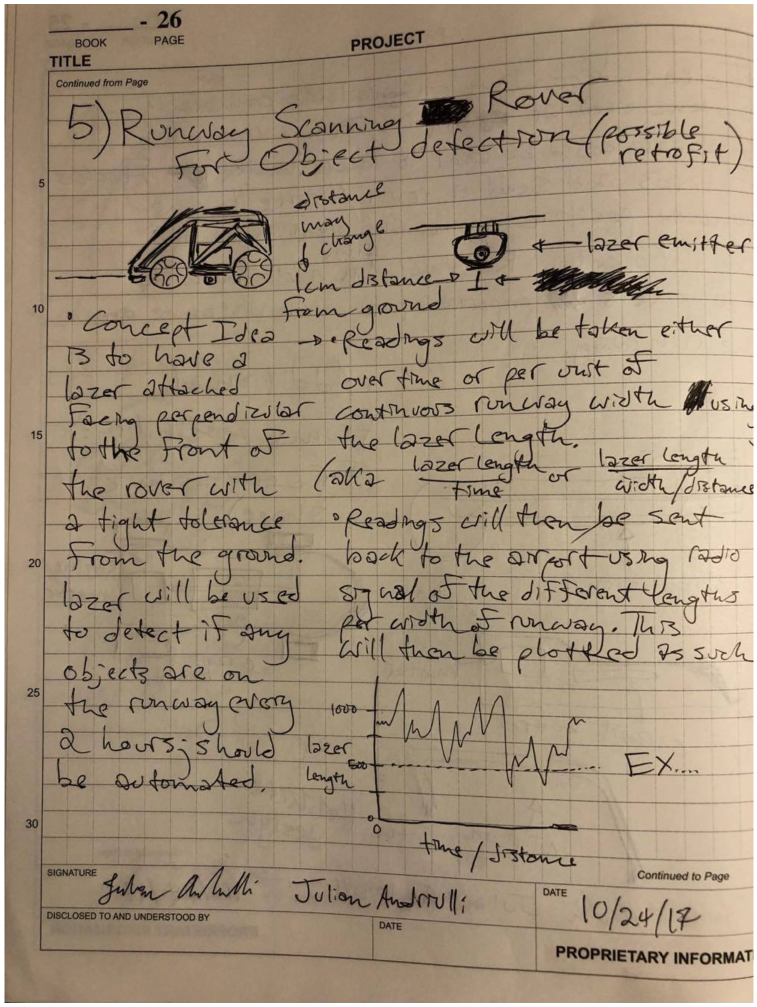


Figure 98: Julian Andriulli Concept 5a

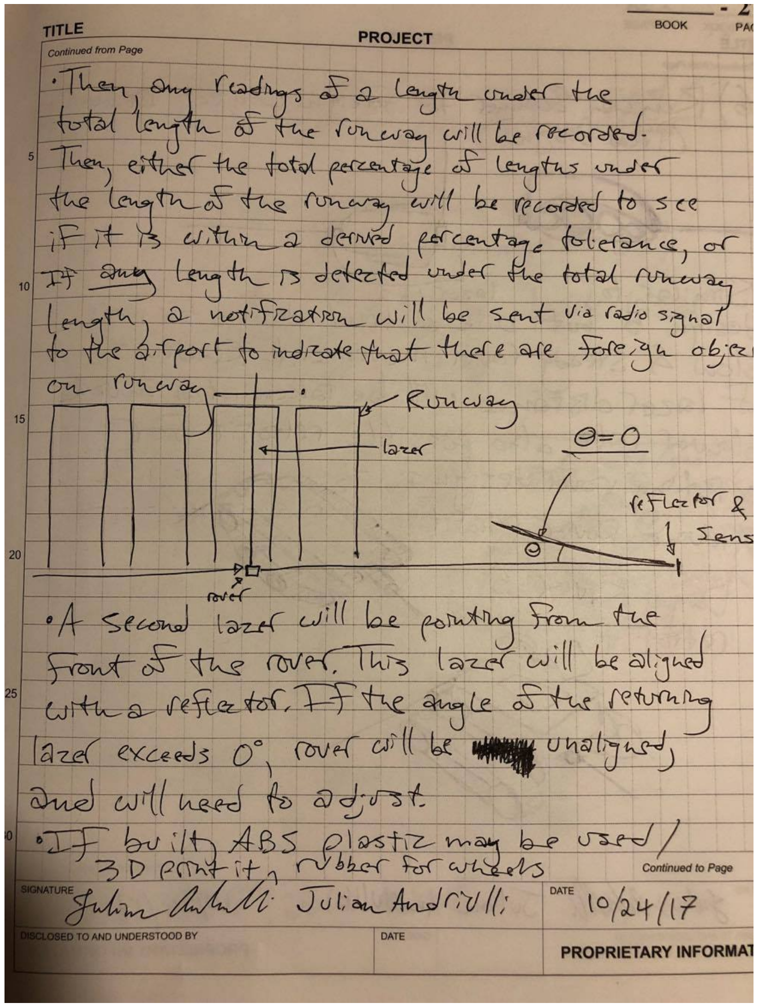


Figure 99: Julian Andriulli Concept 5b

6. Runway scanner for foreign object detection (Tread design): This concept will be similar in function to the previous design concept, only that a 4 axel-powered tread design will be used instead of the standard four wheel design. Lazers will be placed in a similar fashion, but with the second lazer being placed at the back instead of the middle-bottom. These designs could be modeled after the Dagu Rover 5, and could possibly even be a retrofit to the Arduino rover. Relevance rating: 5

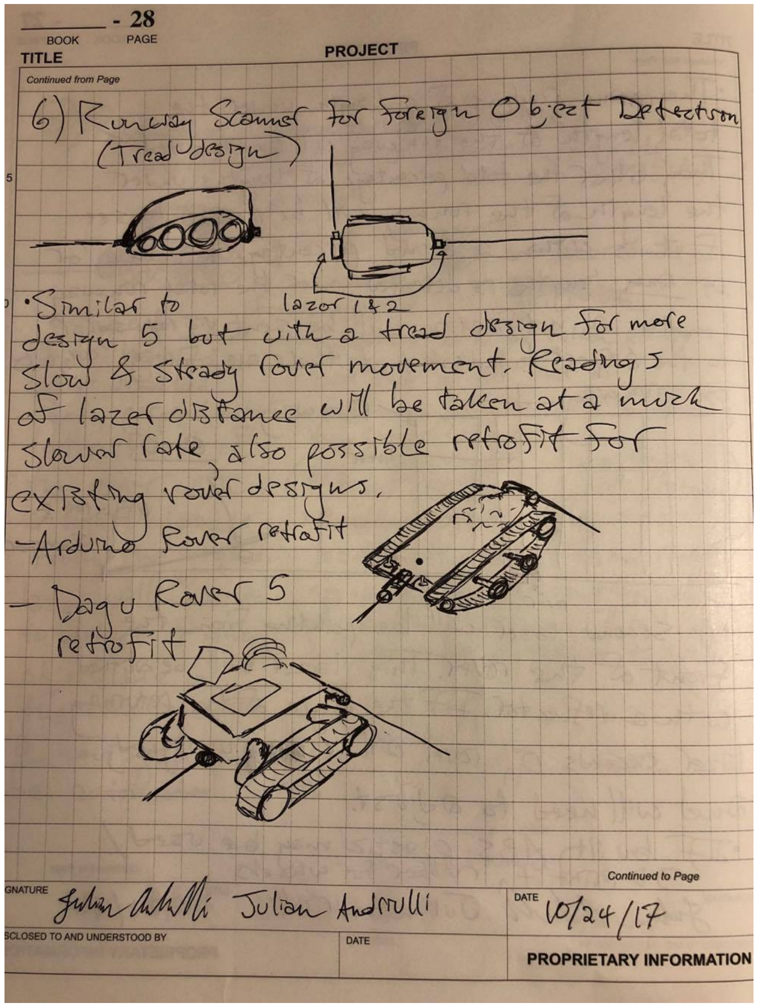


Figure 100: Julian Andriulli Concept 6a

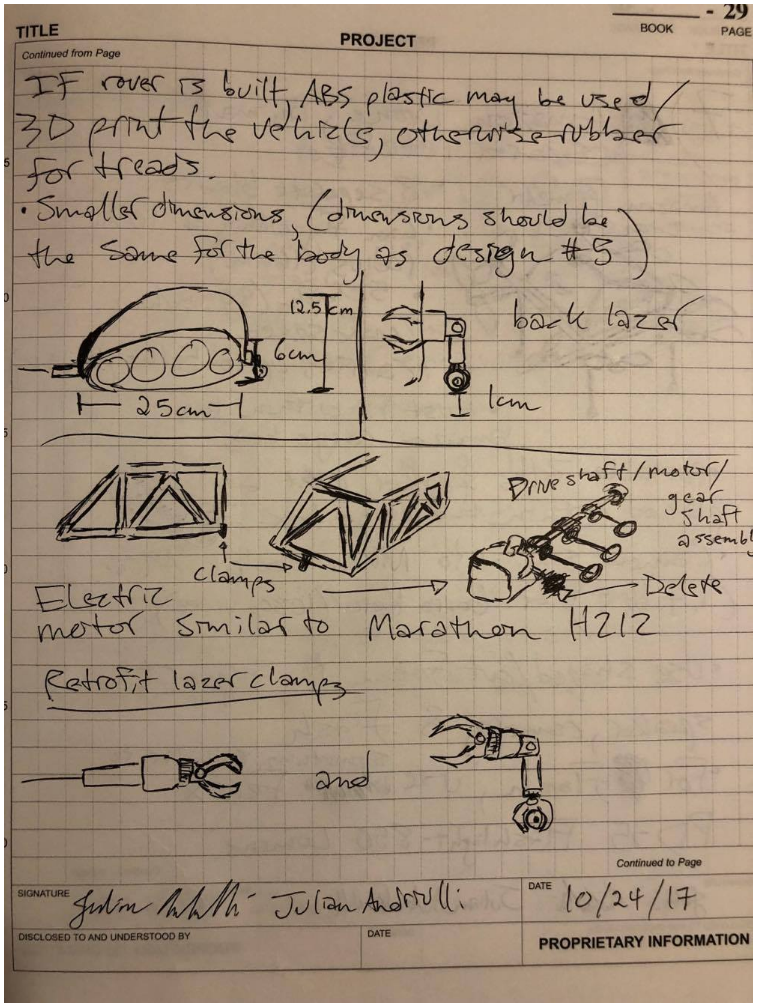


Figure 101: Julian Andriulli Concept 6b

7. This design concept is extremely rudimentary, but would be also extremely easy to implement and cost efficient. As the Amazon prime drone would be used, the speaker system, camera system, and lazer emitter/strobe flashlight could all be placed into the amazon prime product portation box. As the maximum lift capacity of a payload for the Amazon Prime drone is 5 lbs, all items within the drone would need to be extremely lightweight. This provides an extreme weight constraint, but also thereby makes the inserted products cheaper. A Nikon Coolpix A900 camera could be used along with a portable speaker system, and a PD35 flashlight could be used. Relevance rating: 3

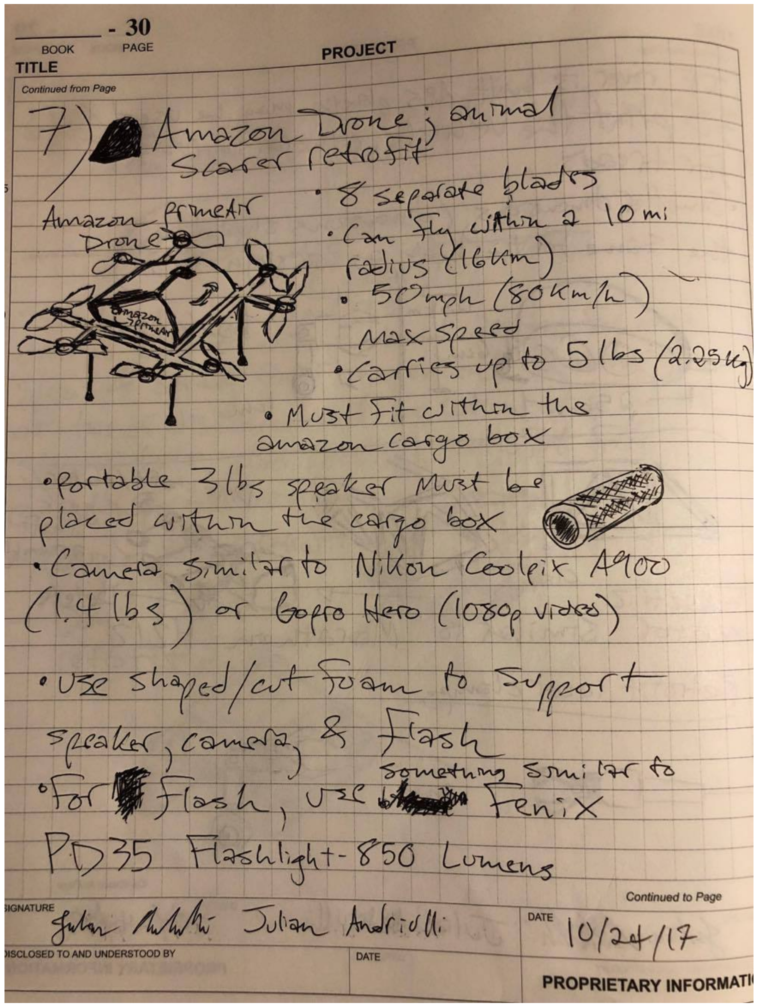


Figure 102: Julian Andriulli Concept 7a

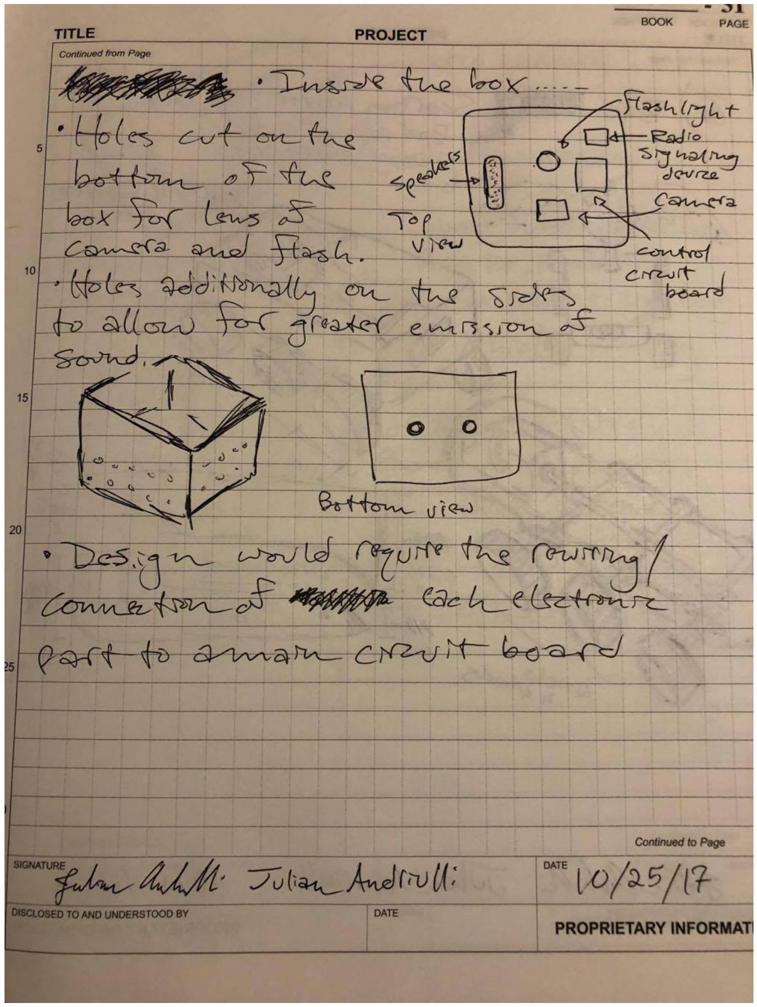


Figure 103: Julian Andriulli Concept 7b

8. Bird scaring rover; non-animated bird prop: As the creation of a moving mechanical bird may prove difficult, It may be a more time efficient option to not put electronics inside a mechanical bird, use a bird prop to function as a Helikite, and place the rest of the electronics within the body of the rover. For this design, the rover would be powered by an 100 Hp electric motor connected to 3 axels on a bottom ABS plastic frame. Placed over this would be a square ABS frame with subsquares for holding the camera, speakers, RFID tag, and exta battery. Relevance rating: 1

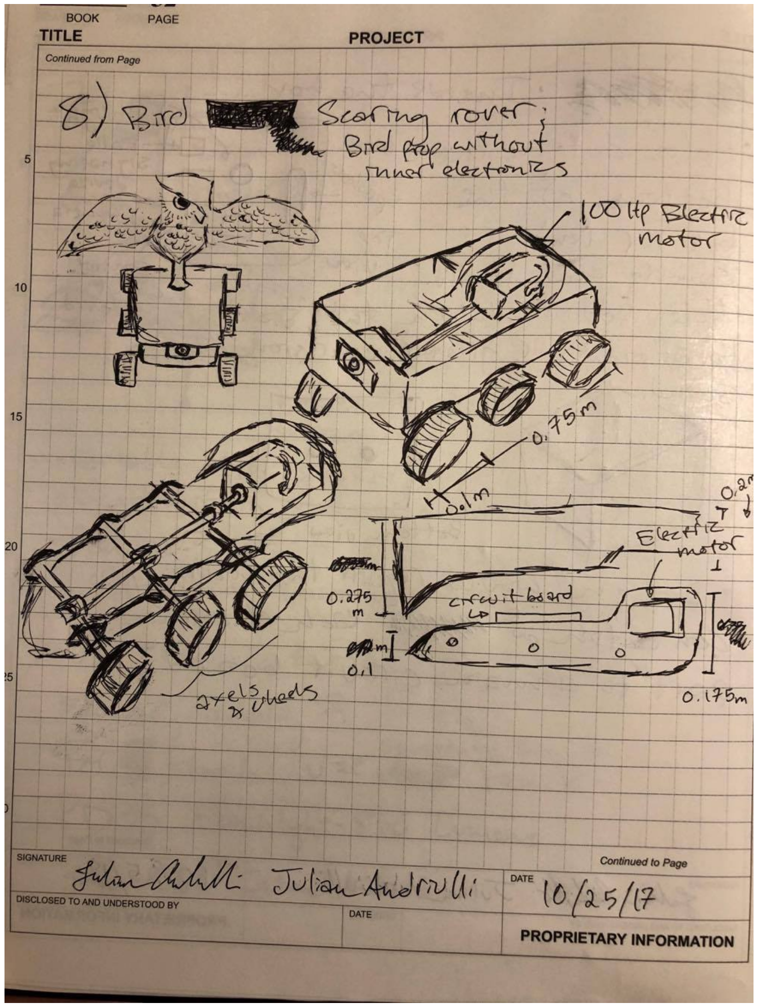


Figure 104: Julian Andriulli Concept 8a

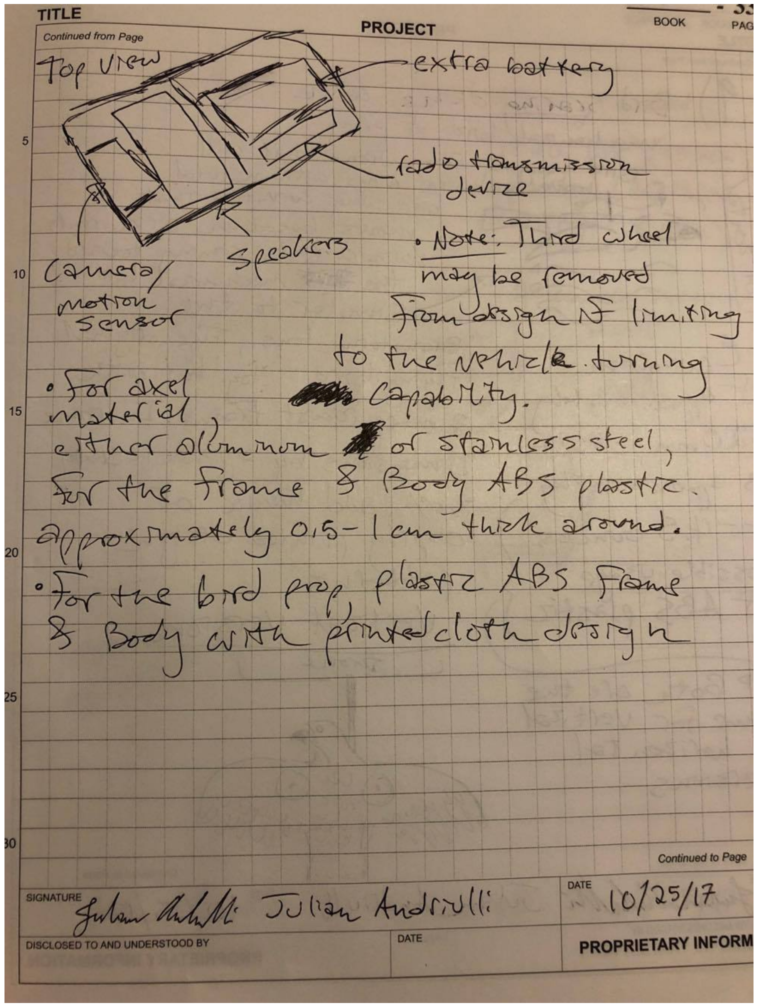


Figure 105: Julian Andriulli Concept 8b

9. Bird scaring drone with moving bird of prey prop: One of the major challenges in implementing a drone with scare tactics is that to scare birds, you need rapidly changing stark contrast in light, extremely loud noises, and frightening images, but all apparatus that have those qualities end up being relatively heavy. Therefore, to assist in alleviating this issue, a heavy lifting drone could be implemented similar to the Freefly Systems ALTA UAV drone that has an 18-kilogram lift capacity and a 35 minute max flight time. Using this, a large speaker system, multiple strobe flashlight and camera system, and control board could all be placed in a container to be lifted by the drone. The container would be made out of either aluminum or ABS plastic, and hanging from the container would be a bird of prey prop with mobile wings that move when an air current passes by it similar to the original "flying bird" toy. Relevance rating: 6

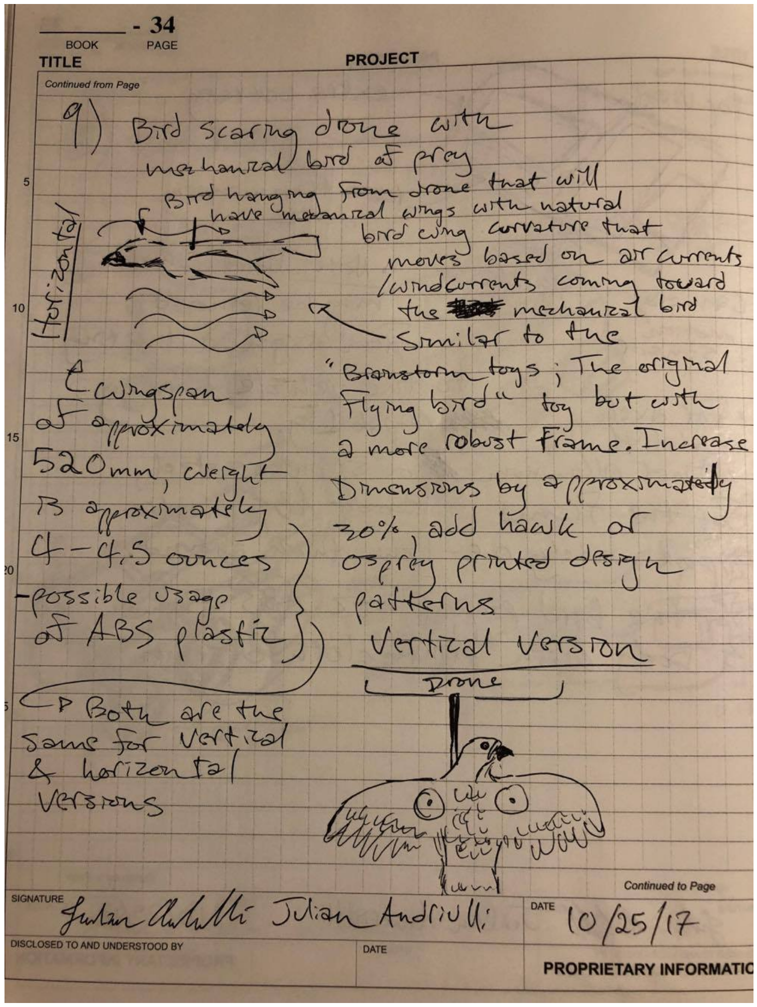


Figure 106: Julian Andriulli Concept 9a

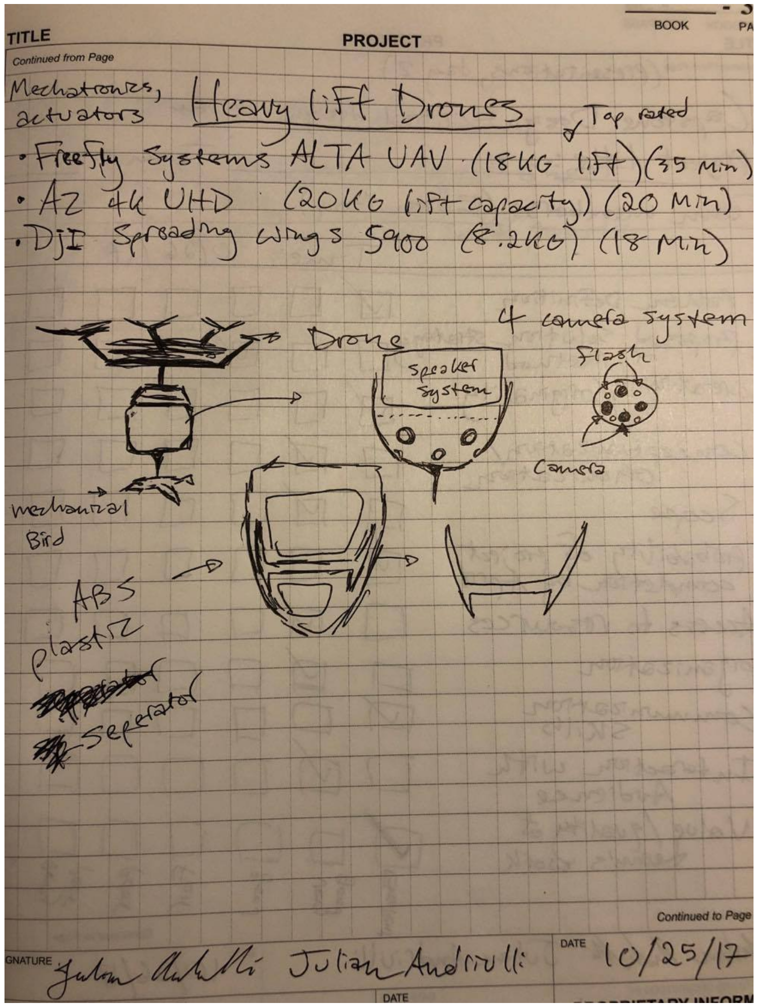


Figure 107: Julian Andriulli Concept 9b

10. Animal scaring rover and image processing software hybrid: Naturally, one of the main purposes of implementing the aforementioned rovers was to scare away wildlife (mainly waterfowl), but in addition it may be possible to implement image recognition software/ image processing software onto a rover as well to be able to detect abnormalities in airport signage and runways. This could be an addition to any one of the rover designs mentioned before, given that the hardware would need to be additionally installed into the rover. Relevance rating: 4

