Eye in the Sky – Drone Detection & Tracking System

Airport Cooperative Research Program: University Design Competition for Addressing Airport Needs, 2014 – 2015

Design Challenge Addressed: II. Runway Safety/ Runway Incursions/ Runway Excursions

Eye in the Sky

Drone Detection System

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Team Sponsors:

The University of Rhode Island College of Engineering

Rhode Island Airport Corporation

Federal Aviation Administration

Executive Summary

Detailed in the following report is the process to design and implement a drone detection and tracking system. There are two project components, to provide the airport the ability to detect when a drone enters the critical airspace surrounding an airport and to inform the operator if his/her drone is within the 5 mile safety buffer around an airport. The project is entered into the 2014-2015 FAA Design Competition for Universities by a team of four mechanical engineering undergraduates at the University of Rhode Island and is sponsored by the Rhode Island Airport Corporation (RIAC).

With ever increasing popularity, there are almost weekly reports of close call collisions between drones and manned aircraft. In addition, if a drone were to cause a collision, there is no way to identify the operator of the drone. In order to prevent this, the project goal is to have a national registration process be instituted by incorporating an RFID tag onto future commercial, and possibly recreational, drones. The RFID tag acts as a registration of the drone. The Drone Detection and Tracking System uses active RFID technology to detect drone flight within critical airport airspace and warns air traffic control of the danger to manned aircraft, thus increasing ATC's and pilots' situational awareness. The Drone Operator Notification System compares current drone coordinates and altitude to airport critical airspace coordinates providing a warning to the drone operator if flying within the critical airspace or over 400 feet. This provides the operator with greater flight situational awareness thereby reducing the risk of midair collisions. The project is a potential asset for the FAA in incorporating commercial drones into the NAS.

Through guidance with RIAC, prototypes were developed that successfully detected and tracked drone flight and relayed this information to appropriate parties.

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1 Problem Statement and Background

1.1 Problem Definition

Over the past few years, (semi)autonomous aerial vehicles have proliferated in number because of advances in vehicle aerodynamics, design, robust control systems, and low cost. Many hobbyists and professionals are now routinely using such “drones” for aerial photography and videography. With the recent influx of UAVs being flown by government agencies, several companies, hobbyists and other aviation enthusiasts, the FAA is in need of a system and method of tracking these otherwise undetected aircraft. The problem and ultimate design was chosen based on its importance to the FAA’s plans to implement drone into the National Airspace System (NAS) [1]. The FAA has several guidelines in place as to how drones may be flown, but without the use of a national tracking and registration system, there is no way to effectively patrol and enforce the airspace in which manned and unmanned aircraft are now currently sharing besides the traditional “see and report” method.

The FAA has been experiencing a great deal of difficulty in integrating unmanned aerial systems into the NAS. The common aviation enthusiast cannot fly a drone without having to be aware of the possibility of crossing the flight path of a commercial or personal aircraft. As the Washington Post reported in an article on June 23rd, 2014, “…airline pilots trying to land at two of the nation’s busiest airports got on their radios to report the unnerving sight of small rogue drones buzzing at high altitudes.” [2] This problem stems from the inability of the FAA to track these unmanned aerial vehicles. An investigative report by The Washington Post concluded that midair collisions with UAS’s have increased dramatically over the past few years. According to the report, there were two separate instances of close calls last year alone of commercial aircraft coming within close range of UAS's near busy international airports. "…on May 29, the pilot of a commercial airliner descending toward LaGuardia Airport saw what appeared to be a black drone with a 10-to-15-foot wingspan about 5,500 feet above Lower Manhattan… …two airliners separately approaching Los Angeles International Airport soared past what they described as a drone or remote-controlled aircraft the size of a trash can at an altitude of 6,500 feet, FAA records show" [2]. The report also states, "On May 3, the pilot of a commercial airliner preparing to land in Atlanta reported a small drone with four legs and bright lights "in close proximity" to his plane, according to the FAA records. The agency recently disclosed that the pilot of a US Airways plane reported a near-collision with a drone or remotely controlled model aircraft over Tallahassee Regional Airport on March 22 in Florida." [2]. Moreover, according to FAA officials, "'In many cases, radar data is not available and the operators cannot be identified," the agency said in a statement.'"[2]. The Washington Post report states that the increase in drone usage, both legal and illegal, is becoming much more frequent and thus the incidents being reported by manned aircraft pilots is increasing dramatically. There have been at least 15 cases over the past two years of drones flying exceedingly and dangerously close to airports or commercial aircraft in flight. NASA has compiled a database of pilot complaints of another 50 instances of improper drone flight practices and close midair collisions, and even legal FAA granted drone usage by government law enforcement agencies, universities, and other organizations have reported themselves of 23 accidents and 236 unsafe incidents since the end of 2009, according to FAA records [2]. This is just one recent incident of drones flying into critical airspace for aircraft landing and taking off from our nation's busiest airports. Occurrences in which aircraft are encountering drones are becoming more of a prevalent problem every year as the technology of these drones continues to increase while costs decrease. There have been at least 236 reported close call collision incidents between UAVs and manned aircraft since the end of 2009 [2]. One can imagine the fatal consequences if a drone were to collide with a manned aircraft during its critical flight ascent out of or decent into an airport. Due to Federal Communications Commission regulations, all radio controlled drones are required to operate using a specific range of radio frequencies and cannot fly over 400 feet. When within 5 miles of an airport, the operator must notify airport operations [3], however, this rarely happens because of unknown regulations, or simply out of operator apathy.

1.2 Project Description

After careful research regarding current issues in the aviation industry and the FAA's efforts towards a *NextGen* airspace system [4], a two-fold system was designed. A drone detection and tracking system was developed to assist airports and pilots in detecting and collecting information regarding drone flight around the vicinity of an airport to improve flight safety. An independent, universal drone operator notification system compares current drone location and altitude to a predefined set alerting the drone operator if he or she is flying within a safety zone of five miles around an airport or above 400 feet. The Drone Operator Notification System provides critically lacking flight information to the drone operator. The objectives of these two separate systems are to successfully integrate drone flight into critical shared airspace with manned aircraft. The purpose of developing the two systems is primarily to increase the critically lacking situational awareness regarding drone flight and usage and to further decrease any chances of midair collisions between unmanned and manned aircraft, thus saving lives and property damage.

2 Summary of Literature Review

2.1 Literature and Internet Search

Throughout the course of the project, the team completed several rounds of literature and Internet searches. These searches provided the team with invaluable amounts of information which was used to help determine the topics to be pursued and possible concept marketability. In particular, much research was conducted to determine the regulations the FAA has put on air traffic safety, statistics of close midair collisions between drones and manned aircraft, and the legal authority and jurisdiction in which the FAA has over UAS flight in the NAS.

The first sources of research that the team sought to find were those regarding the FAA Design Competition. The main source used by the team in this case was the competition guidelines [5]. This source provided the team with the competition background, timeline and rules, project ideas and current issues experienced by airports around the country. Moreover, the team realized that some of the more dependable and essential resources to help with the project idea development, and ultimately the project design, would be sources directly from the FAA and other regulatory agencies. Of the many sources found, a few of the most prominent were the many different Advisory Circulars published by the FAA. Most notably, A.C. 91-57 [3] was extremely useful as it provides clear operating standards as posed by the FAA regarding UAS flight and usage. Additionally, the team found legislation passed by Congress regarding the nation's path towards incorporating drones into the national airspace, the FAA Modernization and Reform Act of 2012 [6]. The law mandates that the FAA develop a national plan to incorporate UAS' into the NAS by 2015. This legislation was important because it lead the team to the FAA's Interpretation of the Special Rule for Model Aircraft [7] which outlines the FAA's interpretation of its authority over UAS as interpreted by prior enacted federal law. Furthermore, other essential documents to understanding the current position on drone flight within the US and the FAA's plans on increased and continued personal, and eventual commercial, usage of drones in the NAS is the FAA's Unmanned Aircraft Systems (UAS) Comprehensive Plan [1] and the FAA's *NextGen* Implementation Plan [8]. Both of these documents provided the team with sound information on how to progress with the project idea and affirmed the need to solve this problem.

The Internet searches completed by the team also provided exceptional background into the project demand, marketability, feasibility, and reasons as to why and how such a system is needed and might be implemented. The Internet search also allowed the team to become more aware of the current political and social impacts involved with increased government intervention into drone usage and flight as well as clear statistics into how many close calls actually happened between drones and manned aircraft. Through the various Internet searches conducted, many newspaper and journal articles were found highlighting and expanding on the topics above. Of the more useful articles found were reports written by the Washington Post, "Close Encounters with Small Drones on Rise" by Craig Whitlock [2], an AP exclusive titled "Drone Sighting up Dramatically" by Joan Lowy [9], and an article by The Wall Street Journal titled "NTSB Rules Drones Are Aircraft, Subject to FAA Rules" [10] which explains how the NTSB recently ruled the FAA has full authority over all objects in flight. Further, some other notable sources include those which explain the desire by many companies to be able to utilize drones in their commercial endeavors, which is currently illegal unless specifically granted permission from the FAA. Some of the more notable companies vying for commercial drone incorporation include Amazon [11] for package shipment, Disney [12] for use within its theme parks, and Google and Facebook who would like to see drones be used to bring Internet capabilities to areas with little to no Internet connectivity. Noteworthy progress was made when the FAA granted commercial drone permits to four companies for aerial surveillance and construction site monitoring of 167 vying companies. This was significant as only law enforcement and other government agencies had previously been granted the right to use drones [13]. The FAA also recently granted Amazon the right to begin studies into its drone package delivery system [14]. Lastly, the FAA recently published some preliminary rules and regulations of full commercial drone flight practices. The rules included who could fly the drone, how they would obtain a license, and it highlighted that all current safe flying practices are still in effect and that flight around airports is strictly prohibited [15]. Among other sources, the team also completed extensive research regarding current airport operations and the technology available to airports in tracking manned aircraft. Moreover, airport radio frequencies, GPS technology, and drone capabilities along with other safety information were found.

2.2 Patent Search

A major part of the research that was undertaken during the initial design development stages of the project were multiple rounds of patent searching. These patent searches were important to verify that the concept was new and would not infringe on any existing patents. One of the patents found that had some relevance to the drone detection system to be developed was US patent 3,549,869. This patent is owned by Gerald Kuhn and was awarded in December 22, 1970. The patent is for a vehicle counting device which could be used to track how many cars enter and exit a specific parking lot [16]. This patent is relevant to the drone detection system, as one of the system's main jobs is to detect and track how many drones are breaching the critical airport airspace around the vicinity of an airport.

US patent 5,379,224 A which was granted in January 3, 1995 to NAYSYS Corporation is for a system utilizing GPS technology which tracks the location and speed of the object in which the transponder is placed. The location and velocity data are then automatically uplinked to a server and logged for future reference [17]. This patent is relevant to the Drone Operator Notification System as a GPS receiver is planned to be installed on drones to track their movement and compare their current position to a predetermined set of coordinates. Like this device, the team's system will report GPS data to the user and operator of the drone automatically. This patent was useful for the Drone Detection System because the patented system allows for the continuous tracking of an object. One of the biggest problems for airports is first identifying and then tracking the drone in order to alert both air traffic control and aircraft which are landing or taking off. There have been over 200 reported close midair collisions between drones and commercial aircraft since 2009. This patent allows airports to relay this tracking information directly to pilots in order to avoid these dangerous situations.

