COVER PAGE

Title of Design: PAWS- Design of a Low Level, Affordable Wind Shear Detection System for GA Airports

Design Challenge addressed: Runway Safety/Runway Incursions/Runway Excursions

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Executive Summary

This report presents a solution to Technical Design Challenge 2, Runway Safety/Runway Incursions/Runway Excursions, for the 2013-2014 FAA Design Competition for Universities. As stated in Challenge 2, the proposed system should demonstrate an innovative process to identify hazards that present the greatest risk to air carrier operations within the runway environment. Furthermore, proposed strategies and solutions should mitigate those hazards and improve safety of airport surface operations.

To address the Challenge 2 directive, the FAA Consulting Team (FAACT) has conceptualized, designed and fabricated the Protection Against Wind Shear (PAWS) system. The system is affordable compared to existing systems with an approximate cost of $10,000. The motivation for designing this system results from a number of aircraft incidents, some resulting in fatalities that have occurred due to wind shear. These deaths potentially could have been prevented if there was a broad spectrum wind shear detection system in place. Four primary design goals were considered in developing this system; 1. to create or modify a system that detects rapid change in wind patterns (i.e., speed and direction) at different heights and in different planes; 2. to utilize the system to generate its own power as it takes measurements in real time; 3. to communicate those readings via wireless transmitter to local ground control for broadcasting over the local Automated Terminal Information System (ATIS) during periods of dangerous weather activity; and last 4. to integrate this system and process into existing systems for accurate detection and communication at an airport. Ultimately, this system has been designed for implementation into smaller general aviation (GA) airports to enhance the safety environment for aircraft.

The PAWS system has been successfully implemented and tested in realistic conditions at our partner on the project, Tweed New Haven Airport.

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1- Problem Statement

This report responds to the FAA design challenge within the Runway Safety/Runway Incursion/Runway Excursion category. The Roger Williams University FAA Consulting Team, FAACT, has been tasked to expand situational awareness of pilots and ground operators on the airfield and to create an innovative design that identifies hazards presenting the greatest risk to aircraft operations on the runway. The team has employed risk analysis of runway incidents and developed a new approach to measure, record, analyze, and display spatial data for improved situational awareness, thus improving the overall safety of airport surface operations. The FAACT has developed an innovative new system: Protection Against Wind Shear (PAWS). This system is an entry into the market where historically there has been a gap in technology for predicting low-level wind shear in the aviation industry at smaller GA airports.

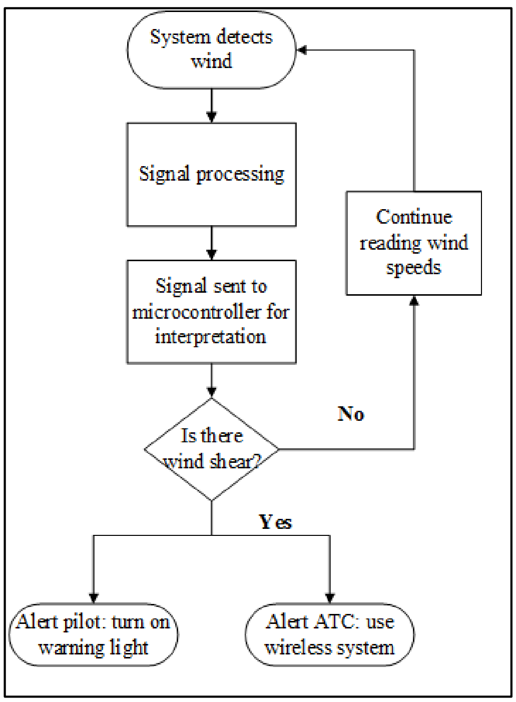

Figure 1: Process flow chart

The PAWS system delivers a safe, self-powered and inexpensive wind shear detection system for recording, analyzing, and transmitting spatial wind speed and direction data to ground operators, while providing an alerting visual aid for incoming and outgoing pilots when instances of wind shear are detected at or near the runway. Figure 1 depicts the process flow chart illustrating how the system operates.