11. Horizontal facing camera drone design (surveillance): Similar to the DJI Drone CP.PT.000500 Mavic Pro, we could design/retrofit a lightweight drone with a cost (camera included) of less than $1000 and use the drone for security surveillance. The drone would be given a GPS mission in regular time increments of 2 hours, and then survey the outer perimeter of the airport to check for trespassers. The drone will do this by recording a constant video and streaming that video real time back to employees working surveillance within the airport. In addition, video could be recorded on the drone itself, stored on the drone's hard drive, and removed after 12 hours to be downloaded

into another computer device for further analysis. Once the drone has completed the mission within a maximum time of 30 minutes, it would go back to its starting position for charging. Once the drone has landed, a maintenance individual must hook up the drone to charge. To optimize the total surveillance time coverage, 2 or 3 additional drones could be used in tandem. Relevance rating: 8

12. Drone charging Pad: Due to the fact that drones are typically unable to land in the exact same place as the takeoff position, a large landing pad could be created made with a copper surface with an electric current through the apparatus. A lining of solar panels approximately 0.2m could be placed along the sides for energy, and if additional power is required a long power chord can be attached to the device. As the drone would need to make contact with the charging surface, the drone would need to have metallic legs to hold a current that can then travel into the drone for charging. Relevance rating: 7

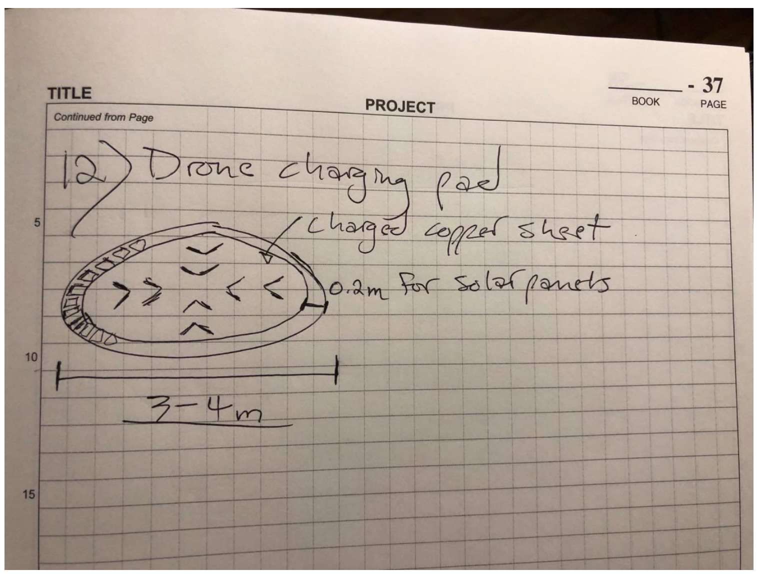


Figure 108: Julian Andriulli Concept 12

13. Surveillance drone; motion sensor and alarm: Due to the fact that grounded motion sensors typically trip too frequently to be effective, a drone-based alarm system could be used. Similar to Concept number 11, the drone would make a regular surveillance route every 2 hours, but instead of only recording a live feed or a monitoring video, the drone would be installed with image recognition software and motion sensors that could detect movement as well as recognize changing pixels/shapes of human forms at a certain distance from the drone. Once the drone has detected these, the drone will either emit an alarm sound, or will send a signal to the airport control room as an alarm. Relevance rating: 8

14. Infrared camera drone; surveillance: As detecting pixel change and different shapes within a live video feed may be difficult, Infrared cameras may be a better option for surveillance drones. A drone can be installed with a infrared camera, and similar to the

aforementioned concepts will survey along a preprogrammed flight path every 2 hours. Once the drone detects a cluster of pixels above a certain orange or red percentage, the drone will emit an alarm or an alarm signal will be sent to the airport control room. Relevance rating: 9

15. 3D scanning drone; foreign object detection: Similar to the 3DR drones used for construction site scanning, a drone could be used to scan runways and generate a 3 dimensional map of the runway to detect any changes in the runway such as cracks, material reduction, or obstructions on the runway. By 3d image comparison, any changes to the runway or it's surface can be recorded, tracked, and located. Relevance rating: 10

16. Vertical facing Infrared camera drone; wildlife detection: As various forms of wildlife can be found around airports, having an accurate method to locate wildlife habitats or animal positioning may prove useful to airports. A drone could be set with a given GPS mission with a one button "deploy" function to be initiated by an operator. After the drone has been deployed, it will go on a predetermined automated route, and will take pictures of all surrounding grassy areas around the airport using an infrared camera. These images will then be uploaded to one of the airport databases, and will then be used to map the current placement and amount of wildlife surrounding the airport. If necessary, a percentage of orange/red pixels per image pixel area will be recorded to give an amount of wildlife per area. Relevance rating: 8

17. 2D image correlation drone; paved areas: For image correlation, an original image at a predetermined set vantage point from a given object must be compared to a newly taken image to determine differences in individual point pixel RGB values, overall pixel RGB values, changes in a given RGB value pixel cluster, and changes in shapes within the image of pixel (foreground detection/image recognition software). For this process, we would need to create an algorithm that could detect pavement lips over 3", holes that are 5" wide 3" deep or bigger, cracks/spalling/heaves, gravel/debris/sand, rubber deposits, ponding, and edge damage. To make sure that all portions of the runway are analyzed, pictures must be taken at a constant low altitude at a set distance interval (Ex: every 50 ft of the runway) until the entire runway has been analyzed. Relevance rating: 10

18. 2D image correlation drone; safety areas: Similarly for the safety areas within airports, things like holes, pavement lips, edge damage, cracks, and debris need to be assessed, but in addition to this, unauthorized objects, obstructions, frangible bases, and support equipment must be taken into account when analyzing safety areas. Relevance rating: 10

19. 2D image correlation drone; signs: Signs differ slightly from pavement and safety area checking in that not only the shape must be analyzed, but the changes in color and sign orientation must be as well. This means that things such as color fading, color change, reflectivity, sign breakage, sign visibility, sign deformation, or any damage of any kind must be taken into account. Therefore, when designing an algorithm and software to implement for sign inspection, not only foreground detection software must be used, but

also color image recognition software must be used. Therefore tolerances for allowable RGB value change on certain portions of each image must be created, as well as making sure that the vantage point from which the drone takes the picture/records the video is consistent. Relevance rating: 10

20. 2D image correlation drone; runway markings: Runway markings are also an important part of runways that involve RGB values and color image recognition software. Markings that are checked must be clearly visible, standard size/shape, well painted, and legible. Markings include directional markings, glass beads, Holding position markings, Taxiway markings, and other extraneous runway information. Relevance rating: 10

21. 2D image correlation drone; lighting: Lighting is very important within airports, not just for the sake of being able to see the runway, but so that airport operators can properly and clearly communicate with pilots and other personnel within the aircraft. If image correlation software is to be used in determining proper lighting conditions, the software must be able to indicate if portions of the runway/taxiway are obscured, evenly lit, correctly aimed, and operable, as well as check for damaged lights and good pilot control lighting conditions. Relevance rating: 10

22. 2D image correlation drone; obstructions: As airplane engines are very powerful and create large amounts of suction, runways must be completely and totally cleared of any debris. Debris can be anything from animal droppings, shells, cranes, or trees, to any miscellaneous personal items dropped or left on the runway. Therefore if obstructions are chosen to be inspected, not only must the software be able to detect small objects approximately a millimeter in width, but varying shapes and object colors must be recognized. Then, as the software compares the original runway image to the most recently taken picture, a percentage of varying pixels from the original image in terms of RGB value, pixel number and pixel cluster size must be recorded and determined to be an allowable percentage obstruction or not. Relevance rating: 10

23. Image recognition software drone; obstructions: Other than the image correlation method, there is also the method of using image recognition software to judge a pixel cluster as a deformity given a specific list of parameters. For this, we could give a series of parameters that detail the RGB values, pixel cluster size, and average pixel distribution of different known deformities, download the software with the given parameters into the drone, and have the drone recognize individual deformities while either taking a constant recording of pavement or a series of individual pictures. Relevance rating: 10

24. Wirelessly sending inspection information: As most drones already come equipped with a camera, drones are capable of saving recordings of their flight on a local SD card, which can then be extracted and downloaded onto another device. Currently, if a drone were to be implemented in an airport for surveillance, an operator would have to manually insert a battery into the drone, initiate the drone mission, switch out batteries/plug in drone for charging, take out the SD card, take the SD card to

an available computer, download the SD card data, and wipe the current SD card information. In order to reduce this operating time, hardware and software could be installed into the drone so that the drone could wirelessly send the image/video and percentage abnormality data directly to be downloaded within the airport control room. Relevance rating: 10

25. Digital image processing drone; paved areas: In most airports, runways will be relatively long, spanning hundreds of feet in length and in width, which in terms of square feet is a very large area to inspect. Although image recognition and image correlation software would be fully capable of detecting runway abnormalities, the issues that stem from using this method on a runway are as follows:

    (a) It would involve sifting through a large number of photos for each inspection
    (b) The images may likely miss or cut out portions of runway
    (c) The system is not adaptable for many different kinds of roads.

    To alleviate these issues, Digital image processing can be used. Digital image processing can not only be used with continuous video shots, but can also be used to analyze different roads of different size and dimensions. Digital image processing first locates the image foreground, and separates the assumed foreground from the strip of road. Then, after reducing image noise, the obstacles within the bounding boxes are detected, and a certain pixel percentage value can be graphed for the duration of the video. Relevance rating: 10

26. 2D image correlation drone; structures: Naturally, regular inspections are very important to optimize airport maintenance, but another possible beneficial implementation of drones within airports would be to use image correlation software on top down views of the airport building itself. Images could be taken of the airport building itself in a grid in a specific order, and then those Images can show via image correlation with the current images taken how the building is changing over time, or if there are any abnormalities on the structure. Rooftops are hard to get to and maintain, so this would be a method to save yet more operator time and/or reduce the human factor. Relevance rating: 8

27. 3D scanning drone; structures: In addition to the image correlation software method for rooftop analysis, 3D scanning model generation would also be an excellent method to map out and detect change in the structure of the airport itself. For any cracks, large abrasions, damage, or unwanted fallen objects that have appeared on the airport building itself over time, this method would not only be able to detect such abnormalities, but additionally track the change of the outermost structure of the airport over time. Relevance rating: 8

28. Image recognition software in existing camera system to send out a drone bird scarer: Most of the prior design concepts have been for implementing image recognition software into a drone/vehicle, but depending on the available camera systems at airports,

it may be possible to implement the image recognition software into the already available camera system held at airports to detect large groups of birds on runways. Using an algorithm correlating number of pixels in a pixel cluster within a RBG value range to distance, the software could alert a drone that there is a bird obstruction on a given runway at a certain distance, and send the drone out to that location point to scare the birds off of the runway. Relevance rating: 9

29. Digital Image processing drone and bird scarer hybrid: Another possibility would be to combine one of the previous bird scaring drone designs (mostly design 9 with a heavy lift drone) with the digital image processing software to simultaneously track runway crack deformities as well as scare off any birds that happen to be on the runway at the time. In this way, not only can part of the inspection be done, but birds can be continually deterred from entering the runways due to the constant appearance of a large inspection drone. Relevance rating: 9

30. Drone waterproofing: A drone used every day would not only need to be durable to resist strong winds and birds of prey, but would also need protection against rain and snow. If a drone must be used for daily surveillance, the number of times a drone could be used for inspection per year would greatly diminish without waterproofing. Some current methods are using anti-corrosion aerosols, sprays, and lubricants such as "Corrosion X Heavy Duty", "Corrosion X Aerosol", and "Corrosion X Turbo Coat". In addition to adding these waterproofing liquids, a watertight cover made of rubber could be placed over each of the motors and areas with exposed electronics to further prevent water damage to the drone. Relevance rating: 10

7.2 Evaluation of Each Concept

7.2.1 Inspection Concepts

Recognized by the entire design team as the most feasible and useful design route for assisting airports, inspections methods were heavily researched using various processes, software, hardware, and mechanical design methods. As all airports conduct daily, weekly, and monthly inspections of the airports grounds and vicinity, inspections would benefit highly from process optimization.

Currently, airport inspection methods require ample time, manpower, and lack a standard minimum level of quality that must be assured by all large and general aviation airports. After discussions with Rhode Island Airport Corporation (RIAC) personnel, it became abundantly clear that the lack of quality assurance standardization and process efficiency leads to the consistent reliance on human personnel utilizing large vehicles and machinery to carry out inspections resulting in a highly subjective quality check. To combat this issue widely faced by all airports, the group looked into methods of automating the current airport inspections to reduce time and manpower costs to airports.

Having easy maneuverability, high range of sight, and speed, drones are an optimal mechanical device to carry out an inspection. Naturally, things that the team concluded to be most desired things to optimize airport inspections were to limit the manpower, inspection time duration, and inspection cost as much as possible whilst maximizing inspection quality, efficiency, repeatability, and ease of use. While creating concept designs, these design specifications were constantly considered, leading the group to often gravitate to drones as an extremely viable solution to the problem. The drone designs address the issues such as inspection item selection, weight capacity/additional device attachment, software implementation, sensors, alarms, camera types, weatherproofing, and battery charging. For inspection item selection, often the most prominent choices were checking for runway cracks/overall state of the runway, signs/runway symbol clarity, runway and taxiway lights, security,and perimeter inspections. For the drone to follow these inspection routes, the default concept method was using the often built in coordinate mission system offered with most drones and their paired smart-device applications, but other additional concepts included the usage of RFID tags for position marking/inspection item marking or sensors for determining distance from inspection items. For perimeter/security checks. Additional devices to add on to the drone included motion sensors, image recognition software, and thermal imaging for detecting trespassers as well as a possible lightweight light and alarm system to alert airport personnel of a security breach.

As the second choice option for carrying out unmanned inspections, rover based designs were also carefully considered. The durability and general reliability of a rover made it a good option. Much like the drone based concepts, the rover concepts relied on a built in coordinate system for the path of the inspection. The rover designs also included a multitude of camera and inspection options as well as the adding of solar panels to upgrade the battery life. The rover designs mostly differed from their drone-based counterparts with their focus of durability and various ways of moving. Designs included grooved tracks, large wheels, fixed and rotating joint legs, and truss geometry frames to optimize the terrain maneuverability along the ground. After visiting Westerly State airport, and speaking to representatives of both the airport and RIAC, the rover-based designs were put to second choice behind the drone-based concepts. Despite the various concepts generated to make the rover suited for the most terrains, the concepts would not be able to overcome the trees and large boulders in and around the airport.

7.2.2 Harassment of Wildlife Concepts

The management of wildlife within an airport is a critical task. Wildlife management is divided into four main points of management: habitat modification, resource protection, repelling/exclusion, and removal. The group focused on the repelling aspect of management, through harassment methods. Current methods of management include restricting access to attractive features like storm water ponds, radar systems for detecting and tracking birds on or near airports, and aircraft-mounted alternating, pulse lights to enhance aircraft detection and deter wildlife strikes [17]. Day to day operations to manage wildlife include sending employees out into the field to harass the wildlife with blank shots, or by driving close to the animal. This method requires unscheduled time and manpower, and lacks a standardized practice between employees and airports. The group generated concepts focused on the harassment of wildlife within the airport. These concepts are focused around the elimination of man hours through an automated harassment tool.

The generated concepts made use of both noise and visual tactics to harass wildlife within the airport, mostly focusing on birds. Much like the inspection concepts, the wildlife management concepts are based on the use of drones and rovers and their built in mission functions for the unmanned automation of wildlife harassment techniques.

Many of the concepts generated use a ”flash-bang” type system as a way to harass wildlife. This ”flash-bang” would use noise makers and flashing lights to mimic the current process of shooting blank ammo around the airport. The generated concepts would improve on this current method by making it automated, therefore saving man hours. This would also make the process more regimented, as the system can be implemented on a regular schedule, instead of just when an employee has some extra time, or when wildlife is spotted. A number of the concepts also include motion detectors that would limit the amount of intrusive noise that the surrounding population would endure.

The groups research showed that effective ways to harass birds include using reflective materials [18]. A number of the generated concepts include these reflective materials attached to a drone as a low cost and low weight addition to the ”flash-bang” system.

Other visual-based designs for the harassment of wildlife include the use of scarecrow tactics. These designs are based on the predator-prey relationship of wildlife. The system would include a model of a common predator of the local area made out of plastic to keep the overall weight as low as possible. This visual approach would be more targeted to a specific species of wildlife. This solution would work best for an airport that had an extreme problem managing one or two species, and was therefore eliminated due to its specificity.

7.2.3 Miscellaneous Concepts

When looking to implement unmanned vehicles into an airport atmosphere, many possibilities can come up. The group generated miscellaneous design concepts as to not limit these possibilities.

Some of the concepts include using vacuums to pick up foreign objects and debris. These concepts are considered to be add-ons to other rover-based concepts. These vacuums could eliminate the need for a human to go out to the field to pick up any found objects. These ideas were eliminated from the final design due to their complexity, and because the runways will not be directly inspected for foreign debris.

Concepts also included ways to weather-proof a drone. These concepts were generated to make the product ready to use at any time, despite any harsh weather conditions. These concepts were eliminated due to their complexity, and because many newer, high-end drones are fairly weather resistant. The focus of the team was shifted away from the weather-proofing of the product due to the availability of more water and weather resistant drone options.

7.2.4 Evaluation Based on Final Definition

The concepts generated for wildlife and miscellaneous and duplicate concepts were eliminated, leaving concepts for inspection only. The concept of a drone with a GoPro to be used for an automated inspection process and use the video on the micro SD card to log the video taken was chosen. Specifically, the reason videos taken will be saved instead of using a live stream is to optimize video quality. The saved videos will be used as a description tool for pilots using the airport and to refer back to if an incident occurs or if the airport is questioned in any way about the inspection. The final problem definition was defined as the automation of daily airport inspections, focusing on the perimeter and security and runway and taxiway lights using a drone.

8 Quality Function Deployment (QFD)

For this project, a QFD analysis was completed in order to define customer needs or requirements and translating them to engineering requirements. This was done by completing all eight rooms in the house of quality. The full QFD house of quality can be seen be seen at the bottom of this section and the breakdown of each room and how it relates to the design process can be seen below as well.

The first step in the QFD analysis is to define the customer requirements or demanded quality and their importance ratings, these can be seen below in Figure 109. The customer requirements chosen are safety, waterproof, durability, lifespan, maintainability, user friendliness, adaptability to difference airports, reduction of man hours, training required, and accuracy, with their respective weight/importance seen in Figure 109 in the left column.

Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")
5.0	Safety
4.0	Waterproof
4.0	Durability
5.0	Lifespan
5.0	Maintainability
5.0	User Friendliness
5.0	Adaptability to Different Airports
5.0	Reduction of Man Hours
2.0	Training Required
5.0	Accuracy

Figure 109: Room 1: Customer Requirements

The second room in the house of quality is the engineering characteristics or quality characteristics, which can be seen below in Figure 110. Along with defining these characteristics, the row above this has up arrows, down arrows, and ”x’s”, which mean to maximize the characteristic, minimize the characteristic, and hit the target, respectively. The engineering characteristics that were chosen are 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.

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)

Figure 110: Room 2: Engineering Characteristics

In the next few sections of the house of quality, symbols are used to correlate different characteristics and requirements. The legend for the symbols use can be seen below in Figure 111.

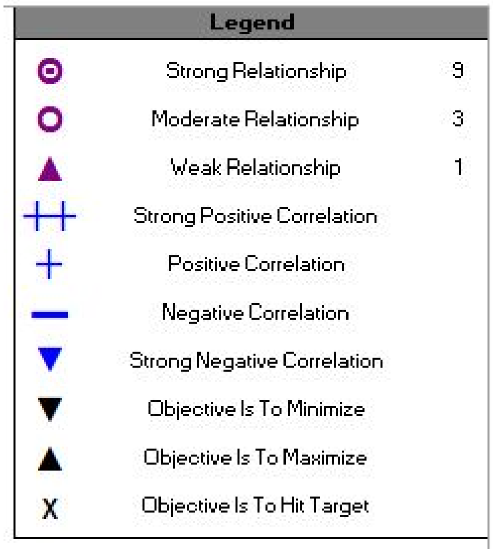


Figure 111: Legend for symbols used in QFD analysis

The third room in the house of quality is the correlation matrix where the different engineering characteristics are correlated to one another, the symbols used can be seen above in Figure 111. The correlation matrix can be seen below in Figure 112.

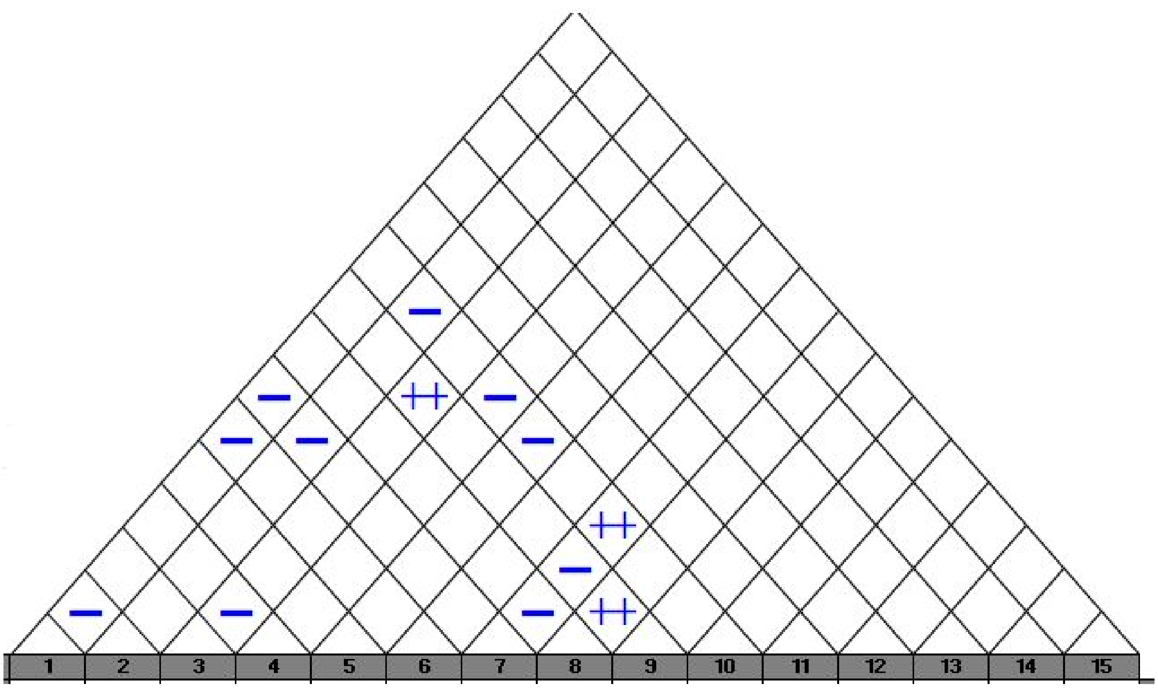


Figure 112: Room 3: Correlation Matrix

In order to see how the correlation matrix correlates each engineering characteristic, room two and three can be seen below in Figure 113. In the correlation matrix, there are four difference symbols to be used, which can be seen in Figure 111. The symbols that can be chosen represent a strong positive correlation, a positive correlation, a negative correlation, and a strong negative correlation. This means that when there is a positive or strong positive correlation that the engineering characteristics are proportional to one another, when there is a negative or strong negative correlation the engineering characteristics are inversely proportional to one another, and if there is no symbol then the engineering characteristics are independent from one another. Using this, the team could evaluate how engineering characteristics effect one another.