The patent search also included searching for patents relevant to the Drone Detection System. Another relevant patent to this system is US patent US20120280836 A1 awarded to Federal Signal Corporation on November 8, 2012. The patent was awarded for a unique take on a vehicle detection system using RFID location technology. As described in the patent's abstract, "A vehicle detection and location system includes a plurality of RFID tags positioned along a parking array. The system includes an RFID reader movable in conjunction with a vehicle identification system along the parking array and configured to interrogate the RFID tags." [18] This patent was extremely relevant to the Drone Detection and Tracking System under design. The team learned through this patent that it is possible to locate drones based upon the relative location of the RFID reader to the vehicle and a number of other known reader and tag locations.

3 Team's Problem Solving Approach

Upon team formation, division of tasks was determined based on prior experience, interests, and student schedules. For instance, Catherine LiVolsi had prior coding experience and a great interest in computer science, therefore she was delegated as leading the coding of the Drone Operator Notification System. Stephen Pratt was chosen as the team leader due to prior leadership experience and his time management and organizational skills. The team leader's job was to keep morale and motivation within the team high as well as to plan and delegate tasks to team members appropriately. The team utilized Microsoft Project as its project management resource. A Gantt chart was developed to schedule tasks and resource allocation, and monitor the team's progress, resources, and monetary funds.

3.1 Concept Generation and Selection

After developing a problem statement and determining the project goals, each team member participated in a concept generation phase where at least 30 concepts were developed independently. The team then went through multiple iterations of review to reduce the amount of concepts to a few viable options. These concept reviews took much time and effort as additional research regarding applicable technologies was completed in order to create a final list that best represented the team's capabilities and to produce the best possible solution to the outlined drone problem. After significant thought, two final concepts were determined:

1. RFID reader and RFID tags placed on drones

This system would utilize a network of RFID readers positioned strategically around the airport periphery to detect and track RFID tags mounted on drones which have crossed into the restricted and critical airspace around an airport. The system would establish a national registration database for all commercial drones, and possibly, future recreational drones. It provides the FAA a direct means to detect and track drone flight around critical airspace and know exactly to whom the drone is registered.

2. GigE Vision Camera with MATLAB:

A drone detection system utilizing object recognition software and specialty cameras stationed at the air traffic control tower and around the airport would allow ATC to detect and see drone flight in the vicinity of critical airport airspace. It could also be used and calibrated to detect other objects and/or flocks of birds in the area increasing situational awareness.

The team utilized a Quality Function Deployment process as an important step in evaluation of the concepts generated to compare the different technology options available, and to compare the team's ideas with competition currently on the market. After much deliberation and thought, the RFID concept was chosen as the most viable option. Figure 1 shows the competitive analysis completed for the Drone Detection System against its competition and other proposed technology options.

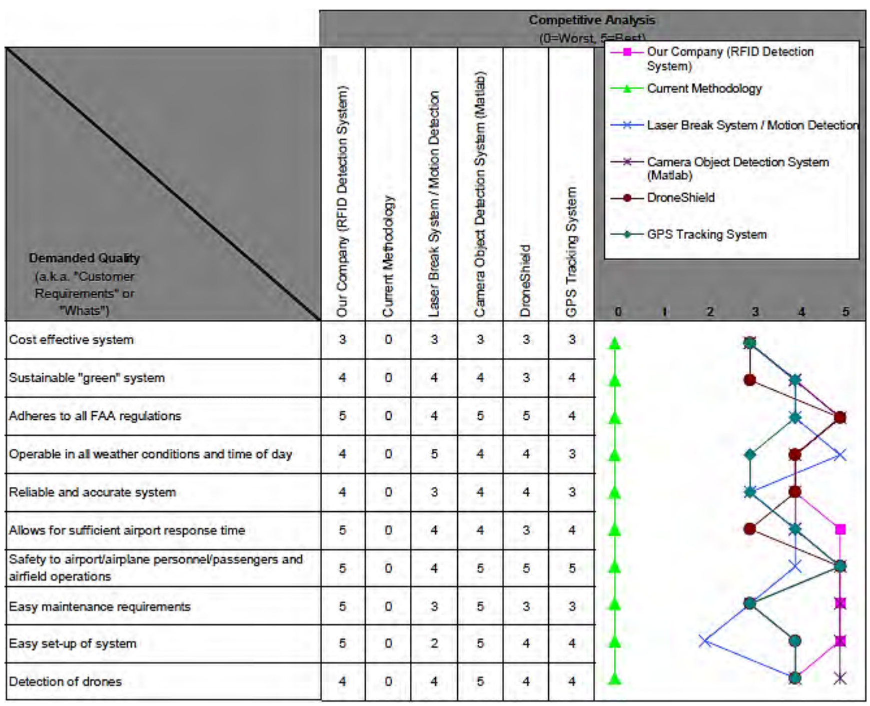

Figure 1: Competitive analysis.

Choosing a final concept, the team and RIAC developed a set of design specifications for both the Drone Detection and Tracking System and the Drone Operator Notification System. The most important design specifications were in regards to airport safety, FAA regulations, and system reliability and read range. The design specifications are shown in Table 1.

Table 1: Product design specifications of Drone Detection System & Drone Operator Notification System.

RIAC Requirements	Product Design Specifications
1) Cost effective system	1a. Cost of system shall not exceed $2,000 per unit
2) Sustainable, green device	2a. 100% power supplied by renewable energy source, solar
3) Detection of UAV	3a. Device will detect and track drones flying within at least 100 meter omnidirectional distance from airport perimeter
4) Operable in all weather conditions and time of day	4a. Operable during both day and night hours for entire drone battery life, 24 hours consecutively
	4b. Operable between -20°F - 110°F
	4c. 100% operability in ideal and adverse weather conditions
	4d. Resistant to moisture, corrosion, elemental affects for 20yrs
5) Reliable and accurate system	5a. 100% reliability and accuracy on detection of tags
	5b. Read 100 tags/second; read tags at speeds of 50mph
6) Safety to airport, airplane personnel/passengers and airplane operations	6a. Detection and warning systems will not interfere with airport operations and aircraft communication systems
	6b. No taller than 14 feet
7) Easy maintenance requirements	7a. Maintenance check of twice a year
8) Drone Operator Notification System	8a. Drone Operator Notification System no more than 1lbs
	8b. Altimeter read ranges above 400 feet
	8c. GPS compares altitude and coordinate readings every 5s
	8d. GPS systems compares current lat/long to known 5 mile radius lat/long around airport
	8e. If match, Arduino lights up a red LED and emits message to LCD screen, alarm sounds within 10s of match confirmation
	8f. RF transmitter range of 1 mile
9) Miscellaneous	9a. Drone detection system weighs less than 50lbs

3.2 Design and Testing

The design process consisted of several iterations of structural and component layout designs through consultation with the sponsors at RIAC. SolidWorks 3D modeling software was used to develop a visual understanding of the relative sizing between the various components of the Drone Detection and Tracking System. It was also used to help determine balance and weight concerns. Finite Element Analysis and other engineering analyses regarding wind drag, structural integrity, power requirements, and sustainability were completed as well. With the components purchased, any additional post processing manufacturing occurred in the URI Machine Shop and assembly of the Drone Detection System was completed by March. At the same time, the Drone Operator Notification System electrical and Arduino components had been purchased and assembled. Arduino coding was a significant challenge to the team; however after much hard work and consultation with the URI Electrical Engineering Departments, the debugging process was completed in March as well. SolidWorks was used to design the transmitter and receiver housings which were produced by 3D printing machines. Upon final assembly of the Drone Detection and Tracking System, the weight of the system was measured. The system measured at a total weight of 45 pounds meeting design specification 9a limiting system weight to 50 pounds or less. The testing phase began shortly after. Various tests were conducted to quantitatively and qualitatively assess and verify the design specifications and the adequacy of the Drone Detection and Tracking System and Drone Operator Notification System.

The first test that was conducted and completed was a waterproofing test of the enclosure housing for design specification compliance and performance verification. The enclosure housing was exposed to prolonged light, medium, and heavy levels of direct water contact. Under all testing procedures conducted, the housing passed whereby no moisture was recorded inside the enclosure housing proving the sealing methods were sufficient.

The second test completed was to verify that all of the electrical wiring had been completed satisfactorily. The power test was conducted by simply turning on the DC/AC converter to supply power to the RFID reader. The test was a success as the RFID reader was successfully powered on and operated as expected. The second part of the wiring test was to verify that the charge controller was adequately regulating the current and voltage between the solar panel and battery. The test was a success as a voltage drop was measured between the solar panel leads and the battery leads, which was expected. Therefore, the charge controller correctly regulates the amount of current and voltage being produced by the solar panel and the amount going to the battery for charging without causing a power overload. The last part of the power wiring test consisted of a solar panel charging capability test. After using the system for other testing purposes, the battery voltage was measured at 11V. The system was then left in direct sunlight for about two hours for charging of the battery to occur. After the allotted time had passed, the battery voltage was again measured at just over 13V. The test was a success in that the solar panel was able to charge the battery and increase its voltage by 2V in just two hours' time. This proves that the solar panel is capable of charging a completely dead battery to being fully charged within 14-18 hours. This is an excellent result as the battery would be able to be fully charged within one days' worth of sunlight. Please note that it could take slightly longer if direct sunlight and temperature conditions are not ideal which varies upon geographical location and elevation. The test results coincide with charging theory presented below, however the theory predicts a much lower charging time requirement as it does not take into account the several inefficiencies previously described.

$$\frac{Battery\ amp\ hours * 1.4}{Solar\ Panel\ Current} = Charge\ time \tag{1}$$

$$\frac{12\ Ah * 1.4}{1.67\ A} = 10.06\ hours \tag{2}$$

Please refer to section for further details regarding solar panel and battery capabilities.

The most important test to be completed was the RFID Tag Read Range Test. The RFID reader and tags purchased are specified as having a 100 meter omnidirectional read range. Therefore, the test procedure began by placing the RFID tags 100 meters out from the Drone Detection and Tracking System. If a reading was detected by the RFID reader, the tag was incrementally distanced by 5 meters until no recognition continued. If no detection was recorded at 100 meters, the tag was incrementally brought closer towards the detection system by 5 meters until recognition occurred. This procedure was conducted 360 degrees, at 30 degree increments, around the system to test the reader's omnidirectional capabilities and any possible metallic RF interference. The test resulted in extremely positive results. Figure 2 depicts the RFID reader's tag read range in the form of a radar chart. The Drone Detection and Tracking System is located at the origin of the chart.

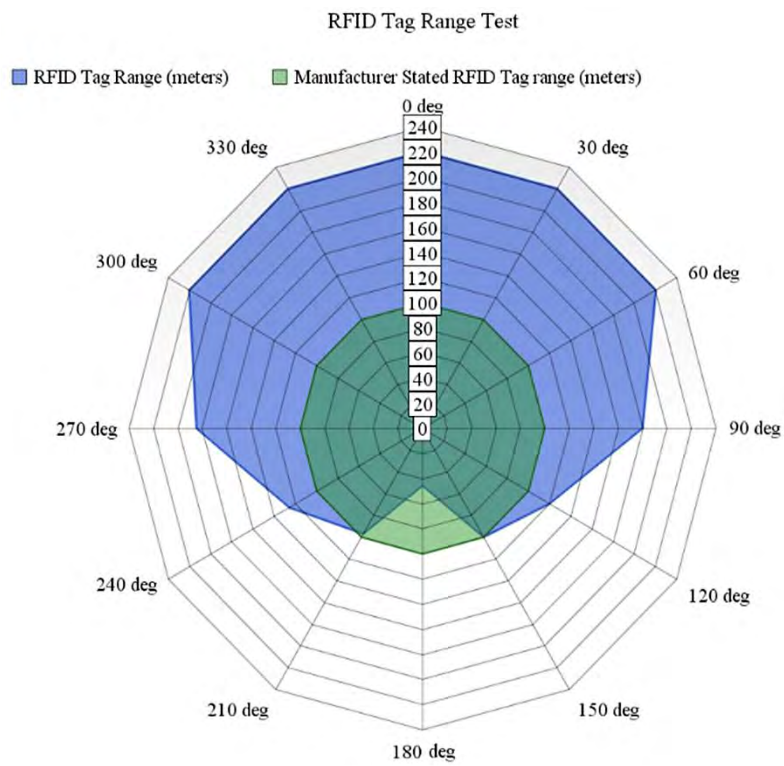

Figure 2: RFID Reader/Tag Read Range Test results.