One of the FAA's top priorities is to reduce the frequency of runway incidents. In response to this concern, the FAA's goals are to reduce the severity, number, and rate of runway incidents by implementing a combination of technology, infrastructure, procedural, and training interventions to decrease prevalence of these accidents and increase the error tolerance of airport surface movement operations. The FAA is developing airport design concepts and surface movement procedures to address such initiatives. In response to the need for an affordable, efficient, and effective wind shear detection system, FAACT presents the PAWS system. This system records all wind acting in both the horizontal and vertical directions within a 50 foot height range from the ground in a designated zone. PAWS will be located within 200 feet of the runway, easily visible to ground operations and pilots. The system is comprised of 16 calibrated anemometers positioned in clusters of 4 units located at 3 different heights on the pole.   In each cluster of 4 anemometer units, the orientation of each individual anemometer is either vertically or horizontally placed as shown in Figure 2. Each anemometer is linked to an on-board microcontroller that communicates to a master data acquisition system (DAQ). The master DAQ implements a Boolean state program that initiates a visual warning and sends a wireless transmission output to ground operations for alert responses to threatening wind shear conditions. In addition, the system is powered by two vertical axis wind turbines that provide the necessary power input for the DAQ system and warning light.

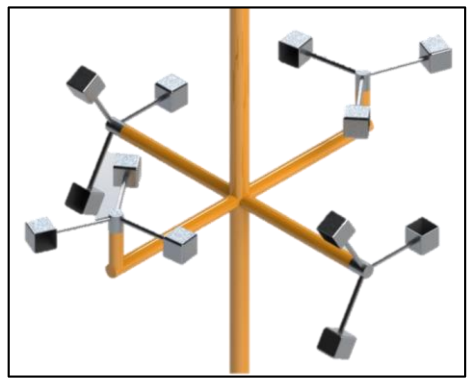
Figure 2: Commercialized design

FAACT suggests that PAWS is an essential technology for smaller airports due to the prevalence of preventable incidents at the runway-level caused by wind shear episodes. Though there are systems in place to address low-level wind shear conditions, they require multi-million dollar investments and are beyond the budget of smaller GA airports. As consequently, there is a need for a reliable, self-powered and affordable wind shear alert system to optimize pilot and ground operations awareness at the runway level, The PAWS system embodies these design specifications.

2- Background

2.1- What is Wind Shear?

Low-level wind shear during takeoff and approach can be highly hazardous to aircraft operations. Wind shear generates eddies between two wind currents of differing velocities (National Aeronautics and Space Administration, 1992). This difference can be in wind speed, direction, or both. The associated vertical motion known as updrafts and downdrafts can produce an increase or decrease in altitude for an aircraft. Thus, information on wind speed, magnitude, and directional shear with respect to varying altitudes is essential for a safe takeoff or landing. Wind shear can be associated with any wind speed gradient or direction in the atmosphere. However, the behavior of the wind in the final 100 ft. of descent, specifically between 100 and 50 ft., is the most important to an aircraft on its final approach. Wind speed shears greater than $0.1s^{-1}$ (6kts/100ft) are categorized as dangerous, while greater changes in wind direction (greater than 40 degrees) are considered hazardous (National Research Council, 1983). Industry experts have emphasized that horizontal magnitude of wind shear of $0.02s^{-1}$ (1kt/100ft) is of major significance. As shown in Figure 3, the final approach landing procedure is critical to the safety of passengers and the aircraft. When wind shear is encountered, the aircraft loses altitude and begins to pitch downward with too little time to recover its position and lift before contact with the ground.

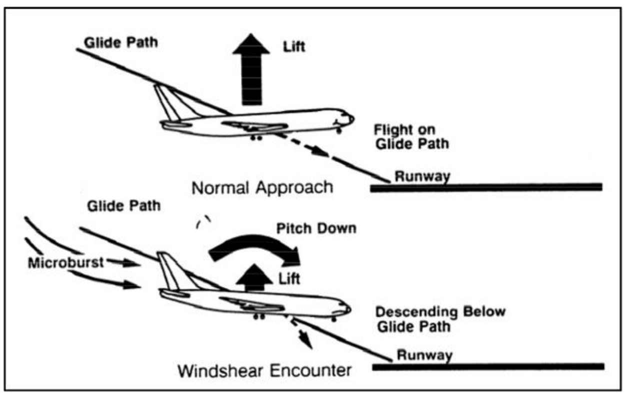

Figure 3: Wind shear effects on flight path on approach. Microburst reduces airspeed and lift at normal altitude which results in pitch down tendency to regain airspeed (U.S. Department of Transportation, 1988)