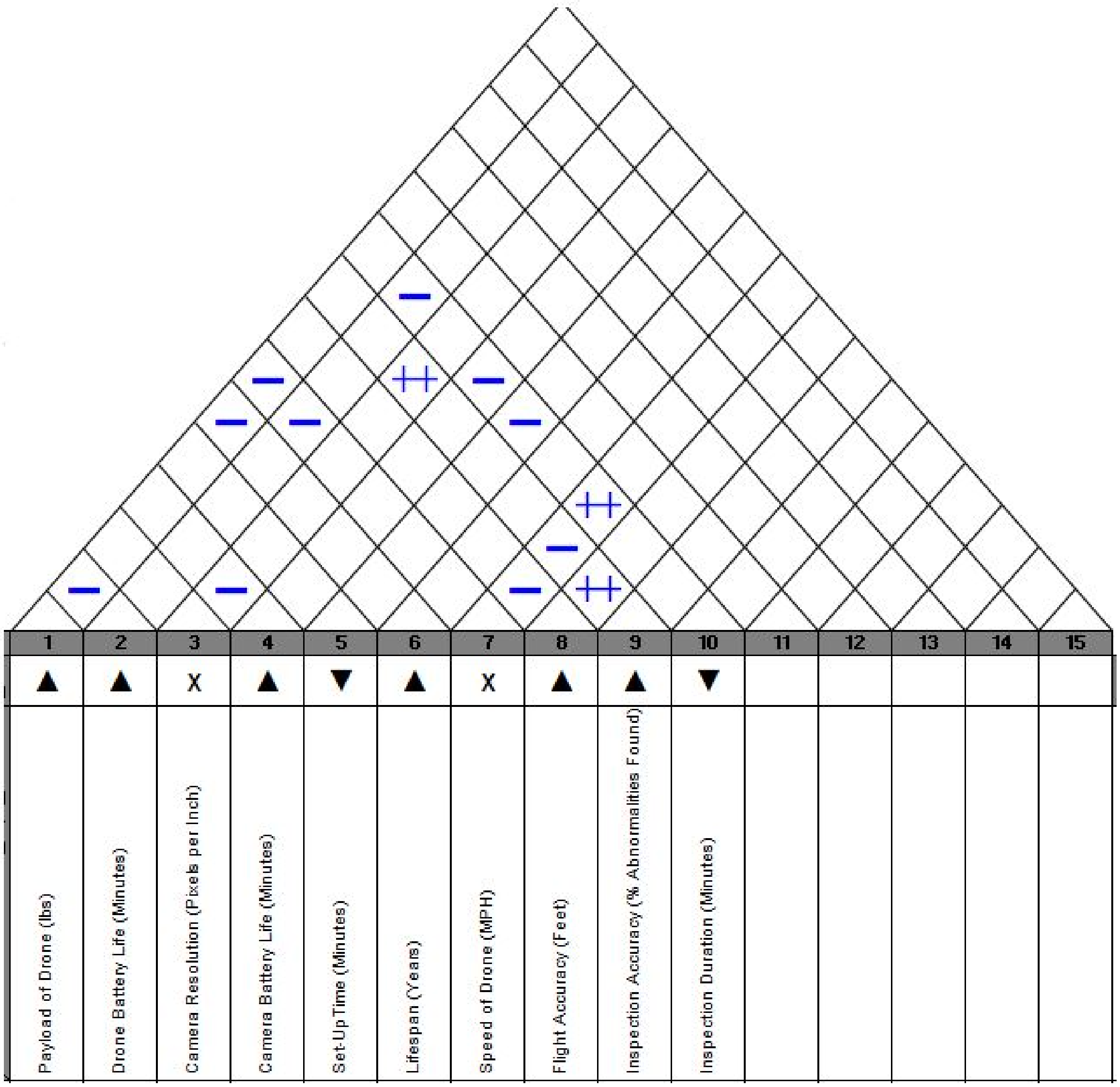


Figure 113: Correlation between engineering characteristics

Next, is room four in the house of quality which is the relationship matrix which relates the customer requirements to the engineering characteristics. These are related by symbols seen in the legend in Figure 111 and the symbols are for a strong relationship, moderate relationship and weak relationship. This can be seen below in Figure 114.

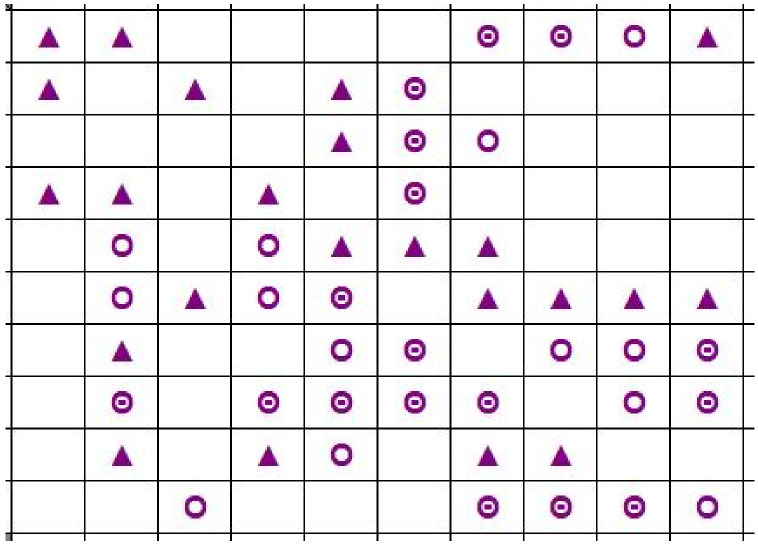


Figure 114: Room 4: Relationship Matrix

In order to show the relationships between the engineering characteristics and the customer requirements, rooms one, two, and four are shown below in Figure 115. The relationship between the customer requirements and the engineering characteristics are related using three symbols, one for a strong relationship, one for a moderate relationship, and one for a weak relationship, or no symbol representing no relationship. Each of the three symbols have a importance rating of nine for a strong relationship, three for a moderate relationship, one for a weak relationship, and if there is no relationship then it is zero. When there is a strong relationship between the customer requirement and the engineering characteristic, it means that the engineering characteristic must be met in order to satisfy the customer requirement. When there is a moderate relationship between the customer requirement and the engineering characteristic, it means that the achievement of the engineering characteristic will have an effect on satisfying the customer requirement. When there is a weak relationship between the customer requirement and the engineering characteristic, it means that if the engineering characteristic is achieved, it will have a small effect on satisfying the customer requirement. If there is no relationship between the engineering characteristic and the customer requirement, then achieving the engineering characteristic will not help satisfy the customer requirement. This helped the team identify which engineering characteristics related to satisfying 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 115: Relationship between customer requirements and engineering characteristics

Room five in the house of quality is the importance ranking of each engineering characteristic, which can be seen below in Figure 116. This room has two rows, one is the weight/importance and one is the relative weight. The absolute importance or weight/importance of each engineering characteristic is calculated by, multiplying the numerical value in each of the cells of the relationship matrix by the associated customer requirements importance ratings, then sum the results for each column which equals the absolute importance of each engineering characteristic in meeting the customer requirements. The relative importance or relative weight is found by totaling the values of the absolute importance, then take each of the values of absolute importance, divide that by the total and multiply by 100. This helped the team determine which engineering characteristics are most important.

Weight / Importance	31.1	204.4	53.3	182.2	275.6	471.1	353.3	248.9	211.1	255.6
Relative Weight	1.4	8.9	2.3	8.0	12.1	20.6	15.5	10.9	9.2	11.2

Figure 116: Room 5: Importance Ranking

Next in the house of quality is room six, which is the customer assessment of competing products, which can be seen in Figure 117. In this section, the teams inspection process using the 3DR Solo drone was compared to the current inspection process of an airport employee walking and driving around the airport conducting the inspection. The manual inspection beats the teams proposed inspection process in a few categories only due to the drone not being fully waterproof and the potential updates needed to the drone system, but the most important customer requirement is the reduction of man hours because this is going to save the airport money and allow the employee that the drone is replacing to complete other tasks during this time. Also, the 3DR Solo drone was compared with three other popular drones on the market, that could be capable to conduct the inspection. The drones that the 3DR Solo are competing against are the DJI Matrice 210, which is fully waterproof, but has a cost of $10,000 compared to the $585 3DR Solo, so the price difference makes up for the 3DR Solo not being fully waterproof. Next, it was compared with the DJI Phantom 4 which costs $1,499, which has all of the same features as the 3DR Solo. Lastly, the 3DR Solo is compared with the Splash Drone 3, which costs $1,699, which is again more expensive than the 3DR Solo. The team could purchase any of these three other drones to increase the range to extend the inspection process to larger 139 airports. Also these other drones add the perk of being waterproof, so inspections could be completed in rainy weather.

Competitive Analysis
(0=Worst, 5=Best)

Our Company (IRIS 3DR)	Manual Inspection (Current Process)	DJI Matrice 210	DJI Phantom 4	Splash Drone 3	
4	4	4	4	4	
2	5	4	2	4	
3	5	4	3	3	
4	5	4	4	4	
3	4	2	2	2	
3	2	1	3	3	
4	5	4	4	4	
4	0	4	4	4	
4	2	3	3	3	
4	5	4	4	4	

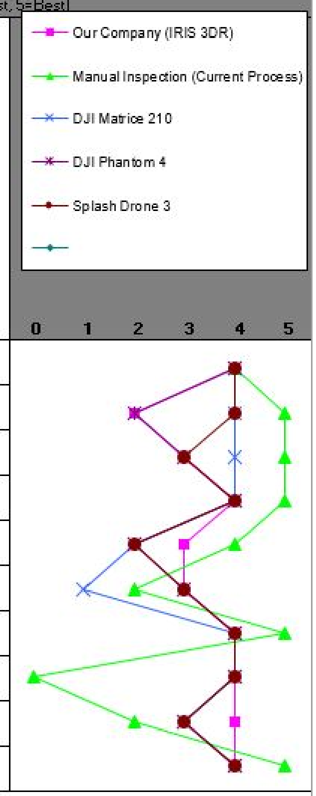


Figure 117: Room 6: Customer Assessment of Competing Products

The next room in the house of quality is room seven, which is the technical assessment, which can be seen below in Figure 118. This section is where each of the engineering characteristics are rated based on difficulty to achieve, on a scale from zero to ten, with ten being extremely difficult to achieve. This helped the team recognize which engineering characteristics are hard to achieve.

Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	8	0	0	0	3	2	1	7	8	1

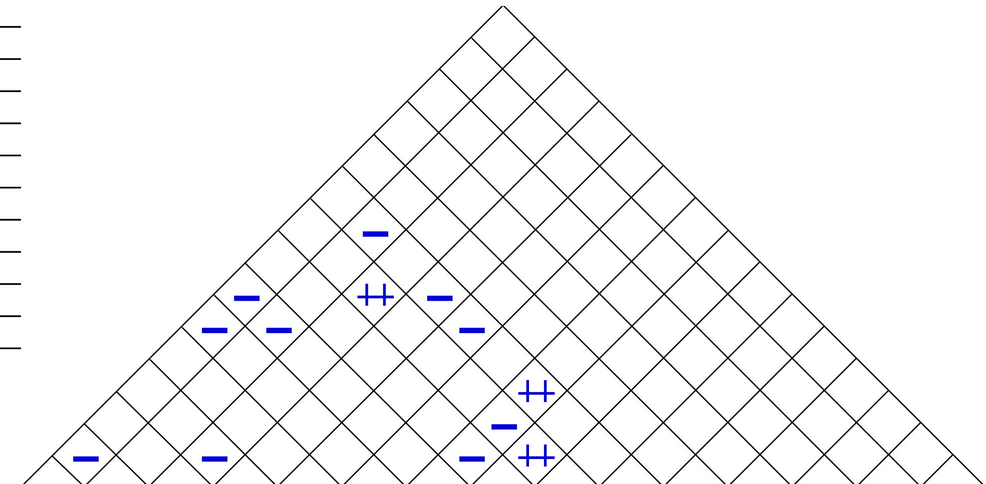
Figure 118: Room 7: Technical Assessment

The last room in the house of quality is room eight, which is the target values for the engineering characteristics, which can be seen below in Figure 119. These are the target values of the engineering characteristics that the team must achieve in order to have a successful design that will meet all of the customer requirements.

Target or Limit Value	0.8	16-22	4K 30FPS	50	15-20	3	15-20	0-2	100	<16

Figure 119: Room 8: Target Values

Title: Inspection of Airports Using Drone
Author: Benjamin Travelyn, Grace Sanita, Scott Liguori, Julian Andriulli
Date: 10/26/17
Notes:



Legend

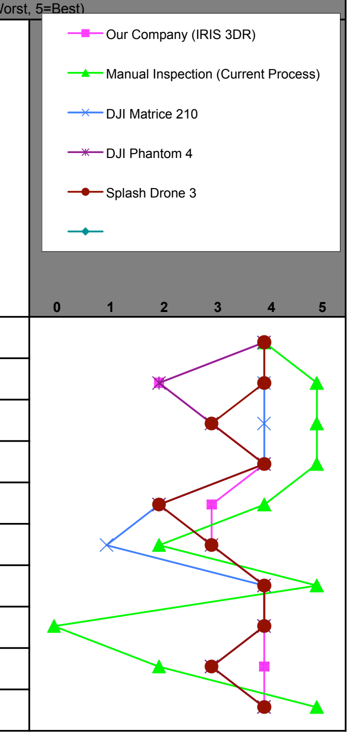
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▲	x	▲	▼	▲	x	▲	▲	▼					
Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Payload of Drone (lbs)	Drone Battery Life (Minutes)	Camera Resolution (Pixels per Inch)	Camera Battery Life (Minutes)	Set-UpTime (Minutes)	Lifespan (Years)	Speed of Drone (MPH)	Flight Accuracy (Feet)	Inspection Accuracy (% Abnormalities Found)	Inspection Duration (Minutes)					

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	**Demanded Quality** (a.k.a. "Customer Requirements" or "Whats")	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	9	11.1	5.0	Safety	▲	▲					Θ	Θ	O	▲					
2	9	8.9	4.0	Waterproof	▲		▲		▲	Θ									
3	9	8.9	4.0	Durability					▲	Θ	O								
4	9	11.1	5.0	Lifespan	▲	▲		▲		Θ									
5	3	11.1	5.0	Maintainability		O		O	▲	▲	▲								
6	9	11.1	5.0	User Friendliness		O	▲	O	Θ		▲	▲	▲	▲					
7	9	11.1	5.0	Adaptability to Different Airports		▲			O	Θ		O	O	Θ					
8	9	11.1	5.0	Reduction of Man Hours		Θ		Θ	Θ	Θ	Θ		O	Θ					
9	3	4.4	2.0	Training Required		▲		▲	O		▲	▲							
10	9	11.1	5.0	Accuracy			O				Θ	Θ	Θ	O					
				Target or Limit Value	0.8	16-22	4K 30FPS	50	15-20	3	15-20	0-2	100	<16					
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	8	0	0	0	3	2	1	7	8	1					
				Max Relationship Value in Column	1	9	3	9	9	9	9	9	9	9					
				Weight / Importance	31.1	204.4	53.3	182.2	275.6	471.1	353.3	248.9	211.1	255.6					
				Relative Weight	1.4	8.9	2.3	8.0	12.1	20.6	15.5	10.9	9.2	11.2					

Competitive Analysis
(0=Worst, 5=Best)

Row #	Our Company (IRIS 3DR)	Manual Inspection (Current Process)	DJI Matrice 210	DJI Phantom 4	Splash Drone 3	
1	4	4	4	4	4	
2	2	5	4	2	4	
3	3	5	4	3	3	
4	4	5	4	4	4	
5	3	4	2	2	2	
6	3	2	1	3	3	
7	4	5	4	4	4	
8	4	0	4	4	4	
9	4	2	3	3	3	
10	4	5	4	4	4	



9 Design for X

Throughout the design process for automating daily airport inspections using a drone, various different factors were considered. This design was designed for safety, environment, adaptability, and cost. The reason for each can be seen below.

9.1 Design for Safety

Safety is the most important design requirement when implementing the automated inspection process into an airport. In order to ensure the protection and mitigate any and all safety risks while employing the drone, several tasks are completed and designed into the inspection process. Firstly, the team was provided an Operational Directive by RIAC to be able to fly the drone at Westerly State Airport and Newport State Airport. Per the directive the team must always be accompanied by RIAC Aeronautics Inspector James Warcup when on airport property, who has ultimate say when and where the team can fly the drone. James is also responsible for radio signaling a Notice to Airmen (NOTAM) to aircraft in the area, alerting pilots about the presence of the team and drone on the airport's property. In the team's inspection procedure, safety designs include performing the NOTAM and shutting down the runways and areas to be inspected before the process begins. The drone must always be in the line of sight of the airport operator, who has the ability to immediately stop the inspection and land the drone in a case of emergency. With the human element, it is impossible to eliminate all risks, but with the safety designs implemented in the team's inspection process, hazards can be mitigated to acceptable levels. Safety Risk Assessments (SRA) were completed to determine whether specific risks were designed for in the inspection process and mitigated to acceptable levels for airport operation, which can be seen in section 10.1.

In addition to maintaining safe practices while designing and testing the automated inspection process, the inspection itself is all about safety. The daily airports are used as a tool to maintain the highest quality environment for pilots to work in. Runway and Taxiway lights are used as signals to pilots arriving or leaving the airport. The runway and taxiway light inspections are used to ensure that if a lighting defect were to occur, it will be fixed as soon as possible, therefore allowing the pilots to see those signals.

The perimeter and safety inspections are often used to find foreign debris or wildlife. This debris and wildlife could be a hazard during take off or landing at the airport. While testing at Westerly State airport, is was very common for the team to find things like banners and golf balls around the airport. During one particular test of the perimeter inspection, the team found a deceased deer. The deer was attracting additional wildlife, turkey vultures, and therefor additional hazards. This deer was found in a location that is very difficult to get to by the traditional inspection practices of driving in a car. Using the drone made it easier and quicker to determine exactly where the deer was, and the easiest way to get to it to remove it.

For a general aviation airport, the perimeter inspection is also used for community safety. Generally, GA airports are not completely fenced around the perimeter, therefore many people are unaware of the airport border. This creates a dangerous situation for accidental incursions onto airport property. The inspection is sometimes used as a tool to see if an unsuspecting person has wandered onto the property. If so, the airport manager will have time to redirect that person before anything bad happens.

9.2 Design for Environment

The team included environmental design considerations in the automated inspection process. The physical flight environment was a large concern for the team. With the design being implemented outdoors, it was impossible to create and maintain a perfect environment. The team chose to test many times over a series of many days in order to test the process in a variety of weather conditions. Video was taken while it was both overcast and sunny out to test the visibility of the lights in both conditions. The drone was tested under consistent crosswind speeds of 25 mph to ensure the drone's stability in a harsh flying environment. Specifically for the 3DR Solo drone, in the test procedure, it is highly recommended the drone is only flown in dry weather conditions and should not be flown in any types of fog, rain or snow; all of which Westerly State Airport experiences respectively throughout the year. Flying in dry weather conditions elongates the lifespan of the drone and mitigates the risk of moisture or water getting into the drone's engines. If an airport looking to implement the automated inspection were to have a larger budget, a more advanced drone, more suited for flying in high humidity or fog, could be purchased.

The objective of the design is to perform a complete, accurate inspection, but the process has additional uses; including wildlife harassment. Airports are responsible for the harassment of wildlife in the area or on runway to train the animals to stay away from the airport environment. By automating the inspection process, the drone's presence and engine noise harasses wildlife in the area, causes birds to fly off the area and not return. In multiple tests, flocks of smaller birds were harassed off the immediate runway vicinity. During one test multiple turkey vultures, up to three times the size of the 3DR Solo, vacated the area near a dead deer due to the drone's presence. This allows for video evidence of wildlife harassment, the airport's legal responsibility, while also allowing airport personnel to deter wildlife in difficult to reach areas. The video evidence of the wildlife can be further used as a tool for biologists to determine wildlife rates in the airport atmosphere. Currently, each airport is supposed to have a wildlife or biology program to keep track of wildlife rates, and common wildlife types at each particular airport. The logging system not only makes it easy to show airport conditions each day, but it also allows biologists to study animal behavior around the airport. Since wildlife at an airport can directly effect the safety of said airport, is it extremely important for a wildlife program to know the probability of an animal being on the runway. This information is used by pilots in order to be ready for the potential of wildlife incidents.

The perimeter and security inspections for a General Aviation airport inherently effect the environment around the airport. The inspection's main objective is protect people from the hazards of an airport. With the automated inspection using a drone, these inspections can more easily be conducted. This creates a safer environment for the people surrounding the airport. The video logging system can also be used to determine when people may be repeat offenders of walking onto the airport property. This will allow airport personal to know when to properly deal with a person, whether it be to simply alert them to the dangers of the airport, or to report a person to the authorities for endangering themselves and the pilots that may be landing or taking off.

9.3 Design for Adaptability

Being one of the most important design components of this project, process adaptability was heavily concentrated on by the design team. As each airport has a different geography, time and employee availability, budget, and many other factors. Not only the process, but the cost and material used must vary based on the location of application. This lead the team to set a range of possible process paths and material purchasing, such as different levels of drone model complexity relative to airport size. Smaller airports, often with a smaller budget, cannot afford to implement a costly inspection system for thousands of dollars, nor do they need to with such small runway size and daily traffic. Therefore, drone recommendation lists were created ranging from $500-$1500, allowing the team to quickly choose a drone based on an airports available funds and size, while taking into account the unique challenges that localized weather bring (increased wind, larger average rainfall percentages, etc.). The drone market is always expanding and growing, therefore the recommendation list could be updated as drone technology becomes more advanced and less expansive. Along with this, multiple process paths were considered for varying airport personnel availability, ranging from the smallest airport with only one employee available to large scale airports with employee availability of ten different employees or more for allowing for a personnel shift based rotating inspection system.

During testing, the team was able to design for the adaptability of the inspection procedure and is able to test at multiple airport sites. With the 3DR Solo, the drone's application allows the capability of creating and saving custom flight paths using Google maps. This allows the team the ability to design flight paths for any airport in the country. The app also allows the ability to implement custom design heights, speeds, and paths which gives the team the ability to adapt to any airport if needed. In adapting the process to a new airport, the team would start with the optimum values for altitude, speed and distance from target found through testing at Westerly State Airport. Then, like at Westerly State Airport, the team would test and modify the path to avoid obstructions and to address airport specific needs. For example, one of the perimeter gates at Westerly State Airport is at the bottom of a large hill. The hill is hard to see on the Tower app, and was therefore only accounted for during the flight path tests. Each airport has its own terrain that the flight path would have to be adjusted for. However, with the easy to use app, the team can quickly adjust the path to fit each airport during the initial process implementation.

To prove the design's adaptability, the team also performed perimeter and lighting testings at Newport State Airport. The team followed the above implementation and modification process to create flight paths for Newport State Airport. In testing the process, the drone flew automated flight paths to inspect the airport's fencing. At Newport State Airport the perimeter fencing is surrounded by inaccessible wetlands that keep operators from driving their vehicle through to conduct the inspections, therefore making it a prime candidate to use the drone-based inspection process.

9.4 Design for Cost

The automated process was specifically designed to optimize the daily inspections conducted by airports in an effort to save time and money. The current inspection process at general aviation airports is time consuming, slow and tedious for operators to manually inspect the entire perimeter and lights. GA airports, from the airport personnel survey sent out by the team, typically employ two operators to conduct inspections and 139 airports employ up to 10 operators due to the increased aircraft size and volume of traffic. The automated inspection process was designed to only require one general aviation airport operator to conduct the inspections and reduce the total time from 60 minutes to 20 minutes, allowing the allocation of a second operator to be directed towards other tasks or eliminated completely. If implemented at 139 airports, such as T.F Green, the process could reduce the number operators and time needed to inspect the airport perimeter and runway and taxiway lights. The time and man power saved from the automated process for GA airports cumulates to 726.7 hours and $27,250.50 yearly, as seen in Table 7 from the Financial Analysis section. The process was also designed to be able to be conducted with a commercial drone as the UAV. Presently, commercial drones are a relatively new product with exponentially increasing technology in terms of control and total capabilities. The team utilized an older drone, a 3DR Solo, in order to demonstrate the inspections can be completed quickly with clear video by a relatively outdated, cheaper UAV, with respect to the current market. Airports do not need to spend thousands of dollars to purchase the latest model in drone technology to implement the automated inspection process and can opt for an older model to accomplish the same goal.

10 Project Specific Details & Analysis

The ARCP competion has several requirements that must be fulfilled for submitted designs to be officially judged. The first requirement is the individual or team of students must attend an accredited university or college. The University of Rhode Island's engineering disciplines are all accredited by the Engineering Accreditation Commission (EAC) of ABET, Inc., the recognized leader in international engineering program accreditation. Along with an accredited university, the team participating in the competition must have a faculty advisor overseeing the work and design process. Team 11's faculty advisor is Dr. Bahram Nassersharif, a distinguished university professor at the University of Rhode Island. Dr. Nassersharif has worked with the team and oversees the design process. The ARCP competition also requires the teams to interact and document their communication and collaboration with airport operators and industry experts in the design process. Team 11 has been in contact and worked with James Warcup, Chief Aeronautics Inspector for the Rhode Island Airport Corporation (RIAC), and Dave Lucas, Quonset State Airport/FBO Manager, throughout the entire design process and have been crucial to the team's project definition and design path. With the help of James Warcup the team was provided with two Operational Directives which provided the team permission to fly the drone in Westerly State Airport and Newport State Airport, along with James Warcup accompanying the team for all tests completed at Westerly State Airport and Newport State Airport. An important aspect of the airport operator and industry expert interactions is the feedback on the practicality of the proposed design and approach. Both James and Dave have explicitly stated the advantages of utilizing a drone to automate the airport's inspection process including reduction of required man hours which in turn lowers the airports cost to pay employees to conduct the inspection to complete tasks, runway shutdown time and importance of logging inspections for record keeping and legal uses. Another requirement for the ARCP national competition is a literature review to carefully consider previous research and solutions to the chosen design challenge. Along with the patent and literature completed by the team for an assignment in MCE 401, the team has reviewed previous winning projects and designs of years past as provided on the ARCP competition website. The review confirmed the utilization of a drone to automate the inspection process has not won the competition in recent years [19]. The team also had to complete a safety risk assessment and a cost/benefit analysis which can be seen below.