As can be seen by Fig. 2, the maximum read range recorded was 220.5 meters, an increase of 120 meters beyond the manufacturer's stated maximum read range. The read range is considered to be even higher as space restrictions constricted the ability to test at increased distances beyond 220 meters. This read range was recorded over a span of 120 degrees directly in front of the enclosure housing where no metal interference occurred. The read range began to drop as the tags were brought around the back side of the system where the solar panel is situated. This part of the system consists of much more metallic components than does the enclosure side, therefore, it was expected that the read range would be diminished. The minimum read range detected was approximately 50 meters away from the reader. The orientation of the system would allow for the solar panel to face inwards towards the airport, thus allowing for maximum read range to be situated out of the airport perimeter. The results depicted in Fig. 2 were completed during ideal weather. However, the RFID read range was also tested during various other types of weather conditions including rain, wind, snow, and sleet. The results obtained in each of these conditions were similar to those obtained during the ideal weather test. It has been proven that the reader is capable of providing similar and adequate read range capabilities in various weather conditions thereby verifying and meeting design specification 3a, 4c, and 5a. It is also important to note that this test was conducted using up to 10 tags at the same time with each tag performing similarly. The RFID reader has the capability to detect and record the presence of 100's of tags per second. Lastly, the RFID reader uses 2.45 GHz radio waves to communicate and detect the tags. When in the presence of other devices emitting the same frequency, i.e. cell phones, no interference occurred. In addition, because the RFID tags will be placed onto moving drones, RFID reader and tags must be able to communicate with each other when the tags are traveling at elevated speeds. Tags were tested up 50mph and detection was recorded.

The Drone Operator Notification System was also tested for adherence to its coding logic and in correctly relaying the message to the drone pilot. The system was tested for its software capabilities in being able to interpret its GPS coordinate location as compared to the pre-defined set of coordinates representing the 5 mile airport safety buffer as well as calibrating an initial altitude reading on the ground and comparing this reference altitude to subsequent altitudes during flight. Testing occurred at various locations and distances within and around the airport safety buffer edge at both the University of Rhode Island and at T.F. Green State Airport. At each location, the system accurately pinpointed the exact location of the GPS during each test. The LCD, LED, and piezo speaker all provided the operator with their respective warnings within seconds of crossing over the safety zone boundary and continued the warning until the drone was brought out of the safety zone or below the flight ceiling limit. Upon crossing back out of the safety zone, the warning message stopped within the next iteration of coordinate comparison. The altitude test was also successful as the system warned the operator upon being brought above the specified altitude ceiling and rightly calibrated an initial ground reference altitude at start-up. Figure 3 depicts the beginning of the warning message being displayed by the LCD screen when the drone was brought within the 5 mile airport safety zone.

Figure 3: Drone Operator Notification System providing warning to drone operator within safety zone.

Upon Drone Operator Notification System assembly, the components were weighed to verify that the attachments to the drone and remote control would not exceed the design specification. As seen by Table 2, each of the components meets the design specification 8a.

Table 2: Drone Operator Notification System weights.

Subsystem	Total Weight (lbs.)	Housing Weight (lbs.)	Arduino Components Weight (lbs.)	Other Application Weight (lbs.)
Transmitter (on drone)	0.55	0.3	0.25	Gimbal/GoPro camera 0.4
Receiver (on remote control)	0.55	0.25	0.3	N/A

Most drones can carry a payload of a pound or more without any significant decrease in flight time and quality. Newer drones have the ability to carry up to 20 pounds of additional weight.

4 Safety Risk Assessment

The primary goal of both the Drone Detection and Tracking System and Drone Operator Notification System is to provide increased situational awareness regarding drone flight to ATC and pilots and drone operators, respectively. As any design process should include, a safety risk assessment was conducted after each design iteration of the two products developed. The team referred to the FAA's Safety Management Systems for Airport Operations (FAA Advisory Circular 150/5200-37) [19] and FAA Safety Management System Manual [20] during the design process. As the responsibility of the design team to all system operators, the team went through the five phases of the SRM process; describe the system, identify the hazards, determine the risk, assess and analyze the risk, and treat the risk.

One potential risk of the Drone Detection and Tracking System is the use of a sealed lead acid rechargeable 12V battery. The battery is housed in a water-tight, fireproof enclosure housing for easy access. If an accident or collision with the device were to occur, the battery could be impacted and damaged with possible leakage of the toxic solution inside. However, the batteries are fully sealed and are designed to prevent and internally absorb any leakage, along with being housed in a water-tight enclosure; this concern has been mitigated and solved sufficiently. An additional safety concern was the possible interference with airport communications by the Drone Detection System. The RFID reader was chosen because it operates in a bandwidth not currently being utilized by airport operations and air traffic control, thus satisfying the major design specification 6a.

OSHA requirements and standards were considered when designing the Drone Detection and Tracking System. Per OSHA and the National Institute for Occupational Safety and Health

(NIOSH) regulations, compliance in regards to operator safety was also considered. The NIOSH handbook [21] outlines that the allowable weight lifted by a worker is based on various factors. The maximum weight of the Drone Detection System, as determined from the handbook, is approximately 50lbs [21]. Given the system weighs 45 lbs., it meets the design specification 9a and complies with the NIOSH regulations. Lastly, from consulting the FAA's SMS [19], promoting and communicating safe and proper use of any system is essential. User training and education was promoted through the development of a manufacturing, assembly, operation, safety, and maintenance manual for both developed systems. These manuals give explicit step-by-step instructions on how to operate and use the products and act as a means to prevent any unnecessary perceived risks.

5 Description of Technical Aspects

5.1 RFID UAS Detection System

The *Eye in the Sky*: Drone Detection and Tracking System is designed to detect drone flight and usage around the close vicinity of an airport. This system consists of several subsystems including the RFID reader, the RFID tags, the support structure, and power system. Figure 4 depicts the fully assembled *Eye in the Sky*: Drone Detection and Tracking System.

Figure 4: Eye in the Sky: Drone Detection and Tracking System.

RFID Reader and Antenna:

Figure 5: GAO RFID, Inc. 2.45 GHz Gain Adjustable Active RFID Reader [22].

The main subsystem to the Drone Detection and Tracking System is the RFID reader and antenna. The chosen system is a lightweight 2.45 GHz Gain Adjustable Active RFID Reader developed by GAO RFID, Inc. as seen in Fig. 5. At a cost of $695/reader, the RFID system has a low cost for one of the best read range abilities on the market today. With the included antenna, the reader features an Omni-directional read range of 100 meters per manufacturer specifications. However, through testing the team has found this range to be at least 220.5 meters (723.43ft), with a lateral range of 1446.85ft. If a specialist antenna is purchased, the reader's range can significantly increase up to at least 500 meters. The system is rated for outdoor and indoor usages with an operating temperature range of -40^{o}F to 176^{o}F. It is designed to maximize read range, operate on low power consumption, and features built-in Power over Ethernet (POE) abilities.

RFID Tags:

Figure 6: 2.45 GHz Active Strip RFID Tag [23].

The tags used in this system are active tags which facilitate farther read ranges but causes the tags to have a finite battery life of around 4 to 5 years. At that time, new tags would need to be purchased by the drone owner. The tags weigh 25 grams (0.055lbs) and therefore do not pose any decrease in drone flight quality or time. The tags have an operational temperature range of -22^{o}F to 140^{o}F. Each tag is equipped with an internally powered lithium battery. Lastly, each tag also has unique features including a low battery warning and an anti-tamper alert.

RFID Computer Software and Database:

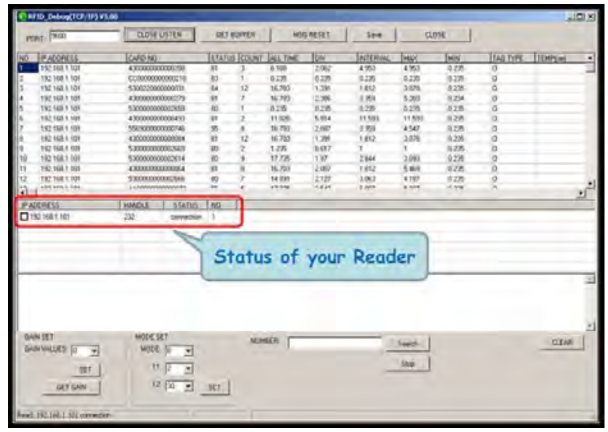

Figure 7: RFID System Software.

The software capabilities include the ability to detect the unique serial number of each tag that was read, what time and duration of the reading, and how many times the tag crossed into the read range. The RFID reader model used in the prototype requires a direct connection via an Ethernet cable to a computer system with the software installed. Other reader models which utilize Wi-Fi technology are able to send information to the computer software. Ethernet cables only have a range of 100 meters, therefore POE is required which extends the Ethernet range up to 1000 meters.

Support Structure:

As the Drone Detection System will be placed around the airport periphery, and outside of the "runway safety area", system height and frangibility is not hindered by FAA regulations allowing fewer required components. The total height of the system is approximately 5 feet meeting design specification 6b. The support structure consists of an aluminum base plate, a low-pressure aluminum threaded pipe fitting, a 5 foot aluminum pipe, and associated miscellaneous hardware. Aluminum 6061 was chosen for the support structure material because of its low cost to strength ratio and its corrosion resistance capabilities. Moreover, aluminum allows for sufficient strength while still keeping the overall system weight below 50 lbs. The RFID reader and other required electrical components are housed in a water- and fireproof fiberglass enclosure, which is also corrosion resistant. The enclosure is 13.5" x 13.5" x


Figure 8: Fiberglass enclosure housing [24].

6.25” to allow for both the RFID reader and 12V battery to fit comfortably inside. The enclosure is mounted to the support structure using two clamping U-bolts.

It should also be noted that from the FEA analysis and drag force analysis conducted, the support structure has the ability to withstand Category 3 hurricane force winds.

$$F_D = \frac{1}{2}\rho A C_d v^2 \qquad (3)$$

where F_D is the drag force, ρ is density, A is area, C_d is the coefficient of drag and is shape specific, and v is velocity. Below is an example of the calculation process followed to calculate the drag force acting on the solar panel.

$$F_D = \frac{1}{2}\left(0.08053\frac{lbs}{ft^2}\right)(2.94ft^2)(0.3)\left(166.04\frac{ft}{s}\right)^2 = 1100.57\frac{lbs}{ft^2} = 7.64psi \qquad (4)$$

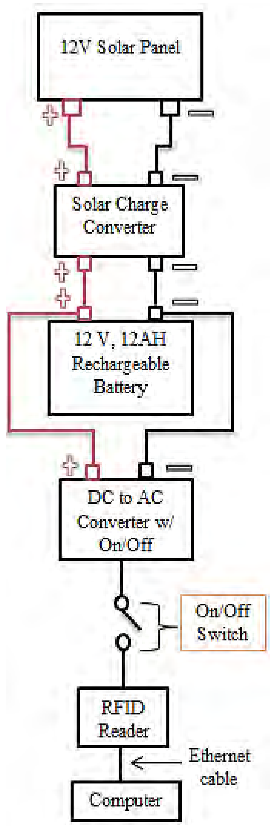

Figure 10: Block diagram of Drone Detection System electronics.

where v is the Cat 3 hurricane force wind velocity acting on the system. Based on the amount of drag that may be experienced by each of the hanging components of the Drone Detection System, the team would ideally like to mount the system into the ground in cement for additional stability. As seen by Fig. 9, the FEA drag force analysis revealed that if the support shaft was exerted by this amount of force, buckling would not occur.