Figure 4 illustrates the types of wind shear from directional and speed perspectives. Directional wind shear acts in the vertical and horizontal planes, while speed shear acts at varying magnitudes (National Weather Service Forecast Office, 2010). Horizontal wind shear affects aircraft velocity, and is classified as headwind or tailwind shear. Low-level wind shear is categorized at altitudes below 2,000ft (National Weather Association, 2003). Currently, the Doppler radar found on most aircrafts has a hazard F-factor and wind shear intensity scale acting to guide the pilot, however when wind shear is considered clear-air turbulence, the Doppler radar is not capable of measuring this condition in advance.

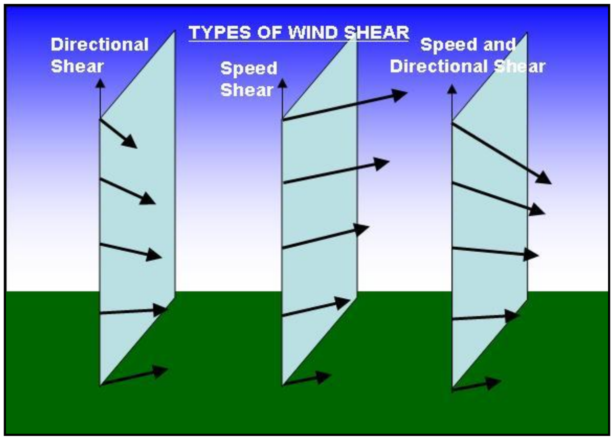

Figure 4: Graphic of different types of wind shear (Weather Questions, 2010)

Many changes to how low-level wind shear is detected and reacted upon have been introduced over the years due to major plane crashes and other accidents. Large airports now have systems in place, such as the Terminal Doppler Weather Radar (TDWR) to help detect dangerous changes in wind speed and direction. The FAA has also implemented and tested the Low Level Windshear Alert Systems (LLWAS). Though that system has proved capable for low-level wind shear detection in some incidents, it has also failed in other circumstances such as the Dallas/Fort Worth crash in 1985. Because of these recurring incidents, the aviation community has lacked a completely reliable solution. Since the 1985 incident, the FAA has implemented the National Integrated Wind Shear Plan which involved better training for pilots’ abilities to detect and handle wind shear situations which led to the TDWRs at larger airports today. (Jones, 2004)

2.2- History of Wind Shear Events

According to several NASA and International Civil Aviation Organization (ICAO) reports, unsteady weather hazards caused by low-level wind shear have been linked to a number of severe aviation accidents within the past thirty years. The ICAO provides statistical reports for weather related aviation accidents; 30 percent of the fatal accidents are due to severe weather patterns (International Civil Aviation Organization, 2005). Though aviation technology continues to advance and provide convenient means of transportation, turbulence caused by wind shear still poses a major threat to aircrafts with no updating alert system during their descent/final approach. Experienced pilots will follow recommended procedures for turbulence caused by storms, however, when it occurs in clear-air, the pilot experiences the invisible enemy with little-to-no warning. Figure 5 demonstrates how a microburst downdraft can cause a plane to reduce its lift and crash.

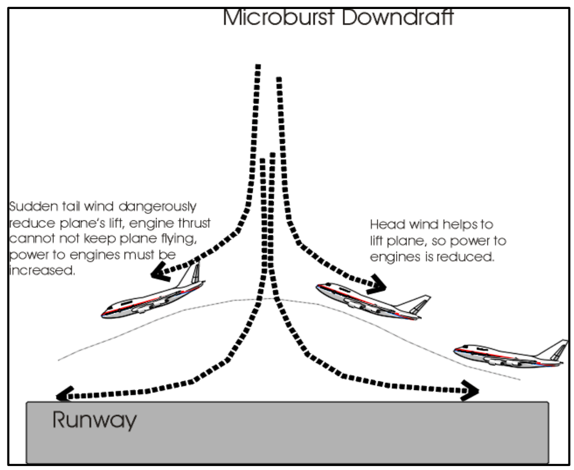

Figure 5: Microburst graphic of plane unable to land properly due to a wind shear event (Ackerman, 2000)