10.1 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 [20]. Within an organization's SMS, safety management tools include assessing the risk and controlling risk [20]. 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 [21]. 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 an 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.

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.

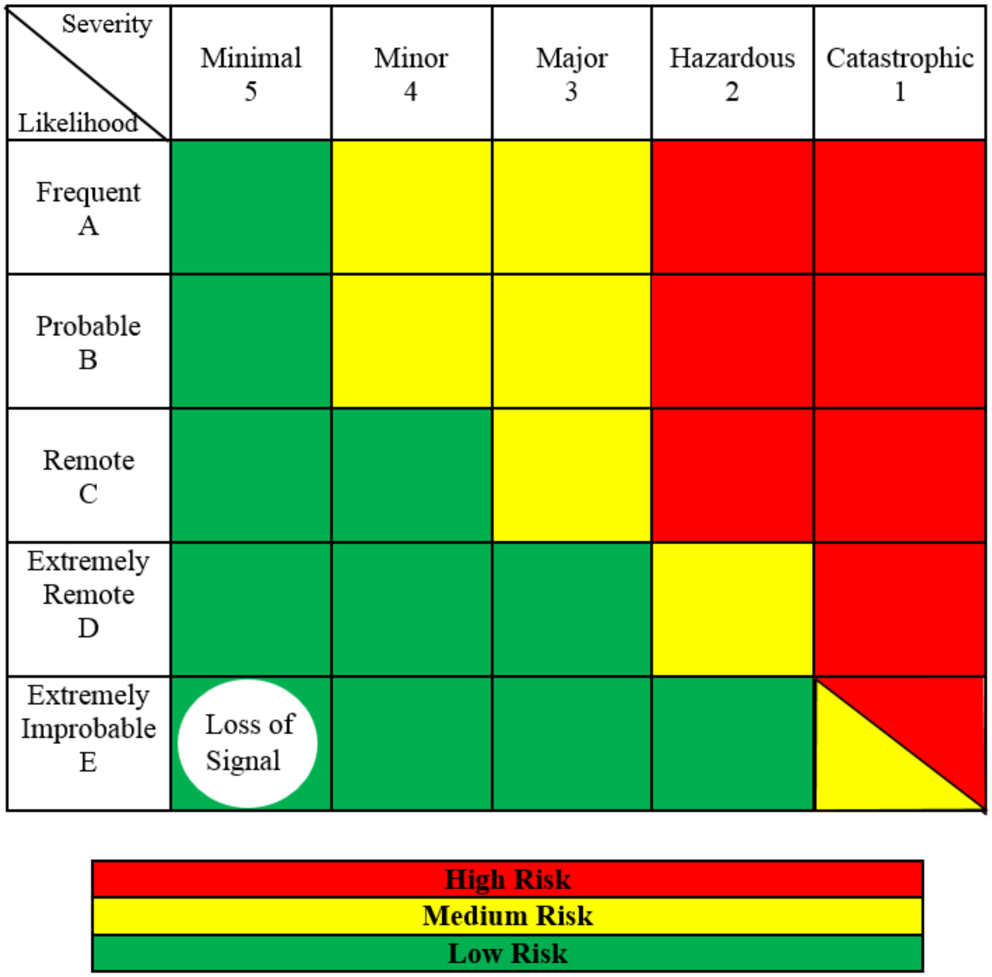


Figure 121: Risk Assessment Chart 1

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.

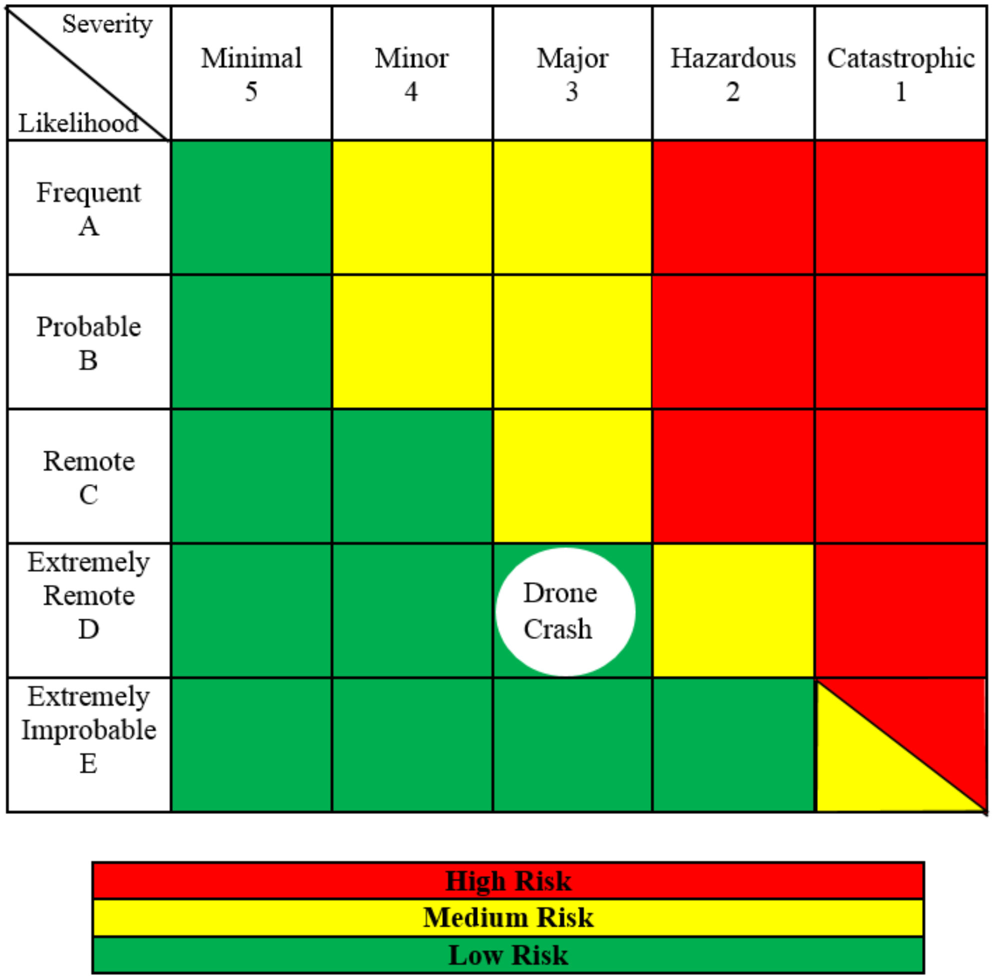


Figure 122: Risk Assessment Chart 2

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.

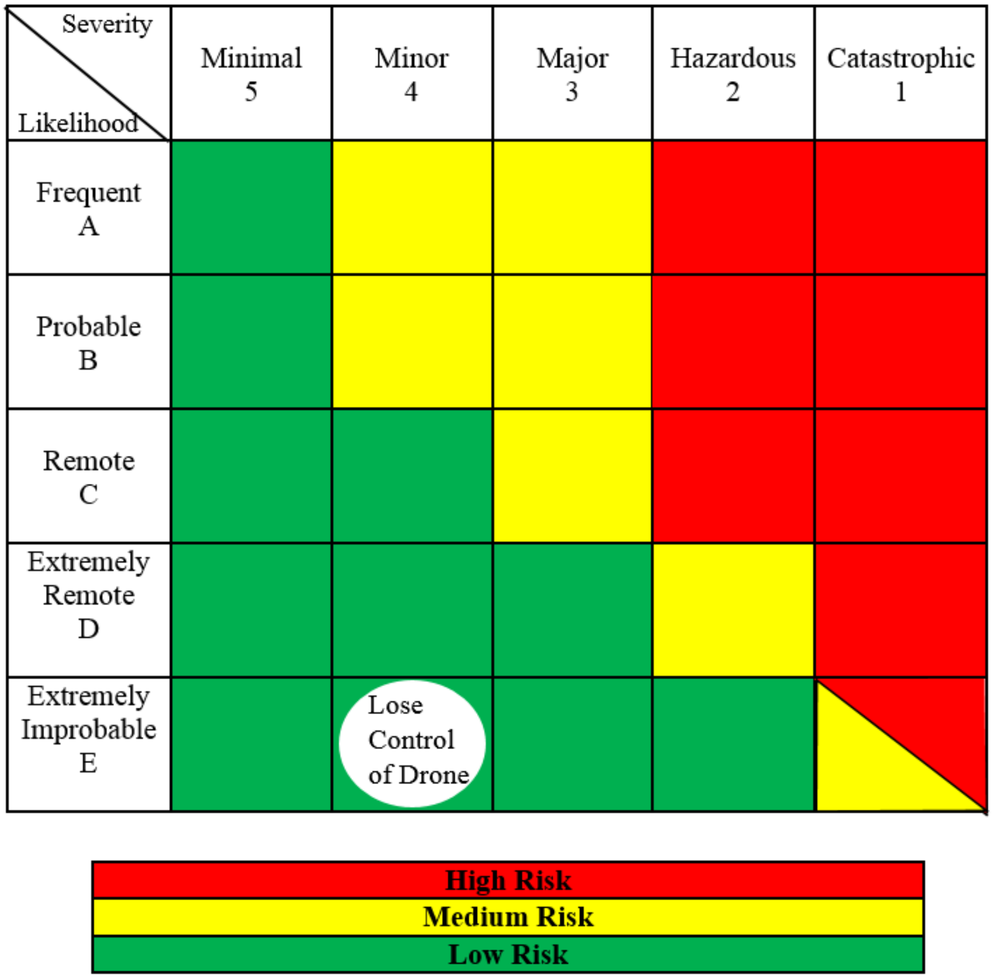


Figure 123: Risk Assessment Chart 3

After reviewing all safety hazards completing a Safety Risk Management process, 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. [21]

10.2 Cost/Benefit Assessment

In order to determine the impact of the design, a Cost/Benefit Assessment was completed [22]. If the total labor costs for students, consultants, travel and materials were calculated, the total would be $59,626.48 as presented below in Table 6 and as discussed in the Financial Analysis section. 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 7 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 6, 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 6: Total Tangible Costs for Year

Item	**Rate**	**Quantity**	**Subtotal**	**Remarks**
Labor- ACRP Design Competition				
Student Efforts	$32.50/hr	1,682	$54,665	4 student - Cumulative Total
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			**$59,626.48**	

Table 7: Benefits of Drone-Based Inspection System

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

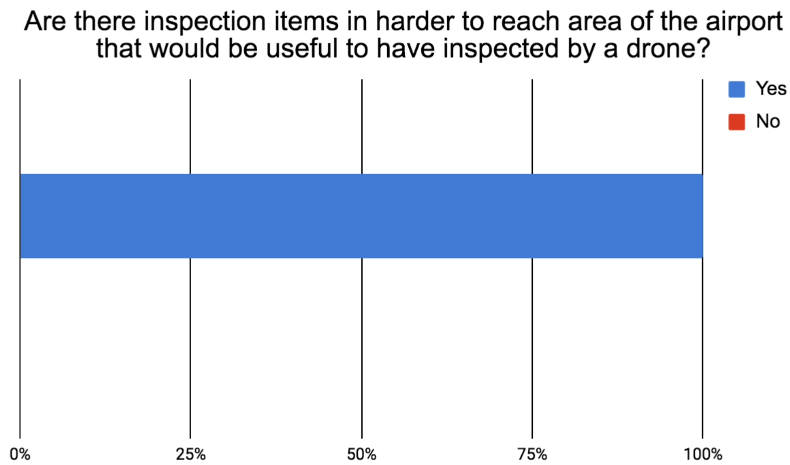
Overall, the benefit of this drone-based inspection system is the reduction of man hours, resulting in a reduction in total costs per year. Over a 5-year period the airport will save a total of $132,235.50, this includes the cost to purchase the items needed and the inspection process from the team.

10.3 Approval to Fly in Airports

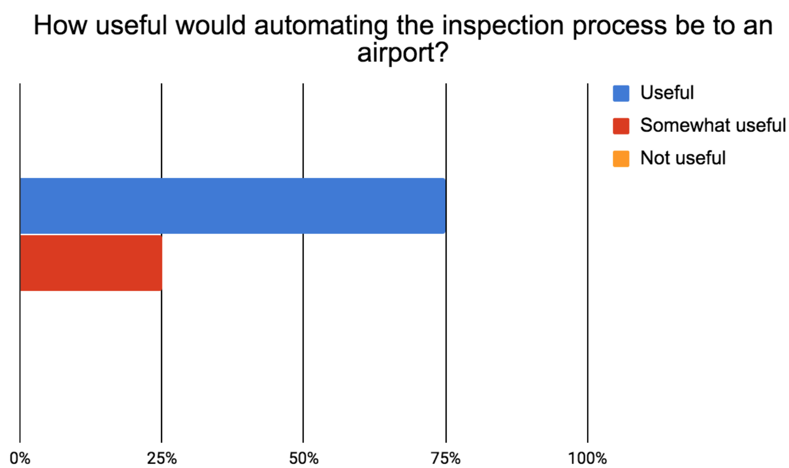
In the beginning of the Fall semester, the teams biggest obstacle was being unable to fly the drone in an airport due to FAA restrictions, but the team was granted permission by RIAC to fly the drone in the airport, without having to go through the FAA. The team was given an Operational Directive from the state of Rhode Island, giving the team permission to operate the drone in Westerly State Airport and Newport State Airport. The team must contact James Warcup, the Chief Aeronautics Inspector and the airport manager at Westerly State Airport a week ahead of time and must be approved before the drone can be flown in the airport. The Chief Aeronautics Inspector or the airport manager will issue a Notice to Airman (NOTAM). A NOTAM alerts all planes in the area that there is a drone in the airport, so they will not enter the airspace. 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 imposed by the Chief Aeronautics Inspector or Airport manager. The Operational Directives can be seen in the Appendices.

10.4 Survey Sent to Industry Experts

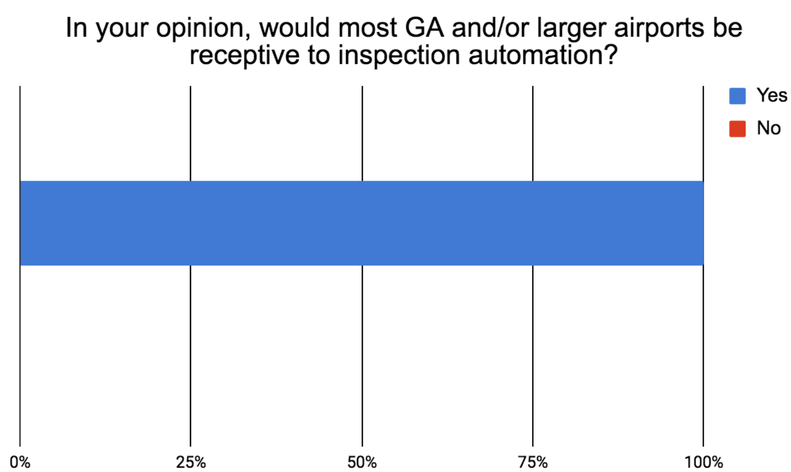
To get a wider range of feedback about the potential use of drones for automated inspections of an airport, the team created a survey that was sent out to various airport officials and executives, airport operations staff, and other airport employees. The purpose of this survey was to gain a better understanding 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. The first use of the survey questions was to assist the team with the cost/benefit analysis to determine how many inspections were conducted per day, how long they take, and how much they cost. The next use for it was to determine if airports like the idea and if they would implement it in the future. 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. The questions used in the survey can be seen in the Appendices.



(a) Survey question 1



(b) Survey question 2



(c) Survey question 3

Figure 124: Survey question answers

11 Detailed Product Design

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. After the process of narrowing down ACRP Design Competition categories and choosing a project, thirty concepts were generated per team member and a concept was chosen. The concept chosen was to inspect the airport using a drone. The process of developing the concept into the final design began with meeting with James Warcup and Dave Lucas from the Rhode Island Airport Corporation (RIAC) at Westerly State Airport. While at Westerly State Airport, they took the team on an inspection in order to help the team choose two main inspection points. From here the team decided to inspect the perimeter and security and the runway and taxiway lights, with the additional option to use the drone to harass wildlife out of the airport and use in the case of an incident to have footage saved.

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 125.

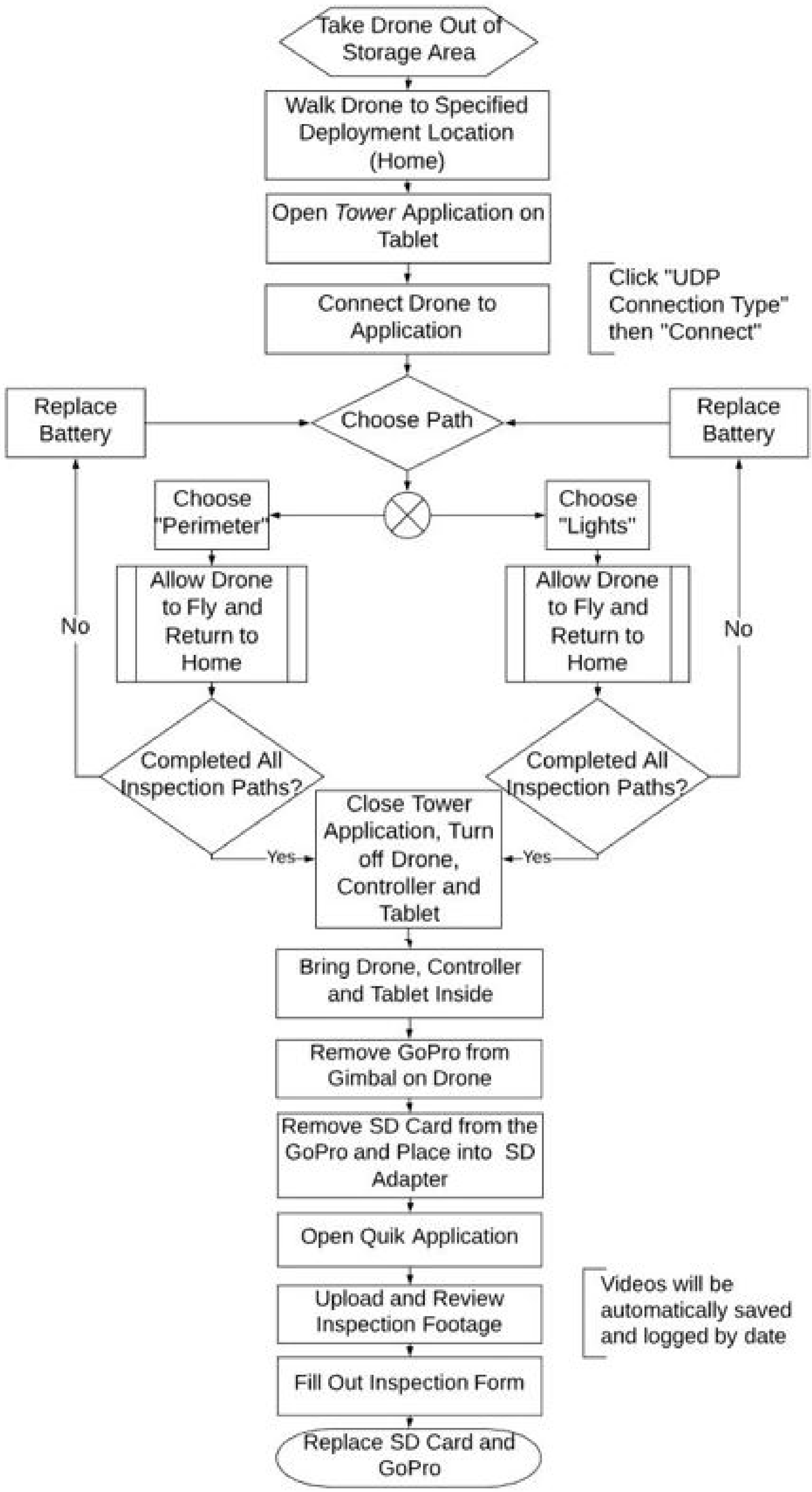


Figure 125: Updated process flow chart after Critical Path Analysis

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 8. 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 8: 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

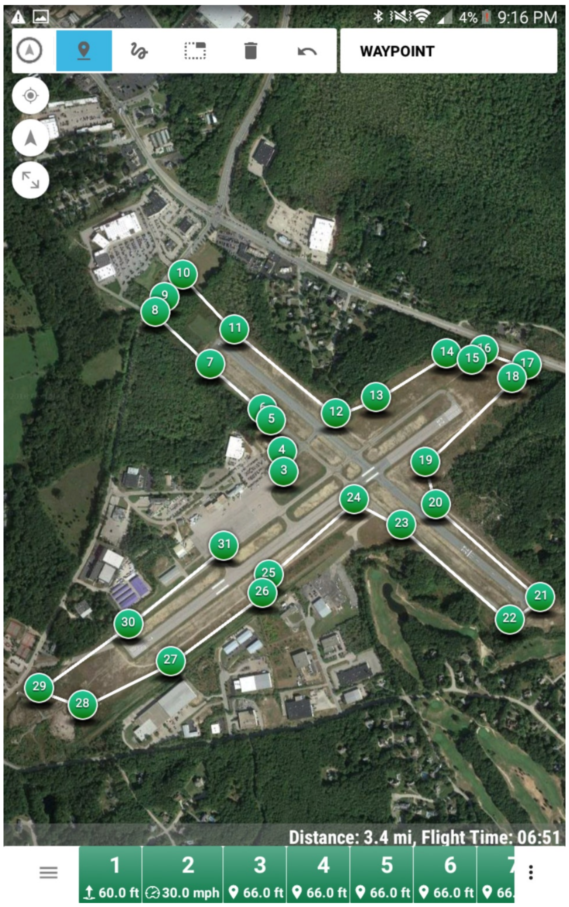
After these test flights were completed, the videos were analyzed and the optimum values were chosen based on visibility and room for variation of drone flight. Once the optimal parameters were chosen, each test and flight parameter was approved by James Warcup, to ensure and guarantee the quality of the inspection videos. The optimum values that were chosen for the altitude, speed, and distance from target are shown below in Table 9. 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 ten feet, the team conducted a lift force analysis of the drone (this full analysis can be seen in the Engineering Analysis section, section 12). 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 9: Test Results

Inspection Item	**Parameter**	**Test Range**
Runway/ Taxiway Lighting	Altitude	10 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 126a and the runway and taxiway light flight path is presented in Figure 126b. 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 126: 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 127.

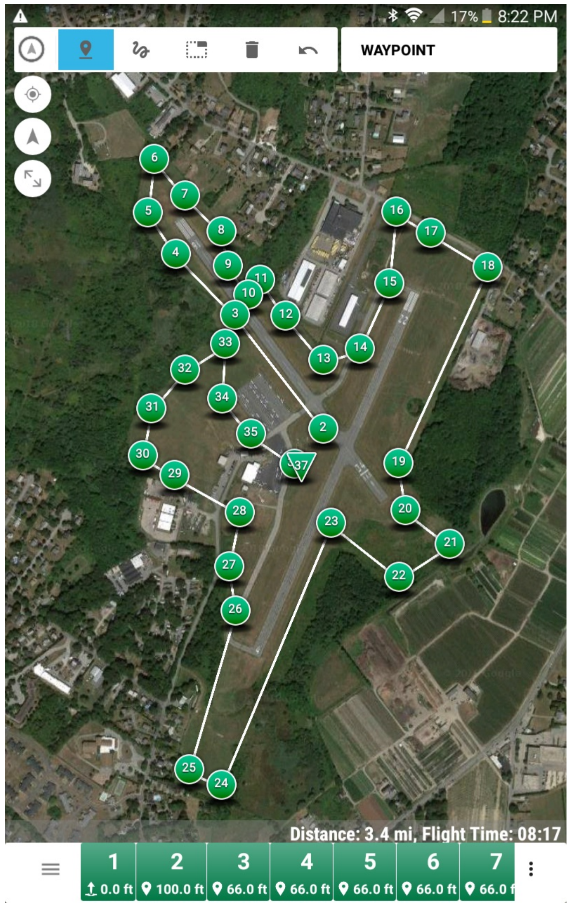


Figure 127: Perimeter flight path at Newport State Airport

On the following page Figure 128a and Figure 128c show runway lights that are off and Figure 128b and Figure 128d show runway lights that are on and the difference can clearly be seen. Figure 129a 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 129b. 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 130a 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 131a and b. The links to all of the videos where these pictures came from can be seen in Sakai under the Video section.

(a) Red runway light off

(b) Red runway light on

(c) White runway light off

(d) White runway light on

Figure 128: Examples of runway lights on and off

(a) Fence in perimeter inspection

(b) Tree line in perimeter inspection

Figure 129: Example of fence and tree line in perimeter inspection

(a) Open gate

(b) Dead deer in airfield

Figure 130: Example of failing inspection points

(a) Inaccessible area

(b) Second inaccessible area

Figure 131: 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.

12 Engineering Analysis

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.

12.1 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 original process flow chart can be seen below in Figure 132 and the updated process flow chart after the critical path analysis can be seen below in Figure 133.

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.