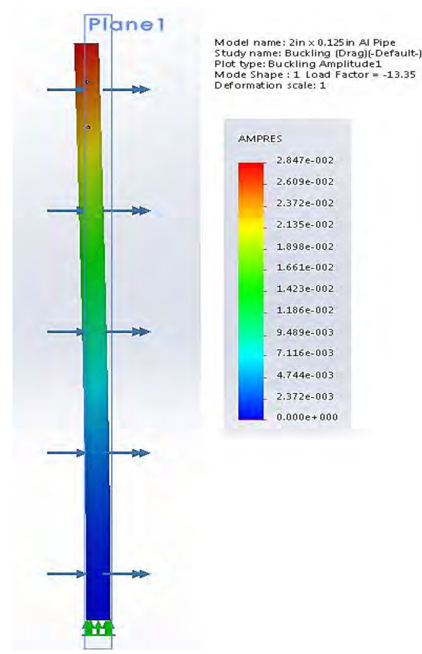

Figure 9: FEA Buckling Test

Solar Panel and Power System:

Based on RIAC “green” initiatives, the chosen method to supply power to the Drone Detection System is with the use of renewable energy. An altE Poly 30 Watt

12V Solar Panel charges a 12V, 12AH rechargeable sealed lead acid battery. Current and voltage are regulated between the solar panel and battery by a Morningstar Sungaurd 4.5A 12V Charge Controller which prevents overcharging the battery. A DC/AC converter is used to convert the battery DC current into usable AC current needed by the RFID reader. With the solar panel wired to the battery, the system will allow for a constant supply of power to the RFID reader during times in which the sun is not present. Figure 10 displays the electrical wiring of the detection system. The battery, when fully charged, has the ability to supply power to the reader for up to 72 hours if needed as seen by Equations 5, 6, and 7. The following power equations were used to calculate the battery life.

$$\mathrm{P}_{antenna} = I^2 R \tag{5}$$

$$0.006\mathrm{A}_{charge\ controller} + 0.06\mathrm{A}_{reader} + 0.1\mathrm{A}_{converter} \approx 0.166\mathrm{A} \tag{6}$$

$$\frac{12\mathrm{AH}}{0.166\mathrm{A}} = 72.3 \text{ hours of power} \tag{7}$$

As seen by the equations above, a 12AH battery will provide sufficient continuous power to the system when the solar power cannot generate additional electricity, i.e. during night hours or continued extreme cloudy or rainy days. The solar panel however, has the ability to generate power even during cloudy weather.

Figure 11 depicts a SolidWorks drawing labeled with the components making up the Drone Detection and Tracking System.

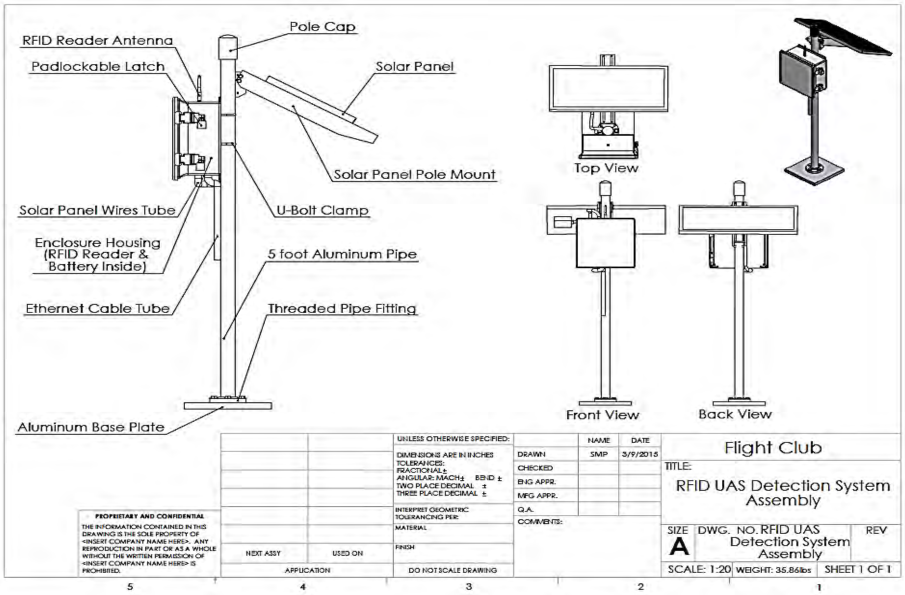

Figure 11: SolidWorks drawing of Drone Detection and Tracking System.

5.2 Drone Operator Notification System

Figure 12: Drone Operator Notification System transmitter housing attached to the drone.

The Drone Operator Notification System is a universal system that can be implemented into all drones providing the operator with a greater situational awareness of where he/she is flying the drone relative to critical airspace. The system to be attached to the drone uses an Arduino Uno R3 board, a GPS receiver, and an XBee Pro S1 transceiver. The system to be attached to the remote control uses an Arduino Uno, XBee Pro S1 transceiver, an LCD display, LED warning light, and a piezo speaker. Custom housings with a self-locking lid have been designed that can be attached anywhere on the drone and remote control. The system on the drone communicates with the system on the remote control via the XBee transceivers. The objective is to have the GPS module obtain its coordinates and

Figure 13: Drone Operator Notification System receiver housing with components attached to drone remote control.

altitude and compare these readings to a preset range of coordinates representing a 5 mile airport safety buffer and flight altitude ceiling. In our case, the list of coordinates will be the 5 mile radius around T.F. Green State Airport, however, the coding logic allows for an unlimited amount of coordinate ranges to be included. A coordinate match will prompt a warning to flash on the LCD screen, the red LED to blink, and the piezo speaker to sound an alarm, all warning the drone operator that he/she is within a safety zone and needs to call the local airport of his/her intentions to fly the drone in the area. The warning will also occur if flight above the 400 foot altitude ceiling is breached. The system is light enough that it will not restrict the drone from normal flight abilities. Moreover, the system can be incorporated into any drone since it is independent of the drone electrical configuration and programming. Perhaps the largest engineering challenge faced by the team was programming the Arduino components using the Arduino programming language.

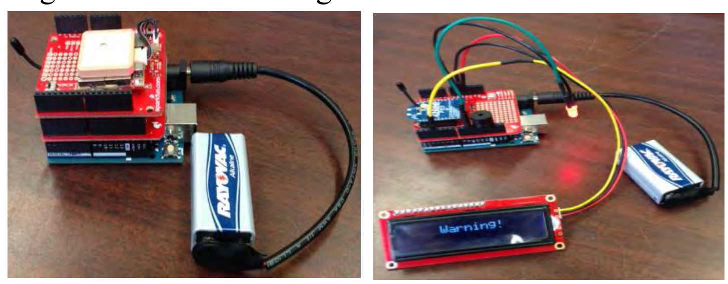

Figure 14: Drone Operator Notification System transmitter subsystem (left), receiver subsystem (right).

6 Team Interactions with Airport Officials and Industry Experts

Throughout the brainstorming, planning, and execution phases of developing the *Eye in the Sky* products, the team had full support from RIAC. In the initial brainstorming phase, the team met with Mr. Alan Andrade, VP of Operations and Maintenance, to discuss ideas that the team had come up with as well as ideas which Mr. Andrade felt would be most beneficial to airport operations. Potential project topics discussed included runway de-icing, construction zone safety, baggage systems, aircraft counting, and runway incursion prevention. However, the team continued searching for a project idea that sparked the interest of each member as well as the RIAC sponsors while succeeding in addressing current and major issues in the aviation industry.

Following the initial meeting with Mr. Andrade, the team decided to work on a system which would aid airports in detecting and tracking drones as they enter critical airspace surrounding airports. After deciding upon a firm project platform, the team again visited T.F. Green Airport to discuss the project plan with the RIAC officials; Mr. Alan Andrade, Mr. Dave Lucas, Mr. Jay Brolin, and Mr. James Warcup. Upon presenting the project idea the team received positive feedback and a number of additional considerations to consider such as detection range, ability to make the system universal and overall cost. In order to gain a better understanding of all critical locations of the airfield in which drone presence would be the most hazardous, Mr. Andrade give the team a tour of the entire airfield and airport facilities, focusing specifically on the aircraft entry and exit points at the ends of each of the runways.

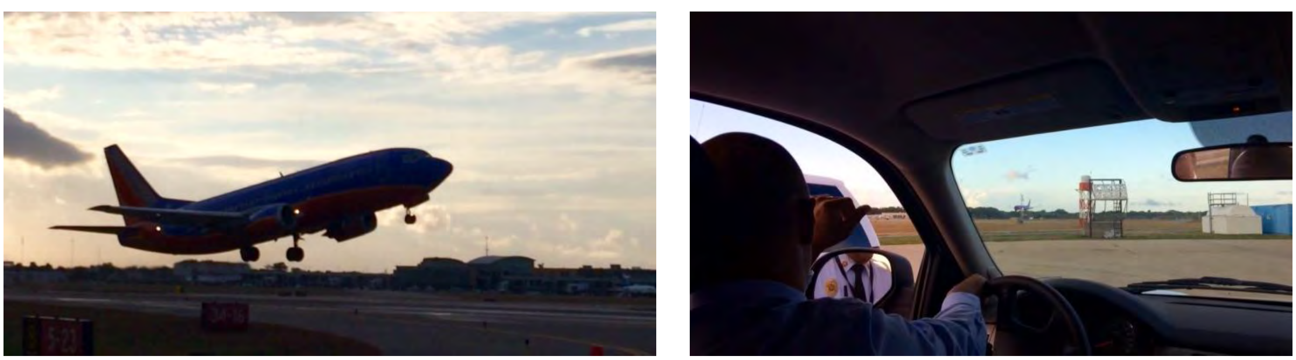

Figure 15: Initial tour of T.F. Green Airport with Mr. Andrade studying flight path into & out of the airport.

In order to gather additional information, the team traveled to Quonset State Airport in North Kingstown, RI to meet with Mr. Dave Lucas. During this meeting the team went over the layout of the airport and critical locations such as ends of the runway, waterfront, etc., and was able to receive some material samples to consider. The meeting also discussed potential military applications as Quonset Airport is the home of Rhode Island Air National Guard. A tour of Westerly Airport was also provided for similar reasons. During the following weeks the team remained in close contact with the RIAC sponsors via e-mail reporting any questions, concerns, or problems regarding design, testing, and rebuilding of the system and ultimately received full support on both systems developed.

Figure 16: Team goes over Quonset Airport layout drawings for system deployment locations.