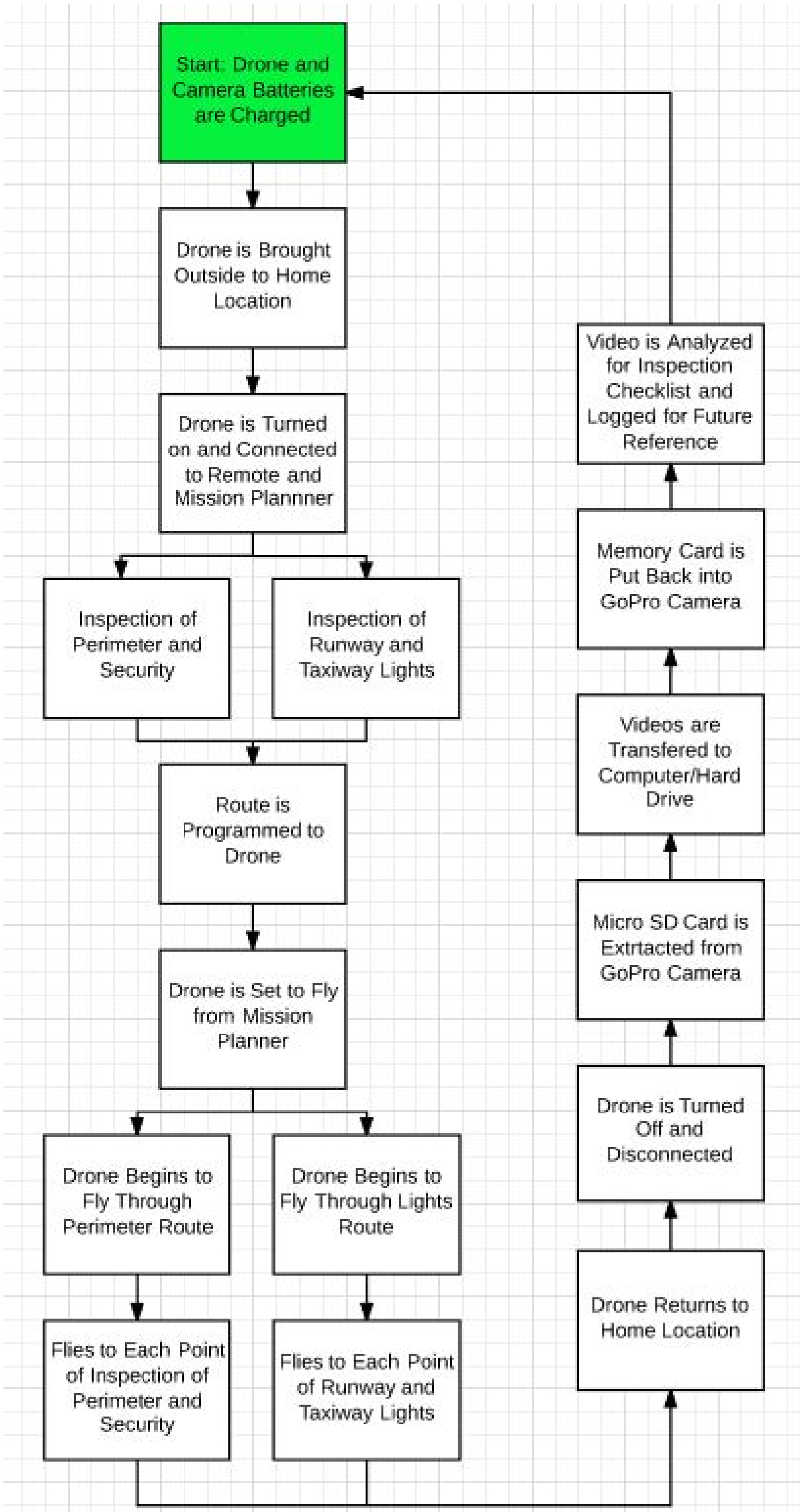


Figure 132: Process flow chart before Critical Path Analysis

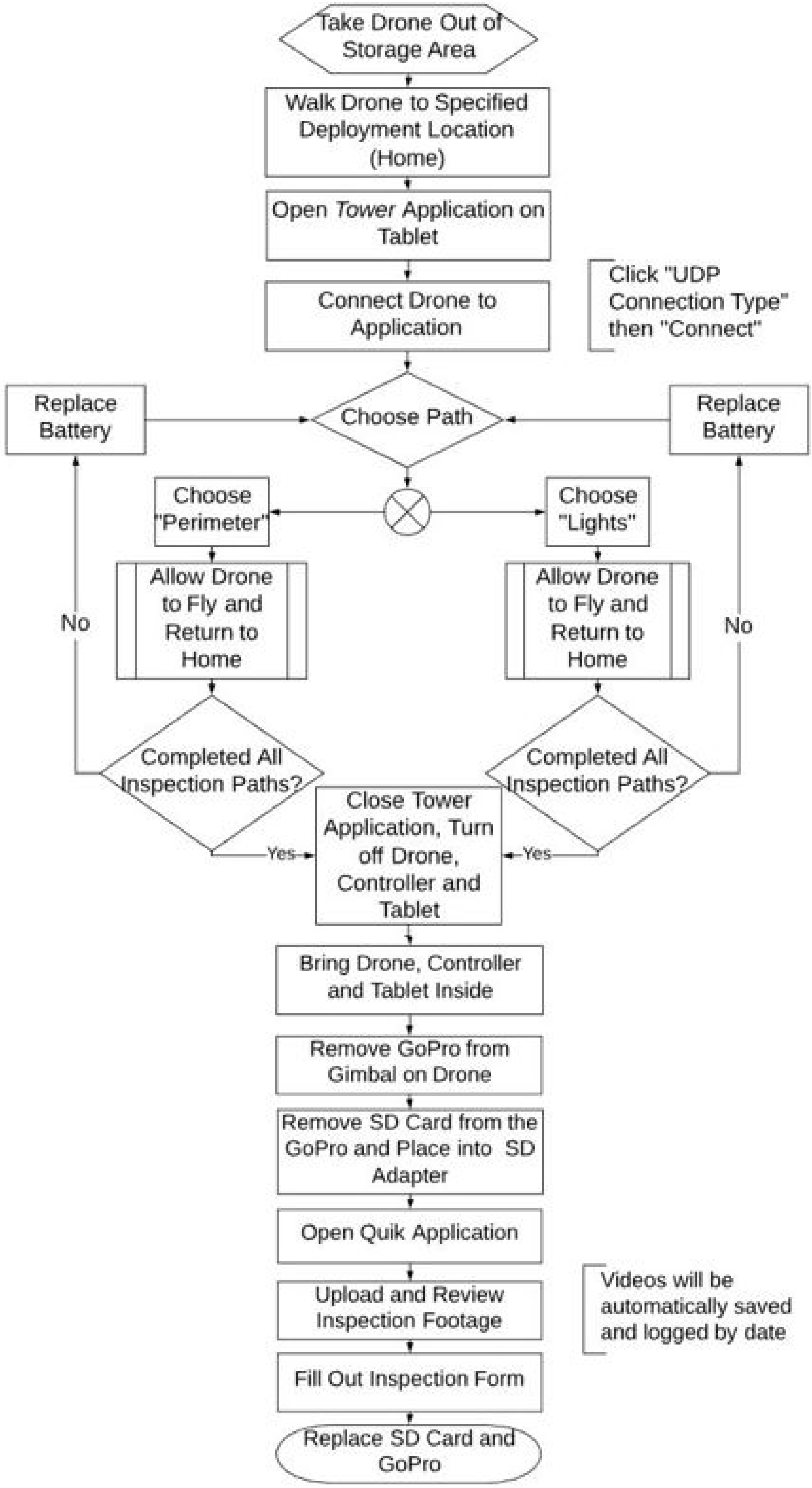


Figure 133: Updated process flow chart after Critical Path Analysis

12.2 Drone Lift

A UAV is ample to remain hovering or flying in air by accelerating a mass of air downwards, creating a reaction force in the opposite direction that is able to oppose the force of gravity. This upward propulsion force is commonly known as 'lift', and requires a substantial amount of power to oppose the constant force of gravity. With this, there is also an observable disparity in aerodynamic pressures between the upper and lower surfaces of its wings. On the upper surface of the wing or blade, there is lower pressure, whereas on the bottom there is significantly higher pressure, functioning as the reaction force implementing mechanism. Yet as the air blades are tilted at a 45 degree angle, the reaction force due to the downward push of air mass is not isolated to the positive z axis direction (assuming that the positive z axis is parallel to the direction of earth's gravitational pull and perpendicular to the ground). There are also horizontal x and y reaction force components, which result in a horizontal force acting on UAV's commonly referred to as drag. For a drone hovering in place, this drag force will increase proportionally to the force of the lift, and will pull the UAV in x and y directions, therefore destabilizing the device. This is why hovering and steady flight becomes more difficult for drones especially in environments containing higher wind speeds.

Given this information, it becomes clear that the main force required for the flight of any physical body is lift. To tangibly define the term, the lift produced is equal to the product of the mass-flow of air entrained and the velocity, u that is given to it in the downwards direction. Within the following chart, the variables of lift, incident angles, and drag will be defined. This can be seen below in Figure 134.

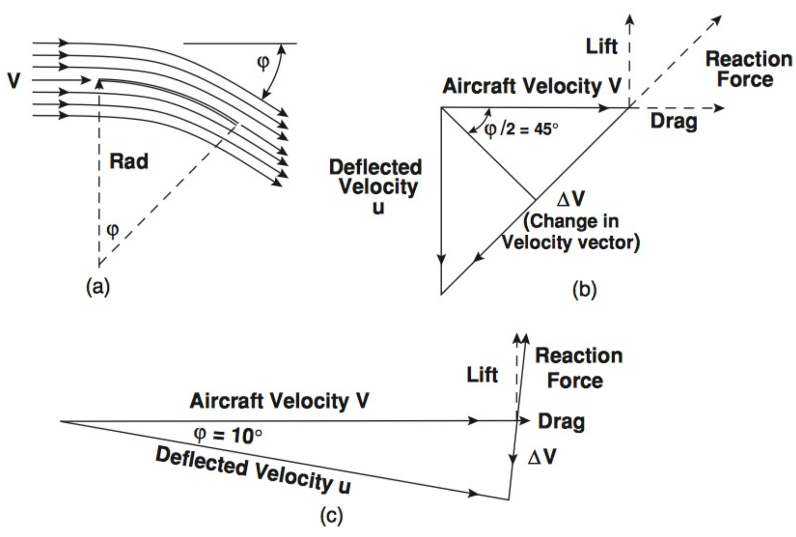


Figure 134: Lift generation on a UAV

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

$$L = 1/2 * \rho * (V^2)S * C_L \quad (1)$$

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.

It should also be duly noted that in the above figure the disparity of aerodynamic pressures between the upper and lower surfaces of the blades is shown, which acts as the catalyst for lift. To generate optimal lift, a ratio of lift to drag is obtained for small air stream deflection angles ϕ, where $\tan(\phi)$ = u/V. With this, the incidence of the wing to the air must be kept low in order to retain a small value of ϕ. In addition, the ability of the air to remain close to the upper surface of the wing fails at a higher wing incidence, resulting in an increase in drag, therefore destabilizing the drone.

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. From these equations and the subsequent calculations, the results can be seen below in Figure 135.

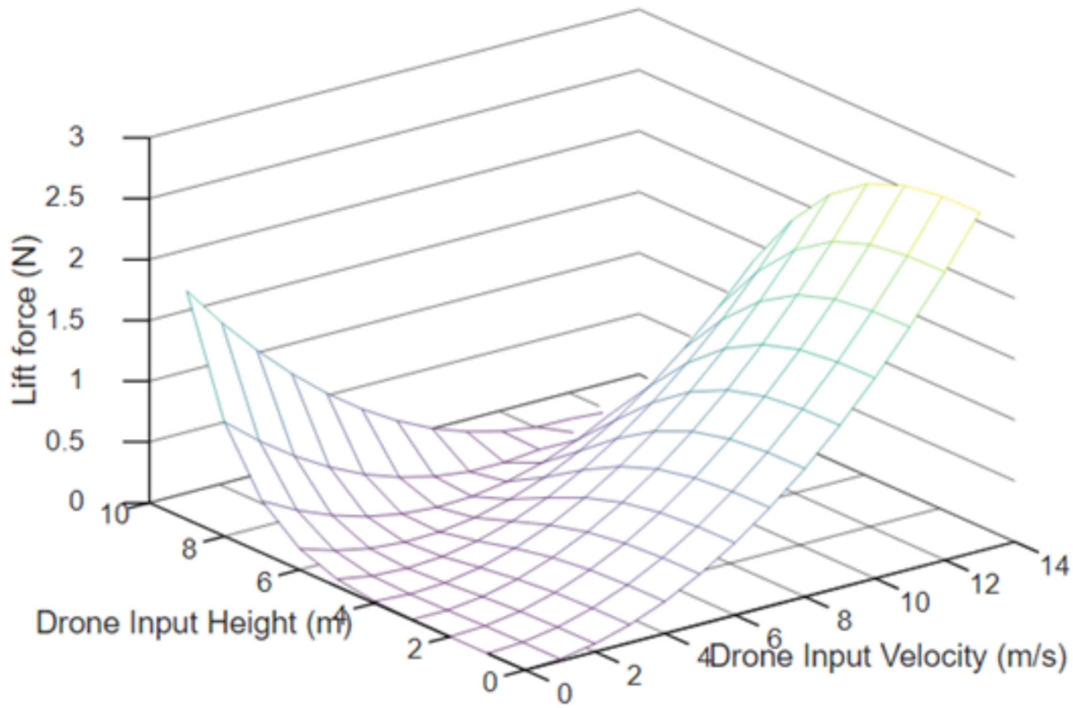


Figure 135: Plot used for drone lift

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 [8] [9] [10].

12.3 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 10.

Table 10: 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.

13 Proof of Concept

After the process of choosing to automate the inspection process using a drone, the team created a final problem definition, which is automation of daily airport inspections for runway and taxiway lighting and perimeter of a general aviation airport using a drone. The team's focus airport is Westerly State Airport, so all calculations were made based on this airport, but the automation process will be able to be applied to other airports, focusing on general aviation airports and private airports. In order to prove the team's concept, there are three main components to the design that the team had to prove. The first being that the camera can clearly see the inspection items, the second being that the drone flight route can be automated, and the third being that the drone will always be in range of the home location and that it will complete the inspection process in less than sixteen minutes.

The first focus is the camera clearly being able to see the inspection items. This was tested using a borrowed drone, due to the team not having the gimbal for the drone to record steady footage. This was proven by the team flying this borrowed drone at various speeds and various heights to show that the user can clearly see all inspection items in the video, regardless of height and speed. The drone was flown from 10 mph to 35 mph, and the video verified that the video is clear in this range of speeds. The video of this test can be seen in the ”Videos” section on Sakai, but still photos from this video can be seen below at 10 mph and 35 mph in Figures 136 and 137, respectively. Next, the drone was flown from 1 foot to 100 feet, and the video verified that the video is clear throughout this range. The video of this test can also be seen in the ”Videos” section on Sakai, but still photos from this video an also be seen below at 10 feet and 100 feet, in Figures 138 and 139. The team analyzed both videos and verified that the video is clear at 10 mph and 35 mph, therefore proving that the video is clear in the whole range. The team also analyzed and verified that the second video is clear at 10 feet and and 100 feet, therefore proving that the video will also be clear in this whole range for the inspection.

Figure 136: Still photo from test inspection at 10 mph

Figure 137: Still photo from test inspection at 35 mph

Figure 138: Still photos from test inspection at 10 feet

Figure 139: Still photos from test inspection at 100 feet

The second focus is the automation of the drone flight. This was done by using the Droidplanner android application, but can also be done on the Mission Planner computer application. The team programmed the drone with a test route using the Droidplanner application at a field to verify that the drone will travel through each of these points. This test route can be seen below in Figure 140. This test was successful, so this proves the drone can indeed follow a route precisely. Also, using the application, at each one of these GPS coordinates, the drone can be programmed to fly at various heights, various speeds, stop at a point for a set period of time, and choose exactly where the camera is pointing.

Figure 140: Test Mission Used for Proof of Concept

The third focus is that the drone will always be in range of the home location and that it will complete the inspection process in less than sixteen minutes. In order to prove that the drone will complete the inspection process in less than sixteen minutes, the team had to calculate the distance of the route the drone will flow during the inspection. This was done using Google Maps for the inspection of the perimeter and security and for the inspection of the runway and taxiway lights. The path of the inspection of the perimeter and security can be seen below in Figure 141.

Figure 141: Inspection route for perimeter and security

As seen in Figure 141, the distance of the inspection route for the perimeter and security is 3.44 miles. In order for the drone to complete the inspection in 15 minutes, the minimum speed the drone must travel is 13.76 mph, which was previously proved that the video will be clear at this speed. Also, if the drone were to fly at the maximum tested speed of 35 mph, the drone would complete the inspection in 5.90 minutes. Next, the path of the inspection of the runway and taxiway lights can be seen below in Figure 142.

Figure 142: Inspection Route of the runway and taxiway lights

As seen in Figure 142, the distance of the inspection route for the runway and taxiway lights is 2.99 miles. In order for the drone to complete the inspection in 15 minutes, the drone must travel at a minimum speed of 11.96 mph. This speed was also previously tested and proven to result in clear video footage. If the drone were to fly at the maximum tested speed of 35 mph, the drone would complete the inspection in 5.13 minutes. Also, the team needed to prove that the drone will always be in its maximum range of 3280 feet. This was also done using Google Maps by showing the distance of the two farthest points of the inspection from the home location. Figure 143 and Figure 144 below show that the direct line from the home point to the farthest point of the inspections are 3068.27 ft and 3017.78 ft, respectively, proving that the drone will always be in range.

Figure 143: Farthest inspection point from home location: 3068.27 ft

Figure 144: Second farthest inspection point from home location: 3017.78 ft

The team spoke with RIAC and were told that the drone could also additionally be used for quick runway sweeps and harassing wildlife. A proposed runway sweep route was drawn in Google Maps with a distance of 2.52 miles, which can be completed in 4.32 minutes at 35 mph. This route and distance can be seen below in Figure 145.

Figure 145: Proposed route of additional runway sweep

Another additional use that RIAC recommended is to harass wildlife out of the airport during an inspection. While test flying the drone, the team flew near a flock of birds, and the sound from the drone scared the birds off of the field and was caught on video, which can be seen in the "Videos" section on Sakai. A still photo from this video can be seen below in Figure 146.

Figure 146: Still photo of harassing wildlife

The team was successful in all three focuses of the proof of concept. The team proved the first focus, that the video is clear at all speeds between 10 mph and 35 mph and all heights between 1 foot and 100 feet. The team proved the second focus, that the drones will successfully fly through all of the points in a programed autonomous route. Also, the team proved the third focus, that the drone will always be in the range of 3280 feet and that the drone will complete the inspections in under 16 minutes. At a speed of 35 mph the drone can complete both inspection points in under six minutes, compared to the current inspection process of 45 minutes. Overall, the proof of concept experiments were successful.

14 Build/Manufacture

The team conducted various tests at Westerly State Airport to determine the optimal values for the altitude, distance from target, and the speed of the drone for the automated flight paths. After these were known, the team programmed partial flight paths in order to verify the values chosen were the optimal values and after analyzing the video and showing it to RAIC Chief Aeronautics Inspector James Warcup, the values were approved. After this, the team programmed full flight paths for the perimeter and security and runway and taxiway lights and completed these flights. Once the team knew the optimum values and tested the flight path at Westerly State Airport, the team applied and tested the optimum values at Newport State Airport to show the adaptability to other airports, and the flights were successful. Using the drone that the team currently has, the flight paths for the inspection can be applied to any General Aviation airport or smaller airport, but if a drone with a larger range was purchased then the process could be applied to larger 139 airports.

The team will market this as a product and accompanying service that can be sold, where the airport would buy the drone, camera, and tablet, and the team would program the flight paths for them and provide them with the process that has been developed. The airport that wants to implement this process will contact the team or company and the first step is that the airport needs to have permission to operate a drone in their airport, this step will be completed on their own, independent from the company. After this the airport will purchase the drone, camera, and tablet. After this, the team will go to the airport and use their optimal values found to create flight paths for the inspection. After the original path is completed, then this path will be tested to adjust if needed to maximize safety and visibility. Once the paths are completed then the process is provided to the airport and training will be conducted. The team will train the airport inspectors on the original set up of the system, the set up each time, how to operate the drone and send the mission to the drone, and upload the video to be analyzed. After this then the airport is all set to begin conducting their autonomous inspections.

15 Testing

Throughout the course of the Spring semester, the team completed various tests. From the user's point of view, all important variables of the drone will be tested to ensure the highest quality videos and to determine the optimal time to complete an inspection from start to finish. For both the perimeter and runway and taxiway lighting inspections, features that were tested include the drone's altitude, speed, and distance from target. Multiple inspection runs will be conducted to determine the optimal altitude, speed, and distance from target by keeping all but one parameter constant in order to single out and more easily test one feature at a time. These features relate to the design specification of ensuring the video footage is clear and inspection items and airfield conditions can be easily identified and recorded. The altitude, speed, and distance from target will help optimize the inspection and increase the drone's efficiency by determining the optimal combination of these features while still capturing quality video. The values that were tested can be seen below in Table 11. All tests were completed at Westerly State Airport. The range of values tested for the altitude was determined by finding the lowest height that has the object being inspected in frame and then finding the highest height that has the object being inspected in the frame. The range of values for the distance from target was also determined in a similar way, by finding the highest and lowest distance that keeps the object in frame. The range for the speed was determined by finding the lowest possible speed to complete the inspections in under the required 20 minutes and then finding the highest speed that the drone can safely fly in with still seeing the items being inspected clearly. The tests were overseen by RIAC Chief Aeronautics Inspector James Warcup, who had control of the radio to make sure that no planes entered airspace and if they did then the drone was landed. Team leader, Ben Travelyn operated the drone while Julian Andriulli recored test data into the test forms, and Scott Liguori and Grace Sanita were responsible for assisting in the plan and test strategy to optimize the test process. The team used the 3DR Solo Drone with an attached GoPro Hero 4 Black to conduct all tests and used the 3DR Solo App to watch the live stream of the drone to ensure the tests were being completed properly. The videos were analyzed during testing with the live stream and then further analyzed using the saved video, this is what was used to determine the optimal values.

Table 11: 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

While these tests were being conducted, the tests were watched on the 3DR Solo App to ensure the drone was consistently staying on the parameters being tested. The videos were also saved to the micro SD card on the GoPro and then analyzed afterward to determine which parameters provided the highest video quality of the inspection items. Along with choosing a value due to being clear in the video, the team also had to choose a value that would never be out of frame if it were to shift due to wind and also that would ensure the safety of the drone so it will never crash. The team saw fluctuation of the altitude of the drone due to wind wile inspecting the lights, so the team decided to conduct a lift force analysis in order to determine the safest height and speed to fly at. After the analysis, the team decided to conduct the inspection at 10 feet. Each test and flight parameter was approved by James Warcup, to ensure and approve the quality of the inspection videos. The optimum values that were chosen for the altitude, speed, and distance from target can be seen below in Table 12.

Table 12: Test Results

Inspection Item	**Parameter**	**Test Range**
Runway/ Taxiway Lighting	Altitude	10ft
	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

During each of these, test forms were completed to keep track of what was being tested and in order to analyze the videos with respect to many different factors. The test forms show what was being tested in red and the other values that were held constant. Along with this it shows the camera angle used, which was always 0 degrees, to keep the camera perfectly straight, the camera field of view used, the image clarity, the drone stability, the set up and pack up time, the weather conditions and the results of each test and any comments. The results are highlighted in green show the optimal value chosen during the testing, which were slightly redesigned after further analysis. Each of the tests from these test forms were compiled into a test matrix in order to be able to look at each parameter tested in a more organized and compiled table. The test forms and test matrix used can be seen at the end of this section. The camera field of view can be seen in each of these tables, where narrow was chosen for the runway and taxiway lights due to its tight view on the lights because of their small size. Medium was chosen for the field of view for the perimeter and security inspections due to the large area being inspected and because narrow is too tight on objects and wide causes video to become fish eyed and too zoomed out.

Once the values were confirmed to be the optimal values, the team created flight paths for half of a runway for the lights and for the perimeter at Westerly State Airport. The flight paths for portions of the airports were completed in order to test these optimal values, rather than testing the full airport, the team wanted to save time and test just a portion. After these tests were completed, James Warcup approved all of these values, so the team moved to completing full flight paths of Westerly State Airport. After these flights were conducted, the team slightly changed the flight paths due to obstructions in the airport, such as obstruction poles and due to height changes on the runway.

After the full flight paths were completed at Westerly State Airport, the team went to Newport State Airport in order to demonstrate the adaptability of the design. The team created flight paths using the same optimal parameters chosen at Westerly State Airport, in which the video came back clear and demonstrated that the optimal values for the flight paths can be applied to various GA airports.