On Friday April 17, 2015, the team met with Mr. Thomas Lafen, District Support Manager of New England Terminal Operations, Air Traffic Services at T.F. Green Airport's Air Control Tower. Mr. Lafen was able to give the team a better understanding of air traffic control protocol regarding all flight operations. He explained that "nothing gets into a five mile radius without it being known." However, he made it clear that drones were the exception to this rule. Drones frequently travel into critical airspace undetected until they are in dangerous territory. During the tour of the air traffic control area the team was able to visit the radar room and see all flight information of every plane entering and exiting the regional approach control and center control regions. Approach control regions were explained to be the areas in which flight below 10,000 feet and speed below 250 knots (approximately

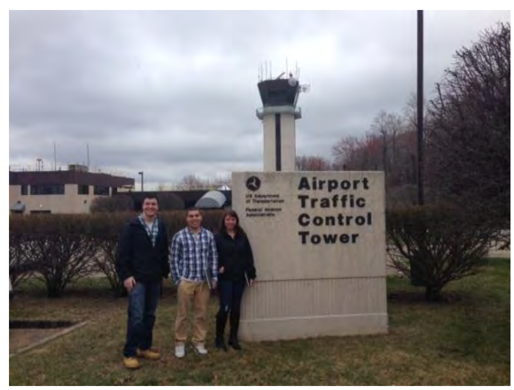

Figure 17: Team visit to T.F. Green Air Traffic Control.

287.7 mph) is controlled. Center control areas cover wider ranges and monitor flight at altitudes from 10,000 feet up to outer space and speeds greater than 250 knots. The closest center control location to T.F. Green Airport is in Boston, MA at Logan International Airport. The team was also able to view the technical operations room and the control tower from which planes could be seen entering and exiting at each runway. Overall, the tour proved to be a very positive experience as ATC staff were very intrigued by the products and their ability to address a large problem the FAA is currently facing.

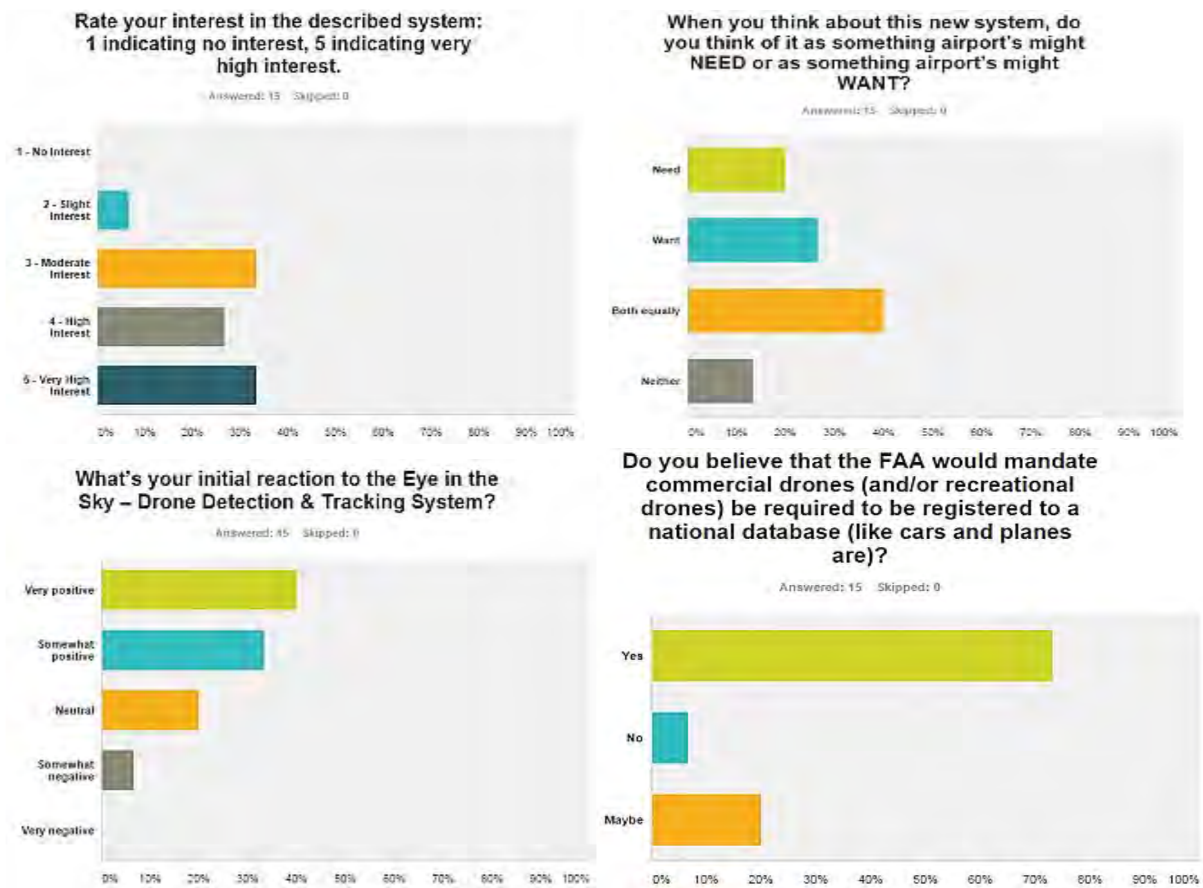

Figure 18: Several survey questions results.

As part of the design process, the team created and distributed a product survey for both the Drone Detection and Tracking System and the Drone Operator Notification System as seen by Fig. 19. The surveys' goal was to obtain a better understanding of the current aviation field's enthusiasm and acceptance for the two developed systems. The surveys were sent out to airport officials and executives, airport operations staff, air traffic controllers, pilots, drone manufacturers, hobbyists and organizations, as well as aviation educators and others involved and related to the aviation and drone markets after emailing many expert advisors provided by the competition and Mr. Tim Funari, FAA ATC Specialist, Mr. Chris Oswald, VP of ACI-NA Safety & Technical Operations, and Ms. Melisa Sabatine, VP of AAAE Regulatory Affairs. The team received extremely positive results with the majority of the contributors expressing great interest in the systems and believing that the *Eye in the Sky* products would be an asset in addressing the problem of drones entering critical airspace. The surveys consisted of questions including how respondents rated their excitement for the systems, how innovative the systems are, if current means are used, initial reactions, desired system features, and optional comments and concerns. The surveys have been valuable to the team as it enabled the participation and inclusion of the aviation community and industry around the country and allowed the team to gage its acceptance and excitement for the developed systems. This interaction with the industry provided the team with insight into possible future revisions and/or enhancements to both systems including adapting the Drone Detection and Tracking System with ADB-S technology to provide drone flight information directly to pilots.

7 Description of Projected Impacts

7.1 Financial Analysis

After finishing the design process of the two systems, the Drone Detection and Tracking System and Drone Operator Notification System, a cost analysis was completed which analyzed project budget, cost/benefit analysis, market demand, and mass production. To obtain funding for the project, the team applied for a $1400 URI Undergraduate Research Grant. Funding was awarded in January at which time purchasing of required materials and components began. The URI Mechanical Engineering Department also contributed $500 to the project budget covering costs relating to prototyping, design, materials, testing, and initial proof of concept requirements.

Presented in Table 3 is a summarized cost breakdown of the two systems developed. The total cost for the Drone Detection and Tracking System is approximately $1,279.69 and the total cost of the Drone Operator Notification System totals $307. It should be noted that despite the number of RFID readers used in the entire system, the reader software package only needs to be purchased at a one-time price of $3,500.00.

Table 3: Summarized total project costs (Note: not all components listed in table).

Comprehensive Budget					
Costs: RFID Drone Detection System					
Component	**Model, Part #**	**Supplier**	**Quantity**	**Cost**	**Notes**
2.45 GHz Gain Adjustable Active RFID Reader	217001	GAO RFID, Inc.	1	$695.00	Have one we can use
2.45 GHz Active RFID Tag	127001	GAO RFID, Inc.	1	$20.00	Have 4 we can use
RFID Software System	Demo kit	GAO RFID, Inc.	1	$0.00	Actual software package = $3500.00
RFID Antenna Connectors	S-311-G-R, 132170	Jameco Electronics	1	$10.44	Conn, SMA, male to male, Conn, RF, SMA, Adaptor
altE Poly 30 Watt 12V Solar Panel Kit	ALT30-12P	altE Store	1	$69.49	
Morningstar Sungaurd 4.5A 12V Charge Controller	SG-4	altE Store	1	$0.00	PROMOALT30/SG4 (free with solar panel kit) ($27.22 separate)
Ironridge Single Arm Side of Pole Mount, 14"	UNI-SA/14	altE Store	1	$50.50	
ExpertPower 12V 12AH Sealed Lead Acid Battery	B00A82A2ZS	Amazon	1	$23.99	12V; 12 AH; .250" Tab Terminals; BLMFM12_12
Submersible Enclosure with Hinged Cover	7740K211	McMaster-Carr	1	$115.70	Padlockable, 13-1/2"x13-1/2"x6-1/4", Gray
Multipurpose 6061 Aluminum Tube	9056K4	McMaster-Carr	1	$61.60	2" OD, .125" Wall Thickness
Multipurpose 6061 Aluminum	9246K63	McMaster-Carr	1	$68.38	Multipurpose 6061 Aluminum, 1" Thick, 12" x 12"
			System Total:	**$1,279.69**	

Costs: Drone Operator Notification System					
Component	**Model, Part #**	**Supplier**	**Quantity**	**Cost**	**Notes**
Arduino Uno -R3	DEV-11021	SparkFun	2	$49.90	$24.95 each
GPS Receiver - EM-506 (48 Channel)	GPS-12751	SparkFun	1	$39.95	
GPS Shield	GPS-10710	SparkFun	1	$14.95	
Sparkfun Xbee Shield	WRL-12847	SparkFun	2	$29.90	$14.95 each
XBee Pro 60mW PCB Antenna - Series 1 (802.15.4)	WRL-11216	SparkFun	2	$75.90	$37.95 each
LED - Basic Red 5mm	COM-09590	SparkFun	1	$0.35	
Serial Enabled LCD Kit	LCD-10097	SparkFun	1	$24.95	
Piezo Speaker - PC Mount 12mm 2.048kHz	COM-07950	SparkFun	1	$1.95	
			System Total:	**$307.00**	

It was determined that for T.F. Green State Airport, Rhode Island's largest airport, to achieve 100% perimeter coverage with the chosen RFID reader, approximately 24 systems linked together in one cohesive detection system for would be required. This would equate to a total projected system cost of $34,212.56. This cost does include the one time purchase of the RFID reader software but does not include extra manufacturing costs, construction, and implementation costs. Moreover, system requirements may require other situational costs relating to airport IT infrastructure. However, after consulting with the sponsors at RIAC, they stated they would only require the detection system be employed at the ends of each runway or out in the airport annex areas. This decreases the system requirement from 24 systems to only 8, thereby reducing the total cost to $13,737.52. If comparing the cost of this system to the costs of foreign object debris damage to aircraft while on the ground or in the air, the cost of possible damage far exceeds the cost for this system. Boeing estimates that a commercial aircraft engine with damage caused by foreign objects can result in damage costs up to 1 million dollars [25]. Moreover, according to an FAA Fact Sheet, Boeing also estimates that 4 billion dollars a year is spent on FOB damages [26].

With the acceptance of our drone detection and tracking system as the national standard for detecting drones around the vicinity of critical airport airspace, the mass production of the drone detection system would greatly reduce cost. It could be possible that if the system were to be implemented at many of our nation's airports that a special price could be secured with the companies supplying components. These parts are easily obtained in bulk dramatically reducing the cost per component. Moreover, GAO RFID, Inc. states that for any order over 10 RFID systems, each reader's cost is reduced by 10%. Lastly, depending on FAA instituted penalties and fines for drone flight infractions drone operators might demand that drone manufactures incorporate our independent Drone Operator Notification System into their drone system architecture as a standard feature. If this occurs, the cost of the system would essentially become zero as most drones and drone remote controls are already equipped with the necessary components for system function. These components however are not coded to do what the Drone Operator Notification System is coded to do, which is what makes the system so unique. The developed coding logic provides a solution to a problem that most drone systems do not provide. It is difficult to determine the projected costs exactly, including construction and any additional IT infrastructure required, as total cost highly dependent on the size of the airport purchasing the Drone Detection System and its desired level of coverage. For example however, the team conservatively estimates that for T.F. Green Airport, estimate construction costs for 8 systems would equal approximately $200,000-$500,000. The system was designed with virtually no maintenance requirements except to replace the battery after 5-7 years. Annual maintenance costs are therefore approximated as equaling $100-$500 including the personnel pay.

Lastly, the FAA and state governments would be burdened by the cost for regulating, operating, managing, and enforcing the drone registration process. The cost to register a commercial drone would be comparable to that for registering an automobile and would be subsidized by the company, organization, entity, or person which desires to register the drone.

7.2 Product Market and Product Demand

As mentioned in the Section 1.1, problem statement and background, with the almost constant reporting of close call collisions between drones and manned aircraft, and the reckless flight practices by drone operators, the need for an effective drone detection system around our nation's airports is of upmost importance. With this data presented, it is highly evident that the Drone Detection System around the vicinity of an airport is critical. This type of system is not currently in place and there is no product on the market that satisfies this ability to the degree to which our system does. Further, the Drone Operator Notification System provides a solution that no other product provides as well.

7.3 Economic Impact

Presented below are a few more statistics regarding the burgeoning drone market. These statistics will all but disprove why a drone detection system around critical airspace locations is necessary and will flourish. With the FAA mandated by Congress to incorporate drones into the NAS by the end of 2015, the unmanned aerial vehicle market is expected to increase dramatically. According to the Association for Unmanned Vehicle Systems International, after the first three years of integration into the NAS, the expected economic impact that the drone market will have on the US economy is about $13.6 billion with added jobs tallying at 34,000 manufacturing jobs and 70,000 new jobs [27]. By 2025, the market will have added 103,776 jobs within the United States and generated $82.1 billion [27]. Figure 19 depicts an estimated market demand for recreational and commercial drones through 2025, years are on the x-axis and quantity of drones is along the y-axis. As can be seen by Figure 19, the largest market demanding commercial drones is the agriculture market followed by public safety. However, there will still be a steady increase of approximately 15,000 drones per year demanded for any other use [27]. Chris Anderson, the CEO of a major recreational drone manufacturing company, 3D Robotics, was recently interviewed saying that his company produces at least one thousand drones or drone guidance systems per month with each drone costing customers at least $600 per system [28]. All of these drones will be subjected to FAA regulations and federal laws. Under our proposed program of drone integration, each will be required to be registered with an RFID tag for detection. Moreover, many of the owners of these drones may desire a device that informs them of the drone's GPS location, altitude, and proximity to critical airspace locations; this is where our Drone Operator Notification System is utilized. With hundreds of thousands of drones on the market each year, the opportunity for sales should be steady if marketed correctly. Our Drone Detection System is currently marketed towards the aviation industry; however, as seen by these figures, the device has relevance to anyone or any company looking to keep tabs on drones flying in its vicinity including government and military contracting company facilities, sensitive corporate and creative campuses, celebrity homes, large entertainment complexes and events, etc.

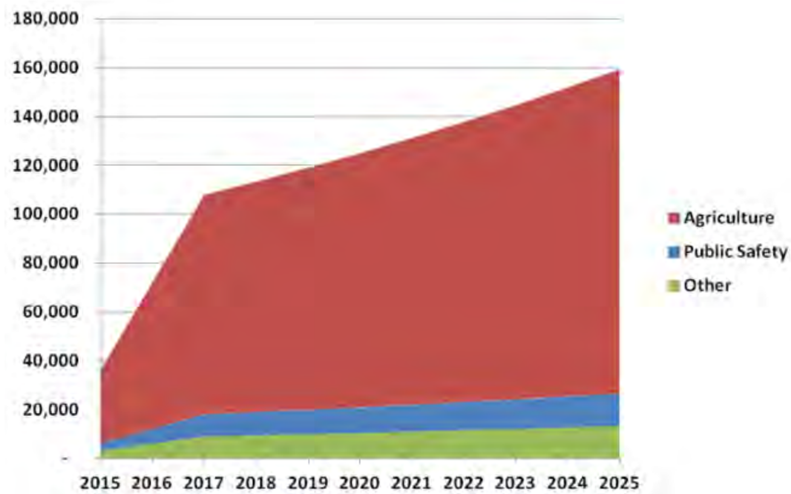

Figure 19: Estimated number of drones demanded by market through 2025 [27].

Some more exciting statistics arise when research is done within the air traffic control equipment industry. A report states that by the year 2020, the air traffic control equipment market will increase to approximately $5.52 billion annually [29]. With air traffic expected to double over the next 15 years, the market will grow steadily with a compound annual growth rate of 4.82% over the next six years [29]. The entire air traffic management and control market is expected to grow at a compound annual growth rate of 16.7% through 2018. With these statistics presented and the market analysis showing both the drone and air traffic control markets increasing dramatically, the *Eye in the Sky* Drone Detection and Tracking System has a highly optimistic future. This is compounded with the fact that in the United States alone there are 545 commercial airports and 18,911 total general aviation (GA) airports as of 2013 according to the US Bureau of Transportation Statistics [30]. The Drone Detection System is most likely to be purchased by commercial airports. This is an assumption made by the team assuming that commercial airports typically have many more operations per day and have a much greater budget than smaller GA airports. However, that is not to say that GA airports, or even private airports, would not consider the system. Figure 20 is a map of commercial and GA airports within the United States, where the blue dots are GA airports and the red dots represent commercial airports [31]. According to the FAA, in 2011, approximately 50,000 flights per day occurred within the United States [32]. There are hundreds of towered airports and tens of thousands of facilities across the country which house and/or use air traffic control equipment [32]. With so many manned aircraft operations occurring and continuing to increase every year, coupled with the dramatic increase in recreational drone usage, and eventual commercial use of drones, the need and opportunity for acquisition of the Drone Detection System and Drone Operator Notification System is unquestionable.

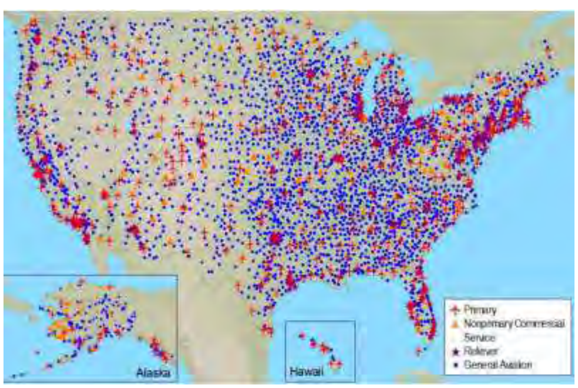

Figure 20: Airports within the United States [31].

7.5 Societal Impact

The impact on society that the Drone Detection and Tracking System and the Drone Operator Notification System will bring is rather significant. The FAA plans to incorporate drone usage for commercial purposes by the end of 2015. Our system using RFID tags would allow the FAA to create a national database for drones being used for commercial uses, based on RFID tag number, and detect and track which drones are being flown within a dangerous vicinity to critical manned aircraft flight paths. This is a huge opportunity for improved safety measures and situational awareness that currently is unavailable. There are a few systems under development that can detect drones, but they do not provide the opportunity to detect a specific drone and acquire information about when, where, and how long the drone crossed into the critical area.

Regardless of the drone in use, the Drone Operator Notification System has the ability to send the operator information regarding altitude, GPS location, and warn the operator if he or she is flying the drone within the 5 mile airport safety radius or above 400 feet. The Drone Operator Notification System should be implemented into all drones as a standard feature to increase drone operator situational flight awareness as no drone provides this valuable safety information and warning to its operator. This knowledge will be very valuable if flight infractions in critical areas were to become more strictly enforced with penalties and fines.

Both systems will increase safety both to the UAS and manned aircraft as well as to everyone else in the vicinity of the flying drone because of the increased situational awareness and information being sent to the drone operator and airport. This increased safety will help to reduce close calls that not only could cost companies and individual citizens thousands or millions of dollars in damages, but more importantly, to mitigate any possible loss of life.

7.6 Political Impact

Perhaps the greatest impact that this device will have is on a political scale. With Congress demanding the FAA to outline and develop a plan for the inclusion of commercial drones into the NAS by the end of 2015, the FAA has been trying to define its role and authority over the use of drones with its *Interpretation of the Special Rule for Model Aircraft* [7]. This interpretation is interpreted from Section B of the *FAA Modernization and Reform Act of 2012* [6]. With recent increased regulations on drone usage, hobbyists and UAS lobbyists have increased their opposition towards the FAA's attempts for increased control. However, the NTSB recently ruled that the FAA does in fact have authoritative jurisdiction over drones. Current wording states that the FAA has jurisdiction over all aircraft. According to the definition as outlined in the law, "…'aircraft' is any device used for flight in the air." [10] The FAA also has the authority to institute a policy that outlines what an operator must do if he or she plans to fly the drone within areas of critical airspace. Currently, guidelines state that anyone planning on operating a UAS system within a five mile radius around an airport must call and inform the tower or airport operations of their activities. The law issues guidelines regarding safe flying practices and a mandate that the UAS not be flown higher than an altitude of 400 feet above ground. Many people either do not know of the law or simply disregard it. With no current real effective way for enforcement, the FAA needs a product that allows it to detect and track if a drone is flying within critical airspace. *Eye in the Sky* allows for this to be possible on an initial, low cost scale. By September 2015, with a national plan to include commercial drones into the NAS, the Drone Detection System would be included as part of a new national drone registration process. Each commercial drone, and possibly future recreational drones as well, would be required to register the drone with the FAA like any manned aircraft, and have an RFID tag embedded within the drone's system architecture. This tag would be placed during drone manufacturing. Each tag will act as the drone's "license plate" or N-Number. When the FAA incorporates commercial drones into the NAS, the tag required to be on each drone as per FAA registration regulations would allow for easy detection of what drone was flown within critical airport airspace and, for enforcement purposes, to whom the drone belongs.

7.7 Ethical Considerations

One of the main ethical concerns that arise with the development of the Drone Detection and Tracking System is regarding drone operator privacy. The concern of intrusion, greater government control and oversight, and privacy loss issues can be mitigated however with careful use and clear guidelines as to the ethical and correct uses of the detection device. The RFID tags in use can only be detected when the drone comes into the range of the RFID reader which would be limited to airports and possibly, any government and military facilities. This should assure drone operators that there is no way for their drone to be detected and tracked beyond the range of the RFID reader.

8 Conclusion

After rounds of research and testing, the Drone Detection and Tracking System and Drone Operator Notification System designs are engineering successes that have incorporated all of the design specifications into an effective and efficient design. The team has extremely high hopes for the aviation industry's regard and acceptance of the designed products, as evidenced through the developed product surveys. The FAA continues to make ample progress towards commercial drone implementation into the NAS which only brings each system one step closer to reality and being product leaders in a new, large, and burgeoning marketplace.

9 Appendices

Appendix A: Contact Information

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Appendix B: Description of University

University of Rhode Island

The University of Rhode Island, founded in 1892, is Rhode Island's public, learner-centered research university, holding accreditation from the New England Association of Schools and Colleges (NEASC). It is the only public institution in the state offering undergraduate, graduate, and professional students the distinctive educational opportunities of a major research university. The main campus is on 1,200 acres in Kingston, Rhode Island with three satellite campuses: Feinstein Providence Campus, Narragansett Bay Campus, and the W. Alton Jones Campus. As of this past fall, there are 13,398 undergraduate students and 3,053 graduate students, of those students, 9,882 are in-state residents and 6,569 are from out-of-state or international. There are over 80 majors offered at the university from eight degree granting colleges: Arts and Sciences, Business Administration, Continuing Education, Engineering, Environmental and Life Sciences, Human Science and Services, Nursing, and Pharmacy.