MCE 402, Team #11, Inspection test form

Name of Testers:	Ben Travelyn, Grace Sanita, Scott liguori, Julian Andriulli
Attendees:	Ben Travelyn, Scott liguori, Julian Andriulli
Date:	2/26/2018
Time:	1000-1300

Runway/Taxiway lights Inspection

Trial	Trial Description	Variable Tested	Altitude (ft)	Set Speed (mph)	Desired Distance from Target (ft)	Camera Angle (In degrees, with respect to inspection item)	Camera Angle (Degrees)	Camera Field of View	Image Clarity	Drone Stability	Set Up Time	Packing Up Time	Weather Conditions	Trial Results	Comments
1	Testing for optimal altitude	Altitude	3	N/A	10	90	0	Narrow	Good	Good	2:15	0:55	15-22 mph winds, cloudy and grey skies	Too low to the ground	Must use narrow field of view to be able to see lights clearly
2		Altitude	5	N/A	10	90	0	Narrow	Good	Good				Best height	
3		Altitude	10	N/A	10	90	0	Narrow	Good	Good				Slightly too high for lights	
4		Altitude	15	N/A	10	90	0	Narrow	Good	Good				Lights are almost out of frame	
5		Altitude	20	N/A	10	90	0	Narrow	Good	Good				Too high	
1	Testing for optimal speed	Speed	5	10	10-15	90	0	Narrow	Good	Good				Speed could be faster	
2		Speed	5	20	10-15	90	0	Narrow	Good	Good				Good cruising speed	
3		Speed	5	25	10-15	90	0	Narrow	Good	Good				Best speed	
4		Speed	10-15	30	10-15	90	0	Narrow	Good	Good				Slightly too fast, shaky above 30 MPH	
1	Testing for optimal distance from target	Distance from target	5	N/A	5	90	0	Narrow	Good	Good				Too close	
2		Distance from target	5	N/A	10	90	0	Narrow	Good	Good				Best distance	
3		Distance from target	5	N/A	15	90	0	Narrow	Good	Good				Almost out of frame	
4		Distance from target	5	N/A	20	90	0	Narrow	Good	Good				Out of frame	

MCE 402, Team #11, Inspection test form

Name of Testers:	Ben Travelyn, Grace Sanita, Scott liguori, Julian Andriulli
Attendees:	Ben Travelyn, Grace Sanita, Scott liguori, Julian Andriulli
Date:	2/28/2018
Time:	1100-1400

Runway/Taxiway lights Inspection

Trial	Trial Description	Altitude (ft)	Set Speed (mph)	Desired Distance from Target (ft)	Camera Angle (In degrees, with respect to inspection item)	Camera Angle (Degrees)	Camera Field of View	Total Trial Time	Abrupt Speed Changes	Image Clarity	Set Up Time	Packing Up Time	Weather Conditions	Drone Stability	Trial Results	Comments
1	Automated flight path	5	25	10	90	0	Narrow	0:35	No	Good	2:15	0:55	15-20mph gusts, direction of the wind 210 degrees, sunny	Varation due to wind	Drone did not complete the full designated flight path	Set 5 feet, drone height varied from 2-8 feet Set 10 foot distance, varied by ~3 feet
2		5	25	10	90	0	Narrow	0:44	No	Good					Drone did not complete the full designated flight path	
3		5	25	10	90	0	Narrow	1:25	No	Good					Completed flight path, video looks good	
4		5	25	10	90	0	Narrow	1:20	No	Good					Completed flight path, video looks good	

MCE 402, Team #11, Inspection test form

Name of Testers:	Ben Travelyn, Grace Sanita, Scott liguori, Julian Andriulli
Attendees:	Ben Travelyn, Scott liguori, Julian Andriulli
Date:	3/5/2018
Time:	1000-1300

Perimeter Inspection (Fence)

Trial	Trial Description	Variable Tested	Altitude (ft)	Set Speed (mph)	Desired Distance from Target (ft)	Camera Angle (In degrees, with respect to inspection item)	Camera Angle (Degrees)	Camera Field of View	Image Clarity	Trial Time	Set Up Time	Packing Up Time	Weather Conditions	Drone Stability	Trial Results	Comments
2	Testing for optimal altitude	Altitude	10	N/A	10	90	0	Medium	Good	N/A	2:15	0:55	10-22 mph wind, direction of the wind is 010 degrees, cloudy and grey skies	Shakes in the wind, but still stable	Almost there	Medium is better than wide, has a better view
3		Altitude	15	N/A	10	90	0	Medium	Good	N/A					Good height	
4		Altitude	20	N/A	10	90	0	Medium	Good	N/A					Good height	
5		Altitude	25	N/A	10	90	0	Medium	Good	N/A					Too high	
6	Testing medium vs. wide	Camera field of view	20	N/A	10	90	0	Wide	Good	N/A					Medium is better	
1	Testing for optimal speed	Speed	20	30	10	90	0	Medium	Good	N/A					Good, speed used for trees	
1	Testing for optimal distance from target	Distance from target	20	N/A	5	90	0	Medium	Good	N/A					Too close	
2		Distance from target	20	N/A	10	90	0	Medium	Good	N/A					Good	
3		Distance from target	20	N/A	15	90	0	Medium	Good	N/A					Good, best distance	
4		Distance from target	20	N/A	20	90	0	Medium	Good	N/A					Getting too far	
1	Automated flight path	N/A	20	30	10	90	0	Medium	Good	0:55					Looks great	Successfully spotted open gate

Perimeter Inspection (Tree Line)

Trial	Trial Description	Variable Tested	Altitude (ft)	Set Speed (mph)	Desired Distance from Target (ft)	Camera Angle (In degrees, with respect to inspection item)	Camera Angle (Degrees)	Camera Field of View	Image Clarity	Trial Time	Set Up Time	Packing Up Time	Weather Conditions	Drone Stability	Trial Results	Comments
1	Testing for optimal altitude	Altitude	40	N/A	N/A	90	0	Medium	Good	N/A	2:15	0:55	10-22 mph wind, direction of the wind is 010 degrees, cloudy and grey skies	Shakes in the wind, but still stable	Too low	Medium is better than wide, has a better view
2		Altitude	50	N/A	N/A	90	0	Medium	Good	N/A					Good	
3		Altitude	60	N/A	N/A	90	0	Medium	Good	N/A					Good, better height	
4		Altitude	70	N/A	N/A	90	0	Medium	Good	N/A					Good	
5	Testing medium vs. wide	Camera field of view	60	N/A	N/A	90	0	Wide	Good	N/A					Medium is better	
1	Testing for optimal speed	Speed	60	25	N/A	90	0	Medium	Good	N/A					Good	
2		Speed	60	30	N/A	90	0	Medium	Good	N/A					Good, faster speed	
1	Automated flight path	N/A	60	25	N/A	90	0	Medium	Good	3:20					Looks great	
2		N/A	60 & 15	30	N/A	90	0	Medium	Good	2:45					Looks great, faster speed is better	Great along perimeter and went down to inspect fence

Inspection Point	Test Variable	Test Value	Results	Planned Resolution
Runway and Taxiway Lighting	Altitude	3 ft	Too low to the ground	Increase altitude
Runway and Taxiway Lighting	Altitude	5 ft	Best height	
Runway and Taxiway Lighting	Altitude	10 ft	Slightly too high for lights	Decrease altitude
Runway and Taxiway Lighting	Altitude	15 ft	Lights are almost out of frame	Decrease altitude
Runway and Taxiway Lighting	Altitude	20 ft	Too high	Decrease altitude
Runway and Taxiway Lighting	Speed	10 mph	Speed could be faster	Increae speed
Runway and Taxiway Lighting	Speed	20 mph	Good cruising speed	Increae speed
Runway and Taxiway Lighting	Speed	25 mph	Best speed	
Runway and Taxiway Lighting	Speed	30 mph	Slightly too fast, shaky above 30 MPH	Decrease speed
Runway and Taxiway Lighting	Distance from target	5 ft	Too close	Increase distance
Runway and Taxiway Lighting	Distance from target	10 ft	Best distance	
Runway and Taxiway Lighting	Distance from target	15 ft	Almost out of frame	Decrease distance
Runway and Taxiway Lighting	Distance from target	20 ft	Out of frame	Decrease distance
Perimeter Inspection (Fence)	Altitude	10 ft	Almost there	Increase altitude
Perimeter Inspection (Fence)	Altitude	15 ft	Good height	Slighty increase altitude
Perimeter Inspection (Fence)	Altitude	20 ft	Best height	
Perimeter Inspection (Fence)	Altitude	25 ft	Too high	Decrease altitude
Perimeter Inspection (Fence)	Speed	30 mph	Good, speed used for trees	
Perimeter Inspection (Fence)	Distance from target	5 ft	Too close	Increase distance
Perimeter Inspection (Fence)	Distance from target	10 ft	Good	Slightly increase distance
Perimeter Inspection (Fence)	Distance from target	15 ft	Best distance	
Perimeter Inspection (Fence)	Distance from target	20 ft	Getting too far	Decrease distance
Perimeter Inspection (Tree Line)	Altitude	40 ft	Too low	Increase altitude
Perimeter Inspection (Tree Line)	Altitude	50 ft	Good	Slightly increase altitude
Perimeter Inspection (Tree Line)	Altitude	60 ft	Best height	
Perimeter Inspection (Tree Line)	Altitude	70 ft	Good	Lower altitude
Perimeter Inspection (Tree Line)	Speed	25 mph	Good	Increase speed
Perimeter Inspection (Tree Line)	Speed	30 mph	Best Speed	

16 Redesign

After the design and testing process there were slight redesigns incorporated in the design process. During initial design and testing, a large focus was put on the connection range of the drone to the home location. During preliminary flights, the team experienced issues with the drone flying out of range when performing perimeter tests at the outskirts of airport property. 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 Wifi Antennas were able to boost the drones range by approximately 1000 feet.

Once the full flight paths were created and tested, the flight path for the tree line and fencing and perimeter were slightly redesigned. The reason this flight path was slightly adjusted was due to the flight path being very close to obstructions in the airport, such as obstructions poles. During high winds, the drone is susceptible to horizontal and vertical displacements while flying. In order to design for high winds, the path was slightly moved away from these obstructions to ensure no crashes and increase the level of safety. After redesign, the perimeter and security inspection paths allow for an altitude and distance from target tolerance, increasing the processes safety factor.

The last redesign was the altitude for flight path for the runway and taxiway lights. The reason it was adjusted was due to the fact that 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 altitude was increased and is somewhere in the range of 10-15 feet for the flight path. The new altitude still has 100% visibility of the lights on the runway and taxiway lights.

Future recommendations for this project would be to purchase a drone with a larger range in order to test at larger airports and potentially reach further inaccessible areas in airports.

17 Operation

The 3DR Solo drone comes with a user manual [4] which has instruction for setup and maintenance and many other instructions needed for the drone, this full operations manual can be seen in Sakai under the ”Manual” section. Once the drone is purchased by the user, then the set up of the drone as seen in Section 17.1 will be completed and will only need to be completed the first time then each time after that the battery for the drone, the controller, the GoPro, and the tablet will need to be charged and then connected. Once connected then the flight paths can be sent to the drone and the inspections can be completed.

17.1 Set Up

As with most commercial projects, the drone will require an initial longer set up time to make sure that all parts are included within the package, functioning properly, and are placed into their ready positions for future inspection flights. First, open the 3DR Solo package, and check that the drone, 3 axis-gimbal, four silver top and four black top propellers, controller, controller charger, and solo drone charger are all included within the package. The aforementioned items should appear as below in Figure 151.

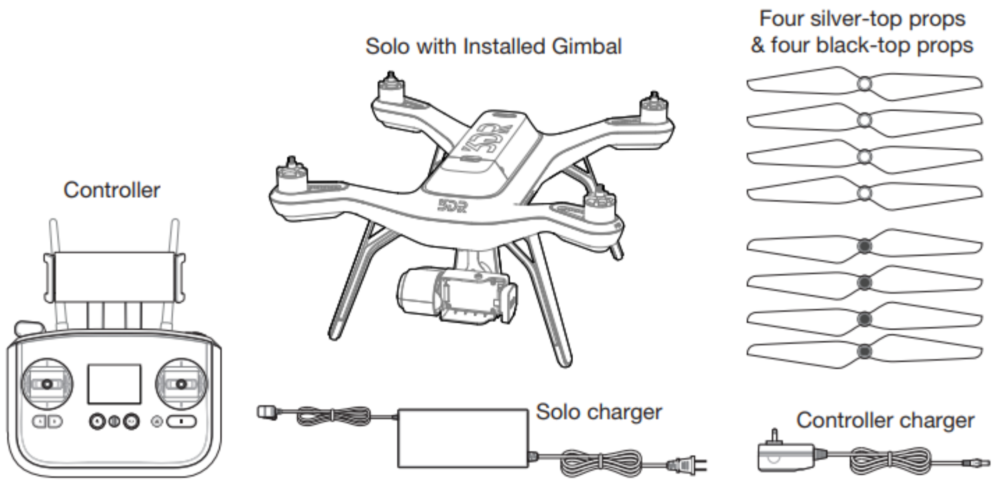


Figure 151: 3DR solo drone parts

After having confirmed that all items are present, the drone battery will need to be charged. To remove the battery from the drone, hold the release button at the top of the drone and slide the battery towards the back of the drone. Once removed, connect the solo charger to the battery and then the wall outlet as seen below in Figure 152. Before charging, the battery charge will be indicated by the lights below the power button. Press the power button once to display the current power level. Once the battery has been plugged into the wall, the indicator lights will begin to pulse. The battery should take approximately an hour and half to charge. It is important not to store the battery when depleted, as it can harm the battery life or permanently damage the battery in other ways. Once the battery is fully charged, it should allow for approximately 25 minutes of flight time.

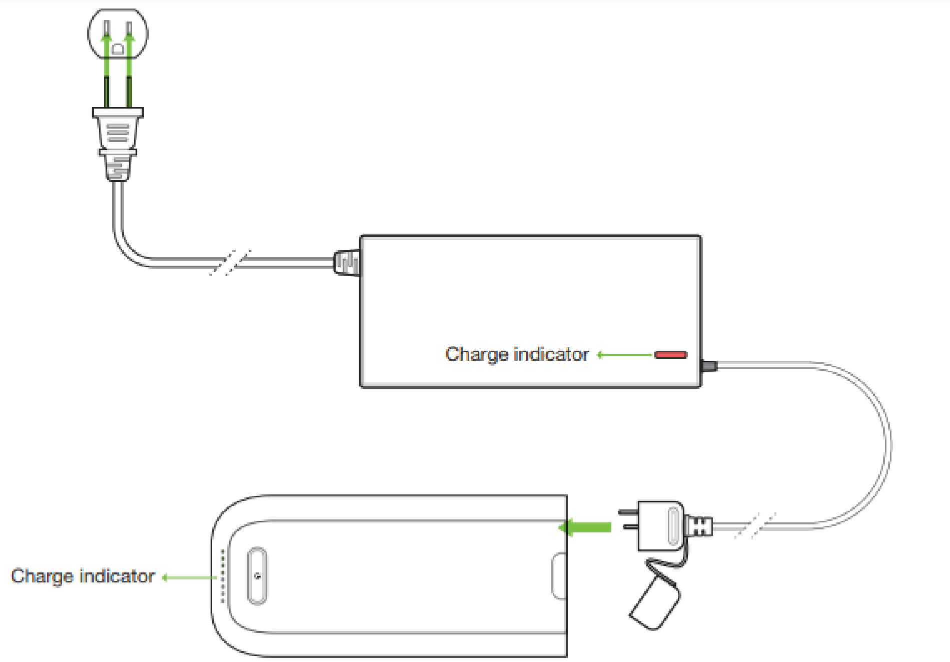


Figure 152: Charging the 3DR Solo drone battery

After fully charging the drone battery, remove the charged battery from the charger and insert it into the Solo drone's battery bay by sliding it forward until it clicks into place, as seen below in Figure 153. To turn it on, press and hold the battery power button, as indicated below. Once the drone has been powered on, a startup tone should ring and an LED animation should be visible on the drones screen.

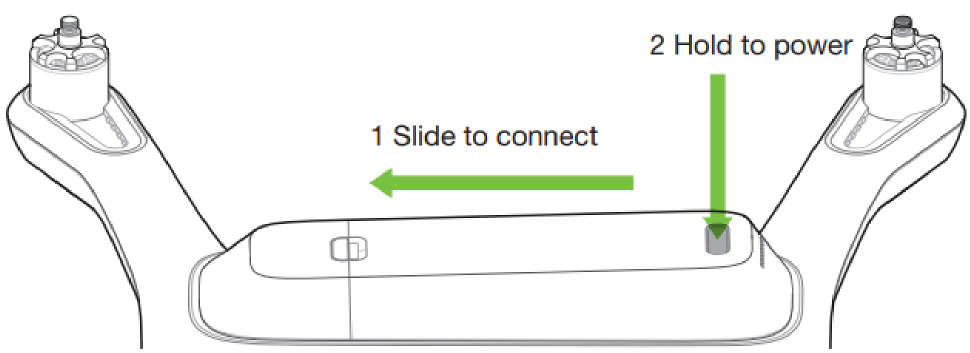


Figure 153: Connecting the Battery back to the Drone

To charge the controller, connect the controller charger to the barrel jack on the side of the controller and then to the wall outlet, as seen below in Figure 154. To check the battery level of the controller or turn it on, press the power button, as seen below in Figure 155. The controller should last approximately 6 hours once fully charged, and takes approximately three hours to charge.

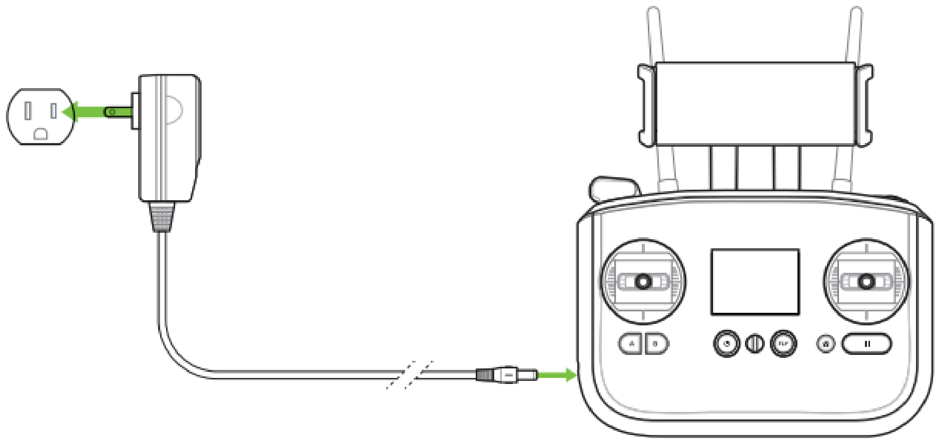


Figure 154: Controller Charging

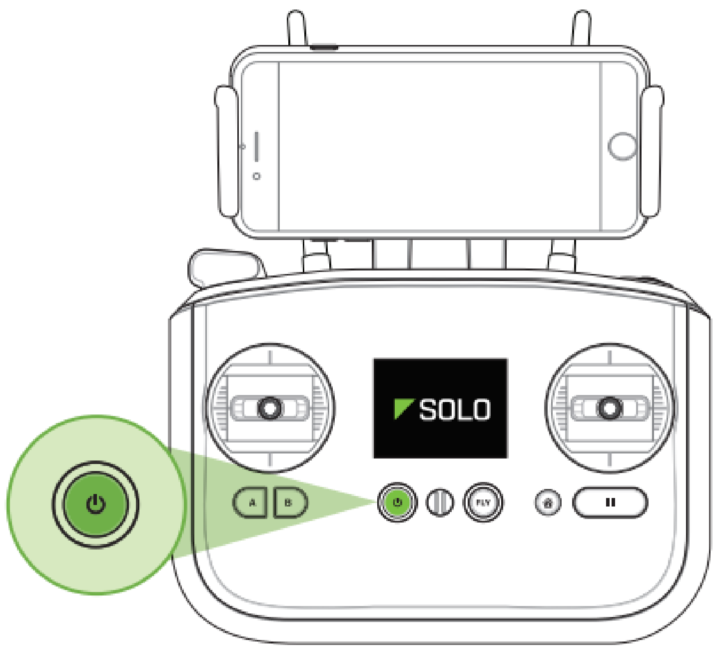


Figure 155: Power on button

After charging the batteries of the controller and 3DR solo drone, the propellers can be installed. Attach two of the silver top propellers to the motors with a silver dot on top of the motor shaft, and attach two of the black top propellers to the motors with a black dot on top of the motor shaft. The silver top propellers tighten clockwise, and the black top propellers tighten counterclockwise. To double check the turning direction, use the lock and unlock indicators on each propeller, as seen below in Figure 156.

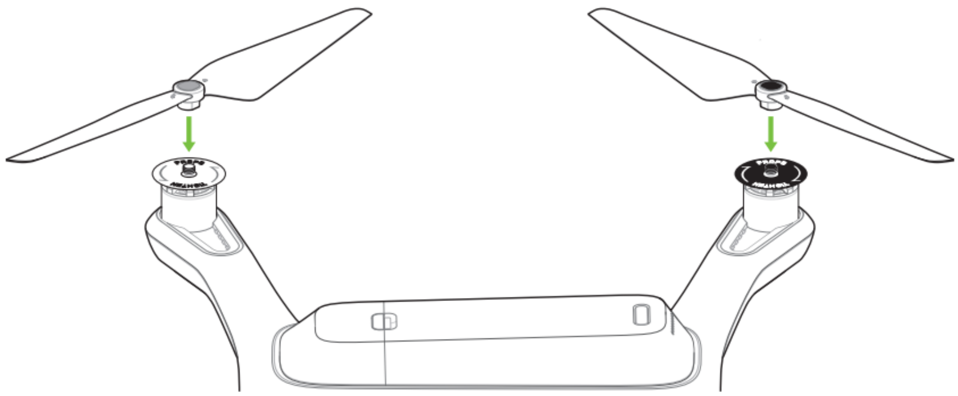


Figure 156: Propeller Attachent

17.1.1 Gimbal Installation

First, check that all necessary 3-axis gimbal items are included within the package. These items should include the Solo gimbal, Sunshade, balanced weights, and screwdriver, which can be seen below in Figure 157. Before Gimbal installation, make sure that the software on the Solo drone, Controller, and Solo App are fully updated and prepared. The recommended versions for the Solo drone and App are 1.2.0, and 3.00.00 for the GoPro.

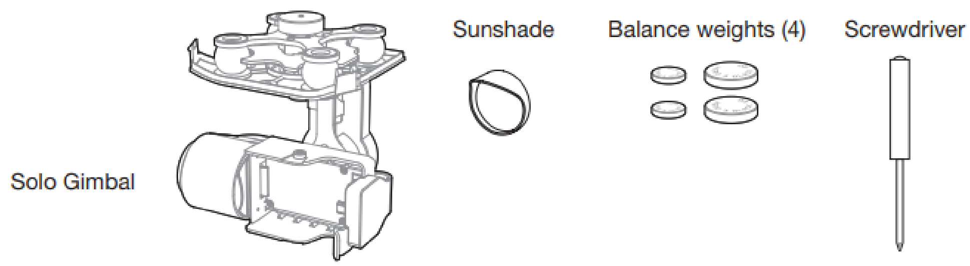


Figure 157: Gimbal Parts

To begin fixing the gimbal to the drone, flip the drone over so that the bottom side is facing up. Next, loosen the three screws that are prefixed into the drone as indicated by the image below. Detach the mount from the Solo by gently lifting up on it. Route the HDMI cable out through the mount. Once completed, remove the foam insert holding the gimbal in place and set it to the side for use during travel. On the bottom of the gimbal plate are two ports: one for the HDMI cable and one for the gimbal cable. Plug in the cables running from the Solo drone to their respective ports as shown below. Make sure when plugging in each cable that they are out of the way of any other internal components. These steps can be seen below in Figure 158 through 161.

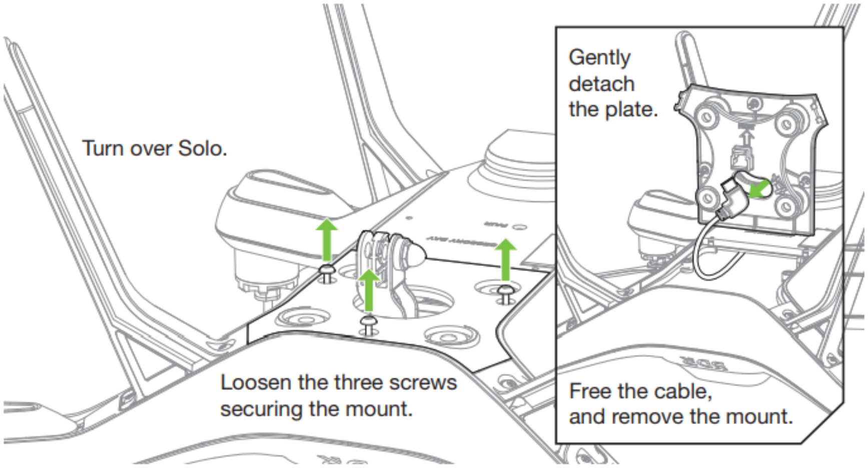


Figure 158: Frame Removal

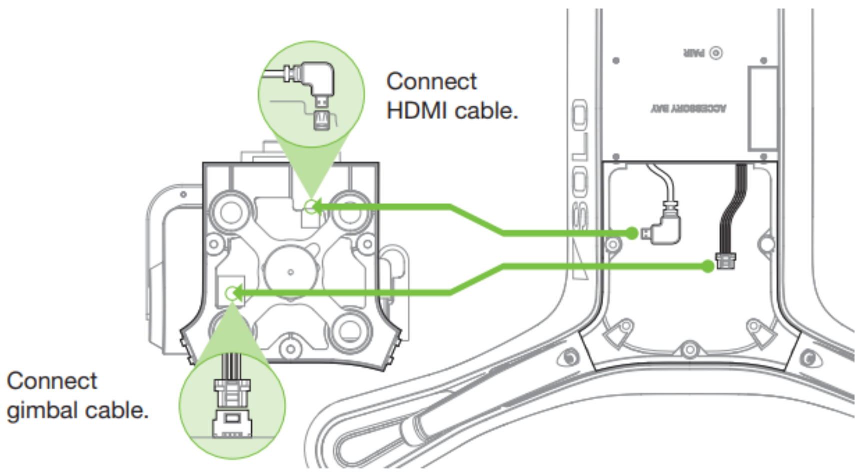


Figure 159: Cable Connection

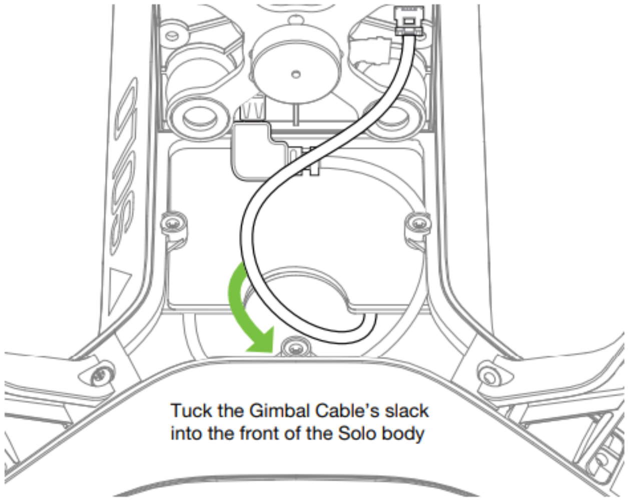


Figure 160: Gimbal Cable Positioning

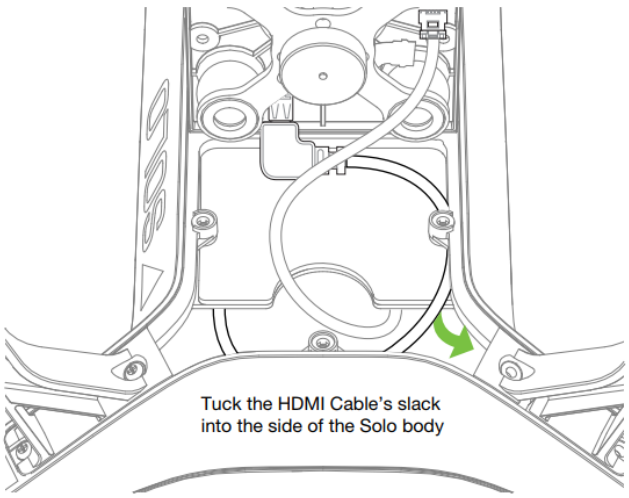


Figure 161: HDMI Cable positioning

After positioning the cables and temporarily removing the mount, the gimbal should be ready to attach to the drone. Position the gimbal plate over the opening in the bottom of the drone, making sure that the three screw positions are aligned with the gimbal. Slide the back of the plate in first, and then pinch the two front prongs in and down to insert the plate. Once the plate is resting in the bottom of the drone, fix the gimbal into place with the three screws, which can be seen below in Figure 162.