College of Engineering

The College of Engineering at the University of Rhode Island has the vision to be "a global leader in engineering education and research." Their diverse community of scholars, students, and professional staff is devoted to the development and application of advanced methods and technologies. The college offers eight different engineering programs to its undergraduates: Biomedical, Chemical, Civil, Computer, Electrical, Industrial and Systems, Mechanical, and Ocean. The college, accredited by the Accreditation Board for Engineering and Technology (ABET) educates all focuses to be creative problem solvers, innovators, inventors, and entrepreneurs and to utilize those skills in the advancement of our society's knowledge.

Appendix C: Non-University Partners

Rhode Island Airport Corporation

The Rhode Island Airport Corporation (RIAC) is a quasi-governmental agency of the state of Rhode Island. Its purpose is to manage all publicly owned airports within the state. Founded in 1992 as a semiautonomous subsidiary of the Rhode Island Port Authority, which is currently known as the Rhode Island Economic Development Corporation, RIAC is responsible for the design, construction, operation, and maintenance of the six RI state-owned airports. It also supervises all civil airports, landing areas, navigational facilities, air schools, and flying clubs throughout Rhode Island. The six state-owned airports include T. F. Green Airport, the state's commercial, and largest, airport with scheduled air carrier service, and the general aviation airports located in Block Island, Newport, North Central, Quonset, and Westerly, Rhode Island. RIAC is governed by a seven member Board of Directors, six of which are appointed by the Governor, and the last appointed by the Mayor of the City of Warwick. The RIAC President/CEO manages and oversees its day-to-day operations.

Appendix E: Evaluation of Experience

Students:

Krista Brouwer –

The Airport Cooperative Research Program (ACRP) University Design Competition for Airports Needs has provided an enlightening and meaningful experience over the course of the past year. Over the course of the competition it became evident just how much goes into the development of a product. Every experience, from the preliminary planning phase to the final redesign phase of the product, utilized skills that had been acquired throughout the course of my entire college experience. Having the ability to apply such skills during the ACRP University Design Competition was exceptionally gratifying. However, there were undoubtedly a number of challenges that arose over the course of the year while working on developing the product. Most importantly the team was forced to learn how to program the Arduino components to measure and relay the appropriate information to the drone operator. Only one of the other team members had any programming experience, but had limited prior experience in working with Arduino systems. In order to overcome this challenge, the team purchased The Arduino Cookbook, a textbook that aided in decreasing the learning curve that had to be overcome when learning how to program in Arduino. In addition to this, multiple team members spent a great deal of time researching and learning proper Arduino coding logic. A second challenge faced by the team came forth in the testing phase of the product. While evaluating the read range capabilities of the system it became evident that the RFID tags were not functioning to their full potential. After a great deal of research the team learned that the problem was due to drained batteries within the RFID tags themselves. Therefore, it was required that new tags be purchased; a process that set the team back in testing by more than a week. In order to stay on track and not lose valuable time while testing was at a standstill, the team worked diligently towards completing a great deal of the documentation necessary for the design competition.

In order to develop a hypothesis the team first considered existing technologies applicable to the team's overall goals and the abilities of such technologies to address the issue at hand; detecting and tracking drones flying in critical airspace. In addition to this, the team evaluated the limitations of all considered technologies as the scope of the project would require optimum functionality of all chosen components (i.e. maximum read range, highest operable temperature range, optimum battery life, etc.). In order to determine which technologies, components, and designs were most conducive to achieving the goals of the team, each team member generated a number of concepts that could potentially be integrated into the system, and no two concept ideas were the same between team members. This made available mass amounts of unique designs from which more ideas could spawn and potential problem solutions could be found. It was at this stage that a general hypothesis was determined. The team believed that with the proper technology and system designs, it would become possible to detect drone activity in critical airspace prior to the point at which a "close call" or other dangerous interaction could occur. In order to quantify appropriate distances/altitudes at which detection would be critical the team turned to current FAA regulations and integrated a number of the specifications laid forth in such regulations into the design specifications the team wished to achieve.

Throughout the process of developing the product the team turned to industry officials numerous times. Most importantly, the team was never without direct support of the sponsors from the Rhode Island Airport Corporation (RIAC). The team's sponsors were always readily available to offer support and guidance, or answer any questions that were asked. On multiple occasions the RIAC sponsors either gave tours or aided in facilitating tours of critical areas of the airport that greatly assisted in helping the team to develop a well-engineered product. In addition to participation by the RIAC sponsors, the team was able to interact with industry officials as they contributed to the project by taking a brief survey associated with each of the two systems developed (the Drone Detection and Tracking System, and the Drone Operator Notification System). Feedback was received from airport officials, drone organizations, air traffic control officials, and a number of other distinguished members of the aviation community.

Upon completion of this project, a vast amount of invaluable knowledge has been acquired. The project required that students learn how to operate not as four individuals, but as a whole with a common goal. Personally, I was able to learn that the final product will often have capabilities, appearances, and components that were nowhere to be found in the original design plans. Having the ability to watch designs, plans, and eventually, the overall product evolve as the year progressed was a valuable lesson learned. It became essential to understand that as a project progresses, initial designs may no longer suit the needs of the system as a whole or the people working on or with the product, and, therefore, must be altered along the way. This lesson alone will be valuable when moving into the workforce. In addition to this lesson, I furthered my abilities in working with CAD software such as SolidWorks, increased my machining capabilities, expanded my knowledge of the aviation industry, and learned to work well with a team of people having different personalities and different skill sets. These are all skills that will be extremely beneficial moving forward.

Thomas Cottam –

The FAA Design competition provided me with a very meaningful learning experience. This project has helped me better understand how much time and research goes into the design and implementation of a new device. It also showed me how it is important to define a problem and then form multiple solutions to this problem. One of our team's challenges was to first come up with a device that could be both easily and quickly implemented into airports in order to solve an important airport problem. Through brainstorming and working closely with our sponsors and professor, we were able to come up with the idea of our Drone Detection and Tracking System. Another challenge in completing our device was obtaining and creating the electronic and coding components needed to make our device function. As mechanical engineers, we overcame this challenge by talking with electrical engineering professors and reading multiple textbooks about connecting electrical components and writing computer codes to control our device.

The process that our team used to develop a hypothesis was for each member of the team to create a table of 30 possible solutions to our defined problem. This meant that since there are four members in our team we had 120 possible solutions. After talking and sharing our ideas with each other, we decided on four main solutions. These solutions were discussed at length and the team decided on which one of the four had the most benefits. Another rewarding and valuable experience was participating in with industry members through our interactions with our project sponsors at RIAC, completing product surveys, and touring T.F. Green, Westerly, and Quonset Airports. Touring the airports not only gave us an inside look about how the airports function but also about how our device could be used to solve the airport's drone issues. Our sponsors could also answer all of our questions about how the device could be implemented in airport security. Participating in with industry was very helpful and gave us new insight about our project.

Overall, this project taught me many things as well as increasing my skills and knowledge needed for entering the workforce. It taught me how to define a specific problem in industry and come up with ways/solutions to solve it. It also helped me understand the concept of a project plan and how it is necessary to meet goals and deadlines in order for the project to stay on track. Finally, it improved my ability to work in a team efficiently and understand that there are many considerations that must go into a device including not only engineering analyses but also political, environmental and economic impacts.

Catherine LiVolsi –

The Airport Cooperative Research Program (ACRP) provided for me a meaningful learning experience. It gave me a look into how the design process is incorporated with application into the market. The amount of research involved with having to know a specific problem to address with the airport gave me a broader understanding of how much work it takes to simply have an open, creative mind. The experiences gained through this opportunity will surely come again in numerous different applications to my life.

In the very beginning, it was hard to determine exactly what area of the airport needed improving; at one glance it seemed as though there would be no better way to do things than as they were. It was difficult to determine what problem to address, and if the problem was within reason for our purposes. In addition to that, it was a challenge to identify a problem that dealt with skills in our field, that we would have the appropriate knowledge to successfully address. Many of the initial problems we identified were better dealt with in a field outside of ours. We dealt with these issues by a very in depth analysis of the process of solving the problem. We had many discussions about what would be required in order to make the solution a success, and how feasible it was for us to accomplish the goal given our field of engineering. We persisted through the problems identified and solutions until we came to a conclusion that a new start was needed. Through many hours of research, we settled on a more suitable project to focus on.

Initially, after a potential problem was identified, every member of the team came up with 30 ideas for a potential solution, which gave in total 120 solutions. Every one of these solutions was ensured that it was a different idea. From here, we took only the solutions that we thought were the best, and did further research into the technology for each item. Alongside this, extensive research was done into the prevailing problem, and all issues surrounding it in the most general and widespread terms, i.e. legality, social, political, and societal impacts, and separate uses for our proposed solution, among other things.

The participation of the Rhode Island Airport Corporation was an important asset as it provided us with a real perspective on the interaction with industry. It was important to be able to communicate with members of industry and to have their input in our project. It helps to have an outside opinion on the project itself that involves members who have had many years of experience working outside of the academic world. Where solutions may seem relevant and appropriate on paper, in a strictly analytical sense, they may not be entirely practical or possible in a real life setting. It was important that we had access to those members of industry who could give us that exterior viewpoint.

From working on this project, I have learned a great deal of things that will inevitably help me in the future. The process of having to work closely in a group and interact with professionals, to locate a problem and to create a solution, to learn a programming language I was moderately familiar with, and to present our work and progress in a technical, yet interesting way were all great skills to learn and to be able to use. Especially in presenting our work, communication is essential in any situation and to be able to successfully and understandably get our ideas across is vital. I know that the experiences I have taken away from this project will help me in all areas of my life for the future.

Stephen Pratt –

The entire process, from initial conceptualization to final product assembly and testing, provided a unique and very educational experience. By participating in the ACRP University Design Competition, I have learned extremely valuable and important skills, tactics, and processes involved in any design project. Being paired up with random students to complete the project was both exciting and a big learning experience. This process has really taught me the value involved with being a team player, good communication, and time management. Lastly, the interaction with the aviation industry was also extremely rewarding. One of the primary reasons why I wanted to compete in this competition is because I have always been fascinated with airplanes. Since a child, I have dreamed of designing commercial or military aircraft or spacecraft. I remember sitting along the fence line at T.F. Green and attending airshows at Quonset. Being able to tour these facilities and air traffic control centers was a once in a lifetime opportunity that most of the public never get to see first-hand and experience. The professional environment working alongside RIAC officials and other aviation industry members provided vital experience to future career endeavors.

Over the course of the design process, the team and I faced various challenges that had to be overcome. The initial huge challenge the team faced was developing a project idea. The team spent much time and effort researching past projects and current aviation issues in an effort to not repeat past projects, but also find a problem with an effective solution by the team. The team researched online, looked through past ACRP projects, and spoke various times with the sponsors at RIAC. In the end, a problem statement was written and 120 concepts were developed to solve this problem. After several rounds of concept reviews and developing a QFD, pros and cons list, and other elimination/evaluation techniques, the team decided on the current project solution. Further, one of the largest challenges to the team was the electrical engineering and computer programming aspects of the design. The team spent some effort in deciding how best to wire the Drone Detection and Tracking System components so that the RFID reader would always be supplied with power. Moreover, the design of the Drone Operator Notification System was almost entirely electrical engineering and computer science based. The design of the system and choosing which components to utilize as well as connecting these components into a cohesive system was challenging, but even more daunting was the computer programming involved in getting the components to do what was desired. The team sought out expert help for guidance and questions and referenced multiple Arduino coding textbooks and resources. In the end, after much hard work, and debugging iterations, the Drone Operator Notification System was coded and tested successfully

The hypothesis development process involved researching various forms of technology that are employed for different applications but that are similar to the problem at hand and that would conceivably be a viable solution if used for our drone application. The team was extremely interested in RFID technology as the team hypothesized it would work for the aviation industry as it has been used for vehicle tracking and monitoring of car rental vehicles. The team conducted research into various other components and types of technology that would be applicable to the system and which would need to be included into the Drone Detection System.