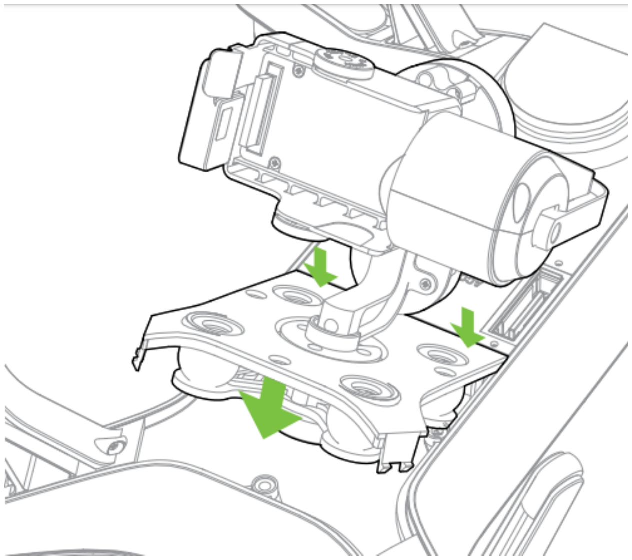


Figure 162: Mounting the gimbal

To install the GoPro, remove the rubber plug and gently press the GoPro until it is flush against the back of the inside of the Gimbal. To add weights or the sunshade, reference the figures labeled "GoPro Weight Balancing" and "Sunshade Attachment" below in Figures 163 through **??**.

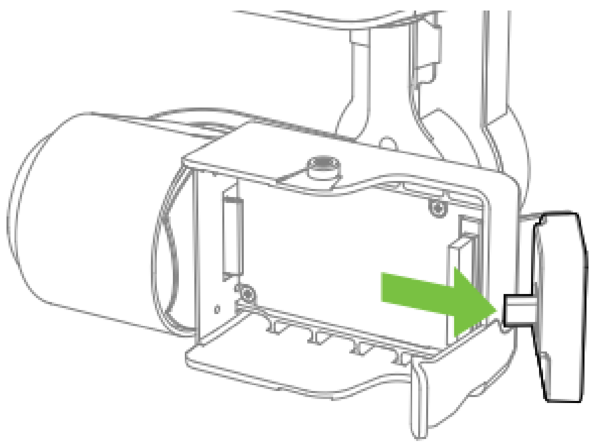


Figure 163: HDMI plug removal

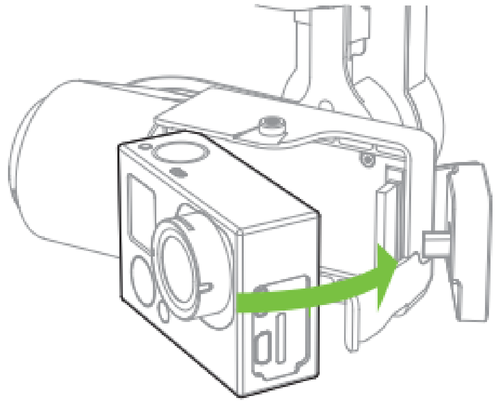


Figure 164: GoPro Attachment

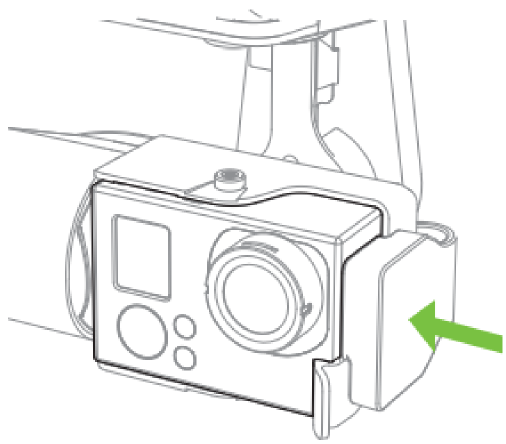


Figure 165: GoPro fastening

GoPro Weight Balancing®	
HERO4 Black	No blalance weights needed
HERO4 Silver	Add the 2.7g balance weights
HERO3+ Silver	Add the 6g balance weights

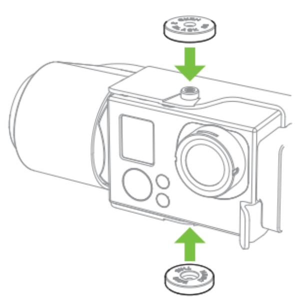


Figure 166: GoPro Weight Balancing

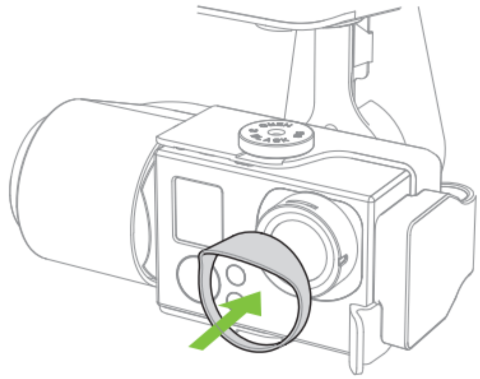


Figure 167: Sunshade Attachment

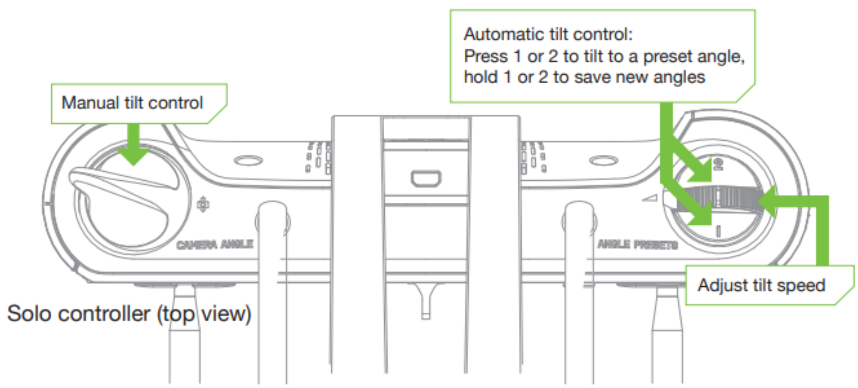


Figure 168: Gimbal Controls

17.2 3DR Solo App

To interact with the solo drone and camera, the 3DR solo drone has a corresponding App entitled "3DR Solo" that can be downloaded from the Android or Apple app store or by visiting the 3dr.com/soloapp website. For android, you must also install the "3DR Services" app. This is the app that will be used if the operator would like to watch a live stream of the video from the drone.

The first time the app is run, personal registration information and the Solo drone serial number must be entered. Upon completion, the user will be taken to the home screen. To connect to the drone's WiFi, first make sure that both the drone and controller are powered on, and then tap the connect button on the home page of the App and follow the subsequent prompts. Connect to the WiFi entitled SoloLink_####. Enter the temporary password "sololink". To change the password go to the settings section of the App and access the options section. Select the Solo drone name and wifi, and then enter a new password, this can all be seen below in Figure 169.

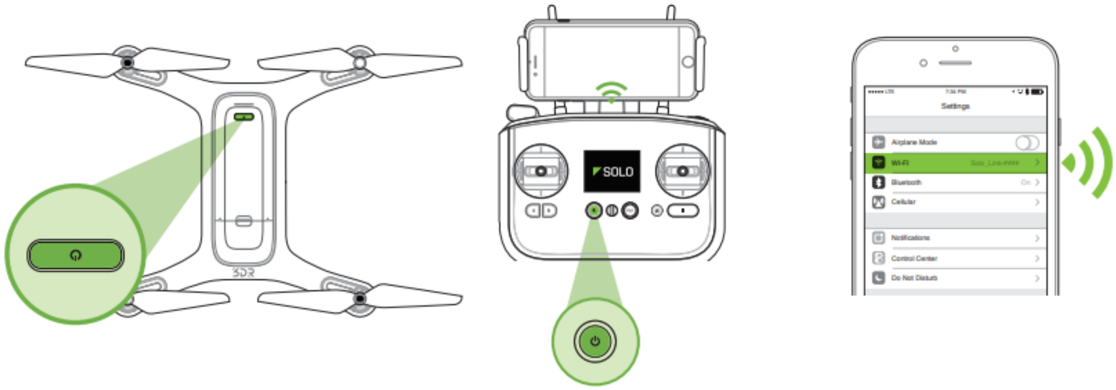


Figure 169: Connecting to SoloLink WiFi

Along with connecting to the drone's WiFi, before using the drone the software must be updated for the Solo drone and the controller with an steady external WiFi source. To update, make sure that both the drone and controller are powered on, and that the WiFi source has been switched temporarily from "Sololink" to your local WiFi of choice. Go to the settings menu in the App and select "Software Update". In order to complete the update, the controller must be connected with the Solo WiFi as well (SoloLink). To do this, follow the prompt instructions that appear within the App after selecting "Software Update". The controller and drone should then download the update for about five minutes, with the controller displaying a screen that says "Controller Updating". Once the device has been updated, the Drone's LED lights should turn green, and the controller will return to the standard takeoff screen. After turning green, the lights should then return to a white-and-red pattern. If this does not happen after a few minutes, please restart the Solo drone.

17.3 3DR Tower App

The flight paths for the drone will be created and stored on the Tower App, this is what will be connected to the drone to send the flight paths. Once the drone, the controller, and tablet are powered on then the tablet will have to be connected to the drones WiFi. To connect to the drone's WiFi, tap the connect button on the home page of the App and follow the subsequent prompts and connect to the WiFi entitled SoloLink_####. Once the WiFi is connected, then open the Tower application and click the "Connect" button as seen below in Figure 170.

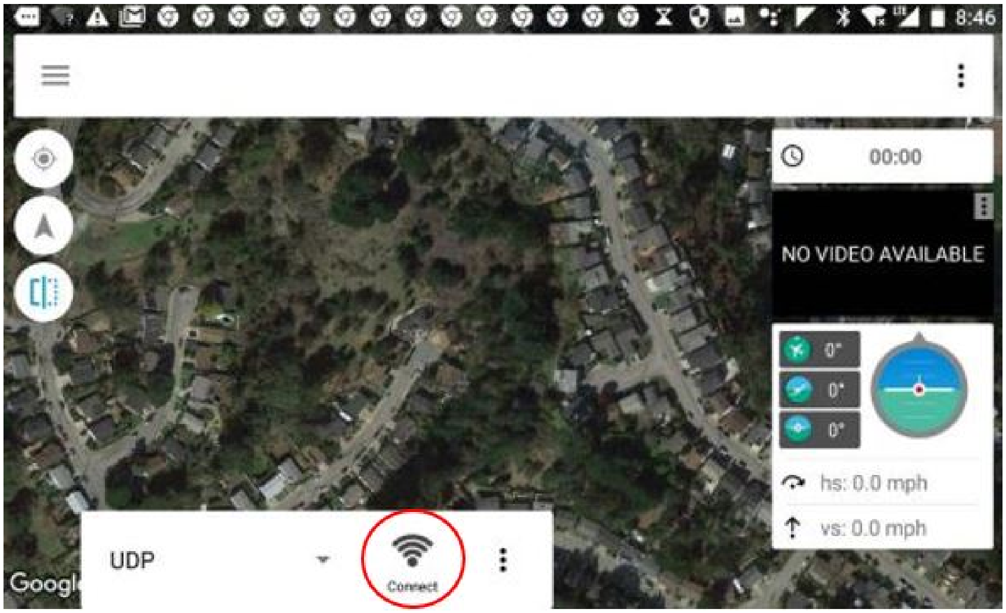


Figure 170: Tower application

Once the drone is connected to the Tower app, then the flight path is chosen and can be seen on the screen as seen below in Figure 171.

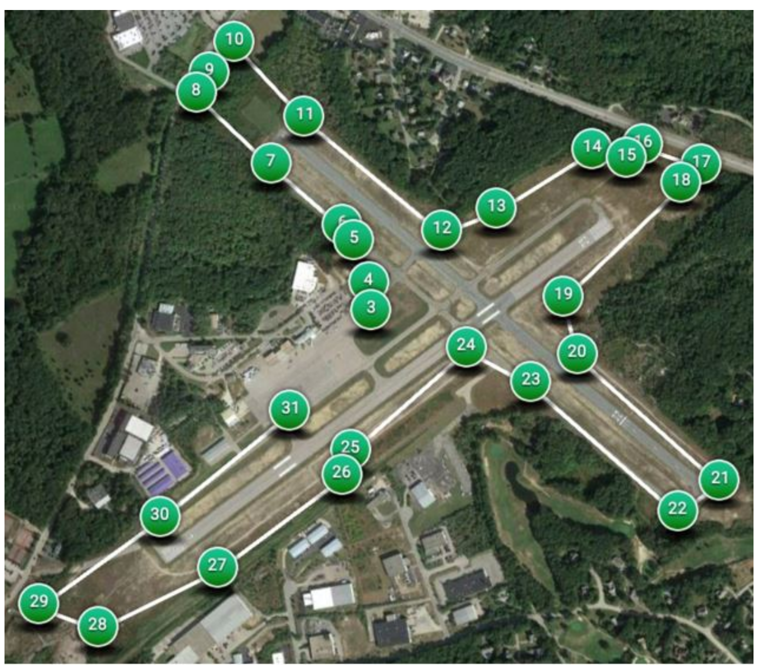


Figure 171: Tower flight path

Once the flight path is chosen then the "Auto" option will be chosen,and after this is selected, then it will ask you to slide along the screen to fly, which can be seen below in Figure 172.

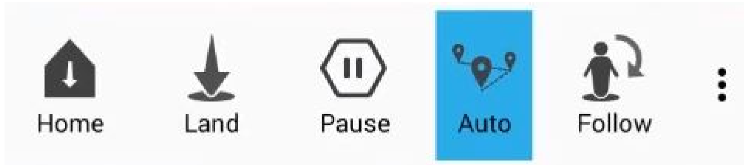


Figure 172: Auto option

18 Maintenance

In order to preserve the drone's life in performing inspection tasks, careful upkeep and maintenance must be followed. When not in use, the 3DR Solo drone comes unassembled in a protective carrying case that protects the drone from any falling damage in an event the case bounces around or falls, especially when transported in a bed of a pickup truck. The drone will be kept indoors when not in use to keep the electronics in a steady temperature. During inspection tests, the drone will be kept out of "wet" weather including rain, fog or snow in order to protect the electronics of the drone and slow the rusting process of the metal engines. The drone is not water resistant and any exposure to wet weather will put the drone in a position to fail and potentially break. Attachments are available online to equip to the drone to make it water resistant. Along with wet weather, exposure to dirt, sand and salt air will damage the drone if particles get into the motors on each wing. As an example, the Quonsett State Airport is located in immediate proximity of the ocean and the daily exposure to sand and salt air will reduce the drone's life expectancy. Along with weather exposure, the drone has a built in landing program that places the body down slowly to prevent landing damage.

The 3DR Solo drone comes with a user manual [4] which has detailed instructions on any maintenance needed by the drone, but the main points can be see in the following sections.

18.1 Calibration

Occasionally, the Solo drone will require compass and level calibrations when prompted by the controller. This can be one through the Solo App, but one must make sure that before beginning calibrations, the propellers have been removed, the drone and controller have been powered on, and that all electronics are away from metal buildings, reinforced concrete, or any other metal structures. To begin calibration, connect the App to the Solo drone's wiFi, go to settings, and select "Compass Calibration". Follow the App prompts, and rotate the drone as needed. If the calibration fails, move to a different location and try again.

18.2 Battery

When the drone has reached the end of its useful life, steps must be taken to properly dispose of the electronics and plastic that compose the drone. In order to safely dispose of the 3DR Solo's lithium polymer (LiPo) batteries. The first step is to drain the LiPo batteries of as much power as possible. To do so, it is advised to turn the drone on and let the batteries drain until the drone turns off while watching the drone in case of a fire situation. The next step is to place the batteries in a warm salt saturated water bath which acts to short out the battery and discharge the last of any power still stored in the battery. To ensure the battery is fully discharged, it is optimal to keep the battery in the salt bath for no less than 24 hours and then check the battery's voltage is at 0.0V. LiPo batteries are environmentally safe and can be disposed of in the trash unlike other, more common batteries. To dispose of the batteries by quicker means, many companies including Best Buy, have battery disposal drop offs and the company will properly and safely dispose of the batteries.

18.3 Drone Part Replacement

Through wear and tear, the legs of the drone may need replacement, which can be purchased through 3DR. The 3DR Solo drone comes with three unique types of legs: two legs with an antenna module, a leg with no electronic components and a leg with a compass module, as seen below in Figure 173.

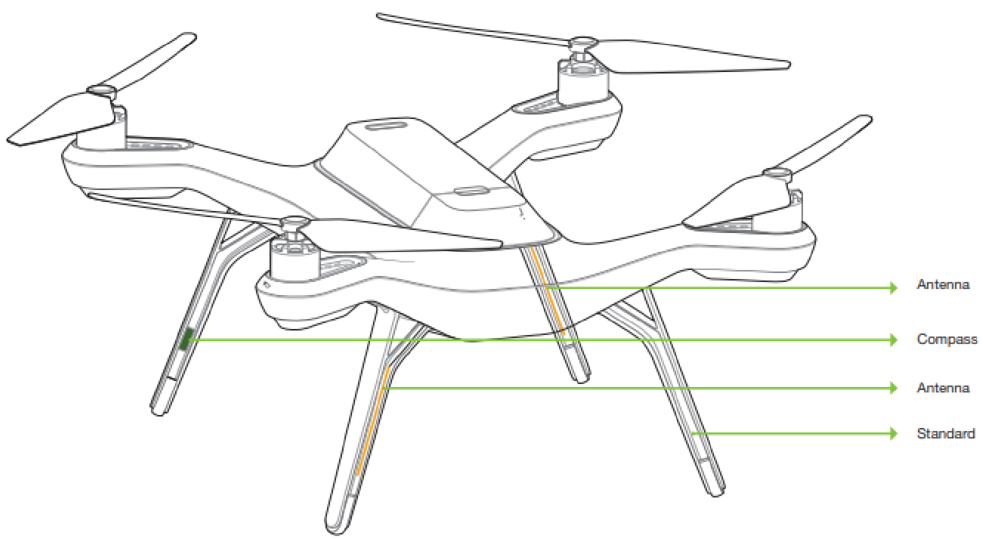


Figure 173: Leg types

To replace a standard leg, simply use a Phillips screwdriver to remove the screws, detach the old leg, and attach the new leg by putting the screws back in again as seen below in Figure 174.

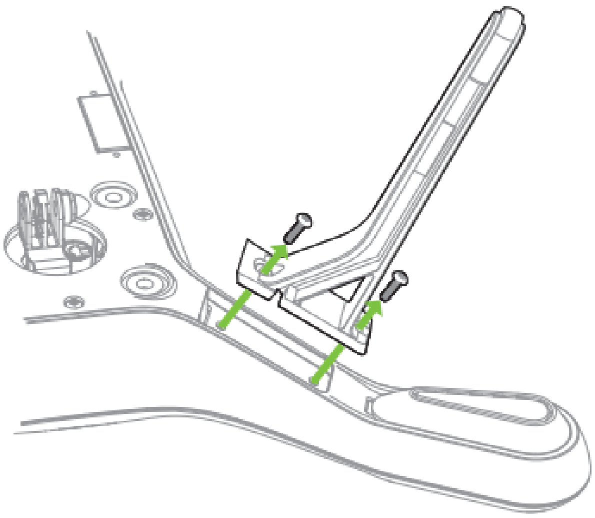


Figure 174: Standard Leg Replacement Process

If instead one of the two legs with antennas need to be removed, first remove the antenna from the old leg. To detach the antenna, remove the plastic sheet from the leg and take off the antenna from the velcro by gently pulling the cable. After cable removal, follow the same steps for the standard leg without electronic components. For placing the same antenna back into a new leg, reverse the step mentioned above and place the antenna in the leg below the plastic sheet. These steps can be seen below in Figure 175 through 177.

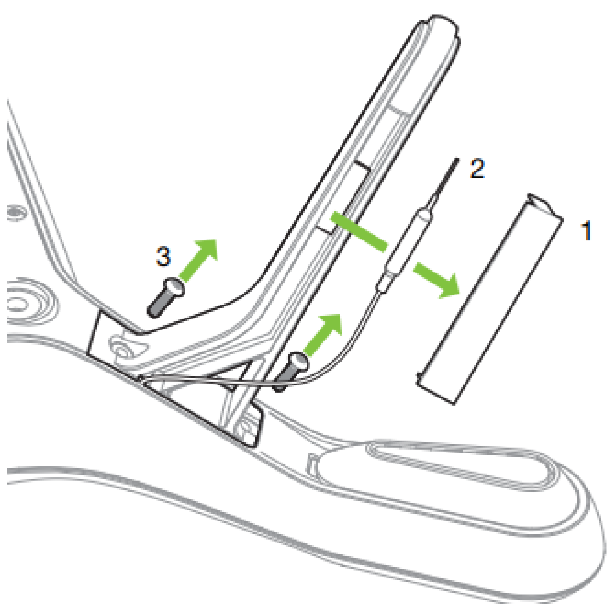


Figure 175: Detaching the Antenna from the Leg

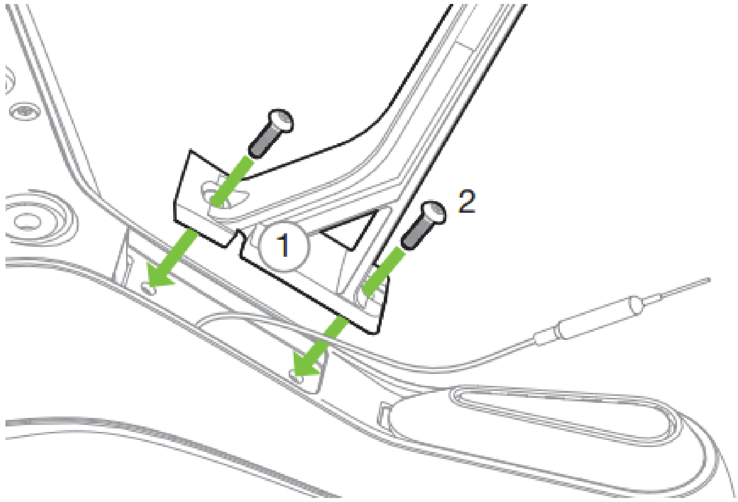


Figure 176: Attaching a New Leg with an Existing Antenna

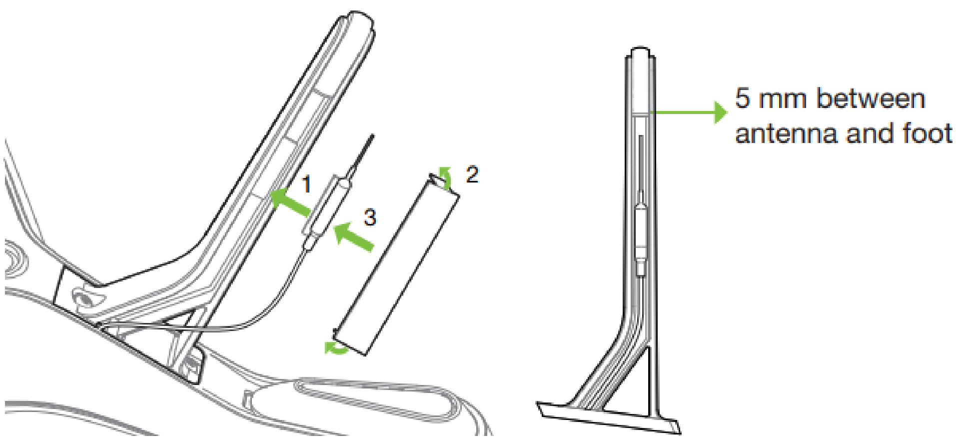


Figure 177: Attaching an Existing Antenna to a New leg

For the leg with an inserted compass module, begin by disconnecting the compass from the drone underneath the battery tray, and then after detach the leg in the same way that the standard leg was removed. To access the battery tray, refer to the following three figures, Figures 178 through 180. The first figure indicates GPS cover removal. The numbers refer to the chronological steps of removal. (1) release the clips outward. (2) Lift slightly while pushing forward to take the cover off.

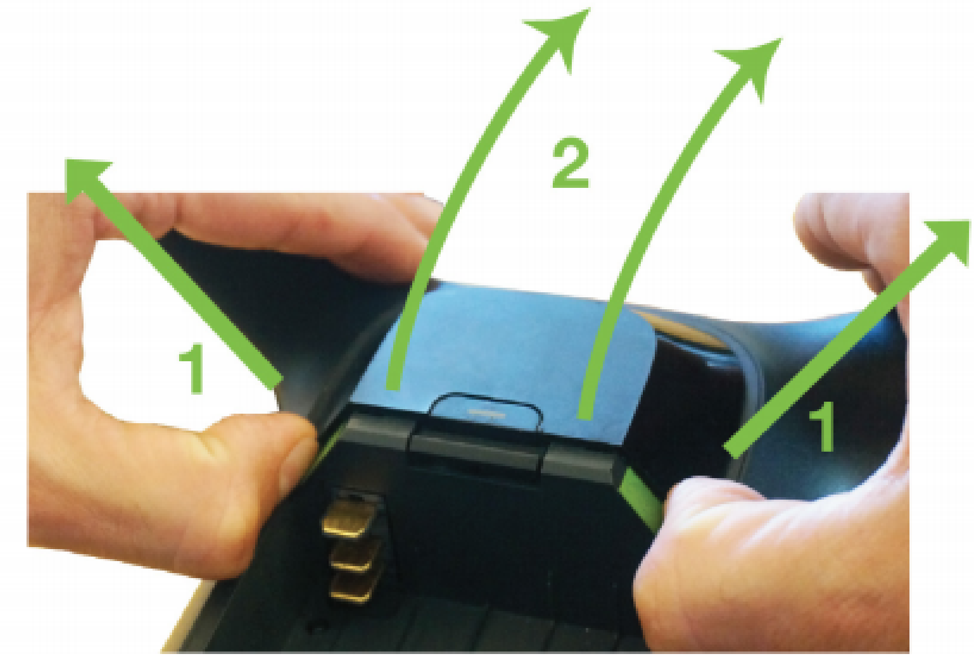


Figure 178: GPS Cover Removal

After cover removal, simply use a Phillips screwdriver again to remove the seven screws as indicated below in Figure 179.

Figure 179: Battery Tray Removal

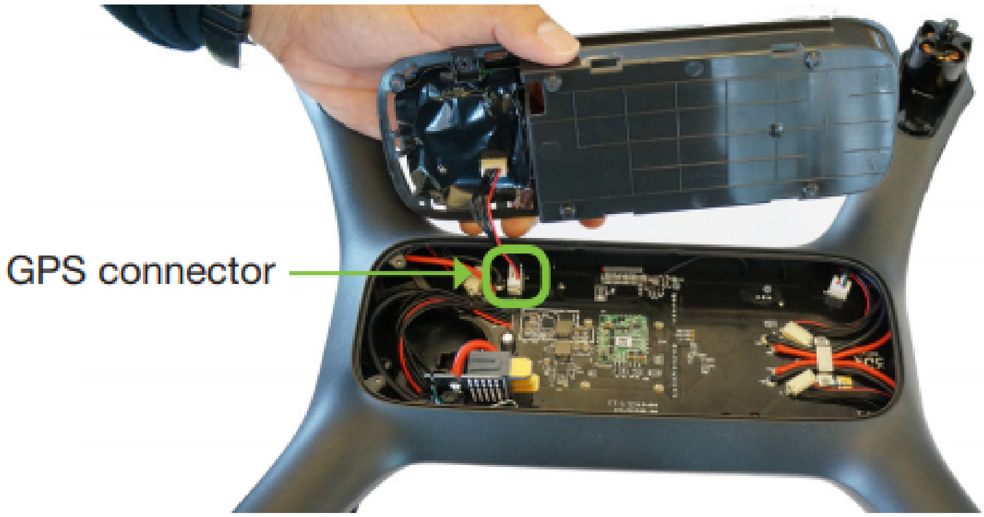


Figure 180: Battery Tray Detachment

After the battery tray is accessed, the compass can be located in the corner as shown below in Figure 181.

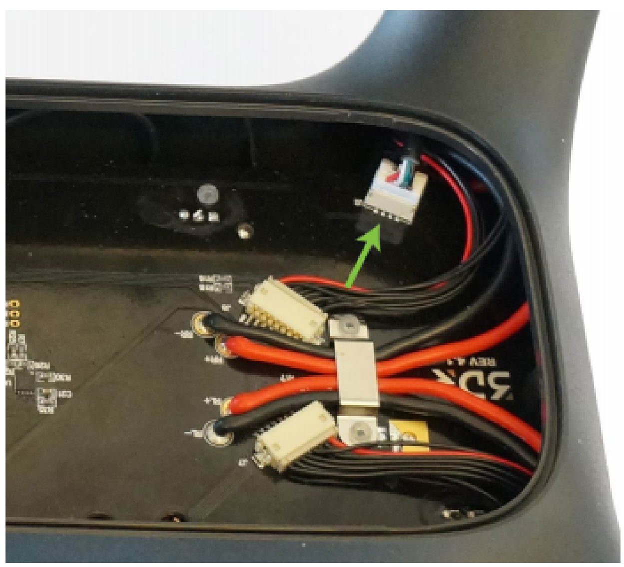


Figure 181: Compass Connector Location

Once located, disconnect this compass connector from the board by holing down the tab on the far side of the connector and lifting it up. With the compass disconnected, the old leg can be removed. Place the new leg into position and thread the compass cable through the arm where it was previously connected to the board. Once the compass has been reconnected, secure the leg into place with the provided screws. This can be seen below in Figure 182.

Figure 182: New Compass Leg insertion

The other part of the drone that can be easily replaced is the propellers for the drone which can also be purchased through 3DR. Once these are received, they screw right on and off. If any of the more expensive parts need replacement, such as the battery or gimbal, these can also be purchased through 3DR. If something major was to happen to the drone, a new drone can be purchased for $585 which is inexpensive compared to the total savings the airport will have by implementing this system.

19 Additional Considerations

19.1 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 10.3 Cost/Benefit Assessment, the team's automated process can significantly reduce the cost of labor and the required man hours for airports to perform daily inspections by 726.70 hours. In the first year, airports can save up to $23,33.50 and $27,250.50 every year after. The money saved each year through the implementation of the team's automated inspection process can be allotted to other needs at the airport including fencing, runway and airfield maintenance along with upgrading equipment and improved work conditions for employees. Along with material improvements, airports can reduce costs or air travel and business operations to public and private aircraft, thus increasing its competition in the market. Airports are companies that are not immune to economical downturns and must adapt to changing and evolving technologies to stay competitive in their respective business. For instance, Westerly State Airports is undermined by rival aircraft fueling company Dooney Aviation, located adjacent to Westerly Airport, who takes the majority of the fueling market using the airport. Westerly sells 100 LL AvGas fuel at $5.45 a gallon but Dooney sells the same fuel for $5.05 a gallon and also sells Jet A fuel service for $4.95 a gallon [25] [26]. By implementing the automated inspection process, Westerly State Airport can afford to lower fuel prices and actively compete with Dooney Aviation for the airport's aircraft fueling market. The same economic benefits and principles can be applied to 139 airports, along with general aviation airports across the state and nation. The 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. The team's inspection process can have an immediate and sustained economic benefit to boost general aviation and 139 airports competitiveness as businesses in their market.

A smaller economic impact could affect the drone market as well. Many people view drones to be a nuisance and unsafe, and many claims are backed up by the FAA restrictions regarding the drones and their pilots. The inclusion of drones into the airport atmosphere would shed a positive light onto the possibilities of drones and the expanding technology. This new market for drone manufacturers may also push for more innovation within the technology, therefore growing the market even more. The team was interested in how drone experts would view this new use for the drone technology, and met with employees from Cloud City Drones, a drone store in Rhode Island, to gather their insight. The employees expressed excitement about the growing market space, and agreed that it would be a great benefit to airports.

19.2 Environmental Impact

The wildlife programs at GA Airports can be improved with the use of the drone based inspection system. One of the most beneficial byproducts from utilizing a UAV in the process is through the increased wildlife harassment at airports. Through the preliminary literature search, the team found that this is already being implemented at a GA airport in Illinois [2]. The wildlife harassment procedure includes operators first performing routine, daily wildlife harassment procedures in an effort to ”train” animals and birds to stay away from the airport's runways and property. The next step in the harassment procedure is to shoot and eliminate wildlife that increase the potential risk or even cause a casualty event from a runway excursion or incursion or a crash event. However, the general aviation airports visited by the team do not execute the harassment procedure correctly by not performing harassment routinely or at all and must resort to killing wildlife if there is a need. In several instances at Westerly State Airport, the team and James Warcup could walk or drive in close proximity of birds or deer in the area without causing a presence to the animals. From preliminary testing and completing full inspections, the drone was able to harass flocks of smalls birds out of the area and remove several turkey vultures from the vicinity of a deer carcass. The UAV's presence was able to successfully harass the wildlife off the airport's runway and property but most important kept the birds from returning while in use. The use of the UAV in routine inspections can conduct daily wildlife harassment to perform the harassment procedure and preventing the unnecessary killing of innocent wildlife.

While the drone-based system is a way to routinely harass wildlife, the video logging component can also be very helpful to airports and their wildlife program. Each airport works with a wildlife program in order to track and report common wildlife patterns around and in the airport. This team of biologists can use the logged videos to observe when and how animals are acting within the airport atmosphere. Many smaller airports use an outside contractor for the wildlife programs, meaning that there is not always a biologist on-site. The biologists are getting all information from either handwritten inspection reports or directly from managers when an animal corpse needs to be removed. Using the videos as an added tool can create a steady flow of data for the biologists. Just like the inspectors, the biologists can fast-forward through the videos to spot and record animal behavior in the airport.

The physical environment that the drone will fly in was also a concern for the team. A drone is susceptible to becoming water-logged in heavy rains and to poor flight control in high winds. The team referred to the drone manufacturer's manual to set boundaries for operable conditions. To test within those conditions, the team set out to test the flight paths many times over many days. The flight was tested and verified on a day with constant 25 mph winds. To test the lighting impact on video visual quality, the team tested on both overcast days and very sunny days. A test video of the lights on a sunny day was shown to volunteers, and determined to be a viable inspection tool.

The immediate community environment surrounding the airport will also be effected by the increased ease of inspection due to the drone-based system. Because the drone-based inspection system is quicker and uses less resources than the current inspection process, airport management can conduct more inspections per day. Therefore the perimeter will be inspected for accidental incursions onto the airport property more often. This will increase the safety of the surrounding community because the airport employees will be able to redirect people off the airport property before they get hurt.

19.3 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. Due to low budgets, 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. With each inspection taking anywhere between 45 minutes to an hour and a half to complete, the total current inspection process is an unpredictable and inefficient utilization of time. The implementation of an automated drone-based inspection process will create a better and more efficient work environment for airport employees by alleviating some of the subjective responsibility of the inspections, and by creating a clear time line for inspections. The predetermined flight paths and organized process plan create a consistent time line for the inspections, therefore allowing an employee to better schedule and utilize their time. 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.

This video logging system can also be used to subsidize other programs at the airport, including the wildlife program. While the main goal of the automated inspection process is to quickly and efficiently conduct inspections with clear video of tasked items, one of the byproducts of the inspection is wildlife documentation produced from the drone presence. The videos used for the inspections can also be used as a way to record and analyze wildlife patterns and behaviors. This information can them be used to inform pilots of the probability of wildlife incursions in the airport or on the runway. The wildlife program can be further enhanced through the inherent harassment of animals from the noise created by the drone during flight. 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. This added value of the drone-based system is being implemented already at Bult Field in Illinois [2].

19.4 Political Impact

By successfully demonstrating the positive implications of utilizing a drone in a General Aviation airport, the project can have a substantial impact on the political and legal aspects of drones in airports. It is common to believe that the FAA, individual airports and drones are at very opposite side of a legal battle. With restrictions being placed on drone pilots to limit flying space, people assume that the two worlds are at odds. Through the implementation of drones into the airport atmospheres in a positive way, the team has proven that airport executives are ready and willing to bring the worlds together.

On the scale of each individual airport, the use of drones to log daily inspections with videos can protect airports and their personnel in an event of a law suit after an accident or crash. The current inspection process leaves the employee with the responsibility to correctly describe the airport conditions. This current process is subjective and can be interpreted in different ways. This leaves the airport open to a pilot interpreting the subjective inspection description in a less-favorable way. For instance, if a plane lands but skids off the runway, the pilot could say the accident was due to improper descriptions of the runway conditions, instead of landing at too high or speeds, and blame the accident on the airport. Using the current inspection process in a lawsuit, the argument will lead to a ”he said, she said” standoff to determine what the airport conditions truly were at the time of the incident. Using the drone-based video logging system, the day-to-day conditions of the airport would no longer be subjective. The video evidence would be an objective and viewable representation of the airport conditions at the time of the incident.

As a political impact, the successful completion of an automated inspection performed by a drone will provide physical evidence of the considerable positive impact drones have on airports. Currently, the FAA restricts the use of drones without prior approval by the administration at all airports, despite size and volume of incoming and outgoing aircraft 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 [2] [3]. These cases of drone usage have required several, necessary FAA directives, requirements and restrictions. By following the necessary safety protocols as described in the report and instruction procedure created, the risk of incidents involving the drone can be minimized and possible eradicated. 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. With low risks of accidents and ample evidence of automated inspections performed by Westerly State Airport, enough evidence can be provided to the FAA to alter the current laws and restrictions for drone usage performed by approved airport operators in GA airports and possibly 139 airports, with time. Drones can provide airports with tools to increase efficiency within everyday maintenance and 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.

19.5 Ethical Considerations

One of the main ethical concerns that arise with the automation of daily airport inspection through the use of a UAV is regarding the privacy of people in neighboring homes and buildings. Despite the drone never traveling outside of airport property and airspace, people living and working in the adjacent area surrounding airports, especially general aviation airports due proximity to local homes and business, could be recorded when the inspection process is being completed. For instance, houses share the same fence line with Newport State Airport and Westerly State Airport borders a industrial work complex with many companies, including Ivory Ella Headquarters which has obstruction lights on its building due to its proximity. People are at the highest risk of being captured on the GoPro footage during the tree line and fencing security inspections where these homes and buildings border the airport's perimeter. 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. The inspection logs can be password protected on the computer to prevent unauthorized personnel from viewing the videos to further protect the security of the public. The drone and its accompanying equipment case can be locked in a secure room within the airport terminal when not in use during shutdown hours. Through these security measure put in place, any video of public homes and buildings can be protected, and public privacy can be maintained and secured.

Another ethical consideration comes with the efficiency of the automated inspection process. The automated inspection process produces better results by eliminating the subjective interpretation of inspections through the use of logged videos, cuts down on man hours needed to complete the inspection and cuts down on the wear and tear of airport vehicles used to complete the inspections. With the number of man hours saved using the UAV to complete timely and costly inspections, general aviation airports can afford to eliminate at least one of the operators employed to perform such tasks. Companies in all fields are replacing human employees with technological advancements to improve overall efficiency, increase accuracy and decrease costs to conduct routine jobs and as a business themselves, general aviation airports are no different. The ethical consideration from this project comes with the dilemma to implement the automated process if it will take the job of an airport employee who would likely be fired. The dilemma is further complicated by the increased efficiency of work left for the remaining employees. One has to consider if the lost job of one is balanced by the betterment of the rest. Further ethical consideration comes if the employee has significant others or a family to support or is nearing the age of retirement as the aging workforce has an increased difficulty being rehired. From a financial perspective, companies would rather hire a younger employee who will, or has the capability, to work for several years compared to an employee prospect nearing retirement to reduce turnover rate.

19.6 Health, Ergonomics, Safety Considerations

The implementation of the inspection process can a great impact on the health, ergonomic and safety considerations the airport must take into account. By utilizing the UAV to perform inspections, airport's can significant reduce the time needed to conduct these tasks and possibly reduce the number of airport operators performing the inspections. Ergonomically, the automated process can reduce the inspection time by 40 minutes per inspection. On average, three inspections are performed daily by general aviation airports and the time saved, two hours each day, will allow operators to perform other required duties. This increases the overall efficiency of the operator. The use of a drone for the inspections will also eliminate much of the time spent driving around the airport to do inspections. During the current inspection process, the operator must drive through the airport while simultaneously watching for failed inspection items, or unexpected debris or hazards. This process puts stress on the operator's body by having to swivel their head and body to be constantly looking out the window of the car. This, in turn, also creates unsafe driving conditions. It is also important to consider that this current inspection process cannot be completed if the employee is suffering from an injury. If the operator has an injury that would effect driving ability, such as a broken foot or leg, the operator would be unable to complete his required job and the airport would have to find a temporary replacement.

The time saved through the implementation of a drone-based inspection system would also help airports significantly increase their operational efficiency. In order to perform a full inspection, airport's must shut down the runway in order to safely inspect runway and taxiway lights and along with areas bordering the landing strips. By reducing the inspection time, runway shutdown times will reduce and allow for more aircraft to land or take off on any runway, if there are multiple. The reduced runway shut down time can be taken as a safety consideration. The safety of its employees and air traffic is the highest priority at airports, general aviation and 139. By reducing the runway shutdown times, planes do not have to wait to for operators to vacate the area to land, giving the pilot the option to land of their terms instead of the operators. Also, the use of an UAV does not require the operator to travel around the airport property and especially the runway area, the location where the highest number of incidents occur. The operator can stay in a safe location while still being able to keep the UAV in eye sight and perform the inspection area.

Also as previously mentioned, there are obvious concerns of the safety of flying a drone in an airport, with the potential of crashing the drone into obstructions like trees or obstruction poles. This can be avoided by safely planning flight paths to have a far enough distance from these obstacles to ensure no crashes. Also the main concern of crashing the drone into an airplane has been considered. There are plans in place to ensure this will not happen, which begin with the airport operator issuing a Notice to Airman (NOTAM), which alerts all planes entering the airspace that there is a drone in the airfield and not to land yet. If the pilot does not listen and does enter the airspace, then the drone can immediately be landed.

19.7 Sustainability Considerations

The use of the UAV will also increase the sustainability of the airport's equipment. Presently, inspections are conducted by having an operator drive an airport owned vehicle around the property and on the runways. Airports, especially in Rhode Island, are located on wetland and rocky terrain which cause mechanical issues that can reduce the life expectancy of the truck. However, by eliminating the daily need to operate the truck through marshes, hills and rocks, the life expectancy of the truck can be increased while reducing any required maintenance caused by excessive "wear and tear" on the vehicle. At Westerly State Airport, James Warcup took the team around the airport perimeter on multiple occasions, taking his Ford Explorer down large hills and wooded trails to gates along the fence, and up rocky terrain to reach certain perimeter lights. The vehicle managed to climb the hills but the airport owned truck is much older and would not be able to overcome the terrain obstacles in order to reach some inspection items. At Newport State Airport, a large portion of the property is marsh that becomes inaccessible from the winter snow and rain and does not fully dry until the mid summer. If an operator attempted to inspect the full fencing perimeter while the land was still wet, the truck would get stuck and need to be towed out. The use of the UAV to automate the inspections would eliminate the need to take the vehicle through the marsh and any resulting maintenance.

Drones are very sustainable due to the fact that they are relatively inexpensive to purchase and even cheaper to maintain. The drone used and many drones that are frequently purchased are used by hobbyist and are designed to have easily replaceable parts if they are to break for any reason. The propellers and legs are the most overused pieces of equipment on a drone and if anything were to happen to them they can easily be purchased and replaced. Along with the cheaper pieces, more expensive components such as the battery or gimbal can be damaged, but these can even be easily purchased and replaced. As previously mentioned, there is a very small chance of a drone crash, but if the drone were to crash it can be replaced for $585, which is very inexpensive compared to the savings the airport will face if this process is implemented.

20 Conclusions

Capstone Design Team 11 was chosen to participate in the Airport Cooperative Research Program (ACRP) National Design Competition. The aim is to plan, design and create innovative approaches to resolve problems experienced by airports and the Federal Aviation Administration (FAA). The team was able to choose between four main categories in which to compete. 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.

Two of the design specifications were set due to the specifications of the 3DR Solo drone. The battery life of the drone ranges from 20 to 25 minutes, so the limiting factor of the inspection time is the minimum drone battery life of 20 minutes. This set the first design specification of the inspection to be less than 20 minutes, which was met by tests conducted at Westerly State Airport, resulting in the inspections taking approximately 15 minutes. The next design specification was that the drone will always stay within its operating range, which was met by purchasing Alfa Wifi Antennas to boost the range and was proved at Westerly State Airport. The next design specification set is that the setup of the system should be easy and require less than 5 minutes. The team had someone who had never use the drone set it up by giving them brief instructions and this took less than 5 minutes. This shows the ease of set up, that the user learns to do it the first time and every inspection after this will be set up in less than five minutes. The set up process consists of putting the battery in the camera, attaching the camera to the drone, putting the battery in the drone, and then pairing it with the Tower application and pressing ”Fly”. This indeed meets the design specifications set.

The design specifications are also set for the financial requirements. The design costs are not to exceed the team’s budget of $1,000. The 3DR Solo drone, the GoPro Hero 4 black camera, and the Samsung Galaxy table were provided to the team, and purchased the Alfa WiFi Antennas for $20, which satisfied the design specification of staying under the budget. Also, the design specification was set to reduce the man hours used for inspections, and in turn save the airport money. The team will market this as a product to be purchased by airports to be implemented, and will charge $3,000 to create the flight paths for the airport and provide them with the process. The items needed for the inspection cost a total of $1,017, so the costs for implementing the system are $4,017. With this process implemented, the airports will be able to reduce from two inspectors to one inspector and shorten inspections from one hour to twenty minutes, saving 726 man hours a year resulting in $27,250.5 saved yearly. So, after implementation, airports will save $23,233.5 the first year of operation and $27,250.5 each year thereafter.

The next design specification was set due to the customer requirement of being easily maintainable. This design specification was met due to easily replaceable parts. The only maintenance needed is charging the drone and camera battery after each flight. Also, the drone has easily replaceable parts, has extra batteries and extra rotors that can easily be replaced, and more can be purchased online if needed. Also, the GoPro Hero 4 Black has extra batteries and uses a micro SD card for memory, that when full, a new one can be purchased.

One of the most important design specification is safety, which was also met. The FAA has regulations set for the use of drones, which is FAR Unmanned Aircraft Systems (UAS) Part 107: Small UAS Rule. This regulation restricts drones from flying above 400 feet and restricts drones from flying in airports, within five miles of an airport and requires the user to always have the drone in their line of sight. The team worked closely with the Rhode Island Airport Corporation (RIAC) and were provided with two Operational Directives, granting the team permission to fly the drone in Westery State Airport and Newport State Airport. The team will still abide by FAR UAS Part 107 of flying below 400 feet, and keeping the drone in the line of sight. Also, the airport will issue a Notice to Airman (NOTAM), alerting pilots that there is a drone in the airport during a set period of time, so there will be no planes landing. The drone will always be kept in the line of sight in case it needs to be immediately landed in case of a pilot not listening to the issued NOTAM.

In conclusion, the design meets or exceeds all of the required design specifications. 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 team hopes that this system will be implemented into airports in the near future.

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22 Appendices

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.

Automated Inspection Survey

We are a team of mechanical engineers from the University of Rhode Island currently working with the Rhode Island Airport Corporation (RIAC) to implement an automated inspection process in General Aviation (GA) airports for the Airport Cooperative Research Program (ACRP) Design Competition. Our team is testing the process of implementing a drone to conduct airport inspections in order to optimize inspection efficiency, save time, and reduce inspection costs. The purpose of this survey is to gain a better understanding of how airports currently conduct their inspections, what problems currently exist in these inspections, and how we can best optimize the process to fit the airport's needs. We are currently focusing on automating inspections for runway and taxiway lighting as well as perimeter and security inspections. The team was provided an Operational Directive from RIAC giving them permission to fly within Westerly State Airport. Thank you for your time, your help in completing our project is greatly appreciated!

1. **Email address** *

2. **How long does it typically take to complete a full inspection at your airport? Additionally, how long does it take to inspect the runway and taxiway lights along with the perimeter of the airport?**

3. **How many inspections are typically conducted per day?**

4. **Do your inspections take place during the day, at night, or both?**

5. **Do you currently implement drones at your airport in any way? (wildlife harassment, construction mapping, etc.)**

6. **What do you feel is currently lacking in the inspection process? (objective data instead of subjective, logging system, etc.)**

7. **What is the current cost to conduct inspections per day?**

8. **How useful would automating the inspection process be to an airport?**

9. **Are there inspection items in harder to reach area of the airport (woods, fencing, water) that would be useful to have inspected by a drone?**

10. **Would you be receptive to a video logging system for inspection in addition to a manual file system, if one is not already implemented?**

11. **In your opinion, would most GA and/or larger airports be receptive to inspection automation? If so, under what conditions?**

12. **Do you have any other comments or concerns?**

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