Participation with industry was extremely enlightening, entertaining, and rewarding. It was without a doubt meaningful, appropriate, and useful. As part of the URI Capstone Design project, each team of students is provided with project sponsors from the company with which the problem originated from. The RIAC sponsors were extremely generous in their time. They made every visit we made to T.F. Green, Quonset, and Westerly extremely fun and interesting.

The sponsors introduced us to other aviation officials and provided access to facilities and resources most other people never get to see and work with. Besides the suggestions and guidance, the sponsors were instrumental in the team's understanding of airport operations, especially through the various tours provided including airport facilities, airfields and runways, air traffic control, etc. Lastly, all of the industry personnel whom participated in the product surveys provided a tremendous help to the team's ability to gage industry support and better refine the products through the additional comments that were left.

As elected team leader, this process has significantly developed my leadership and communication skills. Having to delegate and assess the team strengths and weaknesses and plan how the project would proceed was extremely daunting yet very rewarding. Moreover, the project introduced me to new software packages and types of technology that I had yet to work with or understand prior to the project. It taught me much about how the aviation industry operates and how to systematically approach a problem from conceptualization to product realization. All of the experiences, skills, and lessons I have learned from this project will definitely help me in my future career and study.

Advisor:

THE UNIVERSITY OF RHODE ISLAND
COLLEGE OF ENGINEERING

THINK BIG WE DO

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April 23, 2015

To: Airport Cooperative Research Program: University Design Competition for Addressing Airport Needs, 2014 – 2015 review panel

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

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

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

The student team has done an excellent job in thoroughly exploring their problem (*Eye in the Sky – Drone Detection & Tracking System*). They have designed a practical and very economical solution that is relatively inexpensive to build and implement. They have prototyped their solution and have obtained excellent results to pursue the creation of a marketable product. Their survey of drone operators, airport operators, and airport and airline executives shows high interest in this product. We are in the process of a university level intellectual property disclosure on this design with a subsequent patent application. This is exactly the type of process and experience that we expect for our students on design projects.

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

Sincerely,

Bahram Nassersharif

Bahram Nassersharif, Ph.D.
Distinguished University Professor

The University of Rhode Island is an equal opportunity employer committed to the principles of affirmative action.

Appendix F: Resources

[1] Unmanned Aircraft Systems (UAS) Comprehensive Plan. N.p.: n.p., n.d. THE JOINT PLANNING AND DEVELOPMENT OFFICE, Sept. 2013. Web. 2 Nov. 2014. <https://www.faa.gov/about/office_org/headquarters_offices/agi/reports/media/UAS_Comprehensive_Plan.pdf>.

[2] Whitlock, Craig. "Close Encounters with Small Drones on Rise." *Washington Post*. The Washington Post, 23 June 2014. Web. 31 Oct. 2014.

[3] Van Vuern, A. J. "Advisory Circular 91-57." ADVISORY CIRCULAR (1981): n. pag. Federal Aviation Administration. Federal Aviation Administration, Department of Transportation. Web. 2 Nov. 2014. <http://www.faa.gov/documentLibrary/media/Advisory_Circular/91-57.pdf>.

[4] "Next Generation Air Transportation System (NextGen)." Next Generation Air Transportation System (NextGen). Federal Aviation Administration, 11 Mar. 2015. Web. 21 Apr. 2015. <https://www.faa.gov/nextgen/>.

[5] Federal Aviation Administration. FAA Design Competition for Universities. [Online] [Cited: September 19, 2013.] http://faadesigncompetition.odu.edu/Apps/FAAUDCA.nsf/2013_DesignComp_Booklet.pdf?OpenFileResource.

[6] H.R. 658, 112 Cong., 72 (2012) (enacted). Print.

[7] Barbagallo, John, and Michael P. Huerta. "Interpretation of the Special Rule for Model Aircraft." N 8900.268 - Education, Compliance, and Enforcement of Unauthorized Unmanned Aircraft Systems Operators (2014): n. pag. Federal Aviation Administration, 15 July 2014. Web. 10 Dec. 2014. <http://www.faa.gov/documentLibrary/media/Notice/N_8900.268.pdf>.

[8] Huerta, Michael P., comp. FAA's NextGen Implementation Plan, August 2014. Washington, D.C.: Federal Aviation Administration, NextGen Integration and Implementation Office, 2009. FAA.gov. Federal Aviation Administration, Office of NextGen, Aug. 2014. Web. 3 Dec. 2014. <https://www.faa.gov/nextgen/library/media/NextGen_Implementation_Plan_2014.pdf>.

[9] Lowy, Joan. "AP Exclusive: Drone Sightings up Dramatically." AP Online. AP.org, 12 Nov. 2014. Web. 10 Dec. 2014. <http://bigstory.ap.org/article/99d03e9f1adb46519f39e5b2b6655dfc/ap-exclusive-drone-sightings-dramatically>.

[10] Nicas, Jack. "NTSB Rules Drones Are Aircraft, Subject to FAA Rules." The Wall Street Journal. The Wall Street Journal, 18 Nov. 2014. Web. 10 Dec. 2014. <http://www.wsj.com/articles/ntsb-rules-drones-are-aircraft-and-subject-to-faa-rules-1416326767>.

[11] Rose, Charile. "Amazon Drones: Amazon Unveils Futuristic Delivery Plan." CBSNews. CBS, 60 Minutes, 13 Dec. 2013. Web. 10 Dec. 2014. <http://www.cbsnews.com/news/amazon-unveils-futuristic-plan-delivery-by-drone/>.

[12] Sankin, Aaron. "Disney Patents Drone Technology That's Still Technically Illegal to Use." The Daily Dot. The Daily Dot, 27 Aug. 2014. Web. 10 Dec. 2014. <http://www.dailydot.com/politics/disney-drone-patent/>.

[13] Lowy, Joan. "FAA Issues Commercial Drone Permits to 4 Companies." ABC News. Associated Press, 10 Dec. 2014. Web. 10 Dec. 2014. <http://abcnews.go.com/Politics/wireStory/faa-issues-commercial-drone-permits-companies-27498967>.

[14] "Amazon Gets Experimental Airworthiness Certificate." Amazon Gets Experimental Airworthiness Certificate. FAA, 19 Mar. 2015. Web. 09 Apr. 2015. <http://www.faa.gov/news/updates/?newsId=82225>.

[15] Nicas, Jack, and Andy Pasztor. "FAA Proposes Rules to Allow Commercial Drone Flights in U.S." WSJ. The Wall Street Journal, 15 Feb. 2015. Web. 09 Apr. 2015. <http://www.wsj.com/articles/obama-issues-privacy-rules-for-government-drones-in-u-s-1424015402?KEYWORDS=FAA%2BCommercial%2BDrone%2BFlights%2Bin%2BUS>.

[16] Kuhn, Gerald. Modular Counting System. Gerald Kuhn, assignee. Patent 3,549,869. 22 Dec. 1970. Print.

[17] Brown, Alison K., and Mark A. Struza. GPS Tracking System. NAVSYS Corporation, assignee. Patent 5,379,224. 3 Jan. 1995. Print.

[18] Roesner, Bruce B. Vehicle Detection System with RFID-Based Location Determination. Federal Signal Corporation, assignee. Patent US 2012/0280836 A1. 8 Nov. 2012. Print.

[19] United States. Federal Aviation Administration. INTRODUCTION TO SAFETY MANAGEMENT SYSTEMS (SMS) FOR AIRPORT OPERATORS. Washington, DC: FAA, 2007. Print. AC 150/5200-37.

[20] United States. Federal Aviation Administration. Air Traffic Organization. Safety Management System (SMS) Manual. 4th ed. Washington, DC: FAA, 2014. Print.

[21] NIOSH. (2009, June). *NIOSH Lifting Equation.* Retrieved from ttl.fi: http://www.ttl.fi/en/ergonomics/methods/workload_exposure_methods/table_and_methods/Documents/NioshLiftingEquqtion.pdf

[22] "2.45 GHz Gain Adjustable Active RFID Reader or Receiver." GAO RFID Inc. GAO RFID, Inc., n.d. Web. 18 Apr. 2015. <http://gaorfid.com/product/reader-receiver-gain-adjustable-active-2-45-ghz-rfid/>.

[23] "2.45 GHz Active Strip RFID Tag or Transponder." GAO RFID Inc. GAO RFID, Inc., n.d. Web. 18 Apr. 2015. <http://gaorfid.com/product/tag-transponder-active-strip-2-45-ghz-rfid/>.

[24] "Submersible Enclosure with Hinged Cover." McMaster-Carr. McMaster-Carr, n.d. Web. 15 Dec. 2014. <http://www.mcmaster.com/#7740k22/=v1hyc9>.

[25] "Foreign Object Debris." Foreign Object Debris. The Boeing Company, n.d. Web. 16 Nov. 2014. <http://www.boeing.com/commercial/aeromagazine/aero_01/textonly/s01txt.html>.

[26] Alexander-Adams, Marcia. "Fact Sheet – Foreign Object Debris (FOD)."Fact Sheet – Foreign Object Debris (FOD). Federal Aviation Administration, 13 Nov. 2013. Web. 16 Nov. 2014. <http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=15394>.

[27] Jenkins, Darryl, and Dr. Bijan Vasigh. *THE ECONOMIC IMPACT OF UNMANNED AIRCRAFT SYSTEMS INTEGRATION IN THE UNITED STATES*. Rep. Association For Unmanned Vehicle Systems International, Mar. 2013. Web. 12 Dec. 2014. <https://higherlogicdownload.s3.amazonaws.com/AUVSI/958c920a-7f9b-4ad2-9807-f9a4e95d1ef1/UploadedImages/New_Economic%20Report%202013%20Full.pdf>.

[28] Humes, Edward. "Eyes in the Sky: Will Drones End Privacy as We Know It?" *California Lawyer*. California Lawyer, Aug. 2013. Web. 12 Dec. 2014. <http://www.callawyer.com/Clstory.cfm?eid=930175&wteid=930175_Eyes_in_the_Sky>.

[29] "The Air Traffic Control Market and Management Reports." *PR Newswire*. PR Newswire, 19 Nov. 2014. Web. 12 Dec. 2014. <http://www.prnewswire.com/news-releases/the-air-traffic-control-market-and-management-reports-283207521.html>.

[30] "Table 1-3: Number of U.S. Airports(a) | Bureau of Transportation Statistics." United States Department of Transportation. Bureau of Transportation Statistics, 2013. Web. 12 Dec. 2014. <http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_03.html>.

[31] Boothroyd, Geoffrey, Dewhurst, Peter and Knight, Winston A. Product Design for

Manufacture and Assembly. s.l. : Taylor and Francis Group, LLC, 2011.

[32] Jones, Tammy. "FACT SHEET." *FACT SHEET*. Ed. Paul Takemoto. Federal Aviation Administration, 6 July 2011. Web. 12 Dec. 2014. <http://www.faa.gov/news/press_releases/news_story.cfm?newsId=12903>.