One of the first aircraft accidents attributed to wind shear was a Boeing 727 passenger airplane in 1975. As the prevalence of this clear-air turbulence became universally recognized, the ICAO formally established the Low-Level Wind Shear and Turbulence Group. The group's initiatives are to circulate studies from various countries, and prepare low-level wind shear related documentation. This led to cooperative efforts on many aviation-related assets, such as the FAA and NASA. "In 1981, both national organizations jointly promoted the project of Joint Airports Weather Study (JAWS), which focused on flying skills, flight training, and the evaluation of the low-level wind shear alert system" (Guan and Yong, 2009). Catastrophic events have prompted FAA initiatives to publish advisory circulars addressing pilot awareness of wind shear. The advisory circulars focus on enhancing pilots' skills to identify, avoid, and handle wind shear situations. Severe wind shear conditions are beyond the control and handling ability of aircrafts and even highly skilled pilots. According to the Aviation Safety Network (ASN) of the United States, from 1950-2000, there were over 40 aviation accidents caused by wind shear events. Some major accidents caused by wind shear resulted in over 200 fatalities as presented in Table 1:

Date	Incident Description	Casualties
12/21/1992	DC-10 crashed during landing at Faro Airport in Portugal	56 fatalities; 284 injured
6/17/1993	Antonov-26 crashed when it encountered severe turbulence while cruising over Tblilis in Georgia	41 fatalities
7/2/1994	DC-9 crashed when it encountered wind shear during go around at Charlotte-Douglas Municipal Airport in North Carolina	37 fatalities; 20 injured
6/1/1999	MD-82 encountered thunderstorm and wind shear during landing at Little Rock Airport in Arkansas. Due to strong crosswind after landing, the aircraft failed to stop and crashed	11 fatalities; 134 injured
8/22/1999	MD-11 encountered severe tropical storm during landing at Chek-Lap-Kok Airport in Hong Kong. After hard landing on its right main-gear the aircraft burst into flames, and continued to roll on the runway, resulting in severe structural damage	3 fatalities; 50 injured

Table 1: Incidents of wind shear accidents reported by the FAA Advisory Circular from 1990-2000

As the ASN reports have indicated, major accidents have been caused by wind shear and related occurrences. Though not identified as severe accidents causing fatalities, there have been many more incidents due to wind shear that have caused pilots to alter their final approaches, divert their aircrafts to safer landing zones, and combat the conditions with strategies that are also safety risks. It is because of these tragedies that FAACT decided to focus its efforts on solving the problem of low-level wind shear detection at GA airports.

2.3- Technical Discussion of Wind Shear

According to *Wind Speed and Direction Shears With Associated Vertical Motion During Strong Surface Winds*, as wind shear is encountered during the descending approach, the effects are considered twofold and opposite in direction. One effect is dependent upon the rate of the wind shear, while the other is dependent only upon the magnitude of the wind shear. The effect due to wind shear rate is associated with the pilot's attempt to maintain appropriate airspeed. As a standard example, if an aircraft is on an approach at ~60 m/s with ~ 10 m/s headwind, the ground speed will be approximately 50 m/s. If that headwind were to cease, the aircraft would need to compensate by accelerating to a ground speed of 60 m/s to maintain their airspeed. In order to accomplish this, the pilot would adjust the nose of the fuselage and decrease altitude or apply thrust to accelerate the aircraft at a rate equivalent to the rate of the acting wind shear. The effect due to wind shear magnitude is associated with the pilot's attempt to fly at the recommended glide slope. If an aircraft encounters instantaneous wind shear, the airspeed will drop, the nose will pitch down, and the aircraft will drop below the glide slope. The loss in altitude will be directly proportional to the new wind condition, assuming the thrust is maintained constant. Once that energy has been exchanged from potential to kinetic energy, the aircraft will have an excess amount of thrust, forcing the aircraft to gradually gain on the glide slope and overfly it, as seen in Figure 6. This then leads to runway incursion and excursion accidents. Also important to note, is the resulting accidents that would occur if the aircraft were within 100 ft. from the ground because the aircraft would have no time to recover from a downward pitch in that instance.

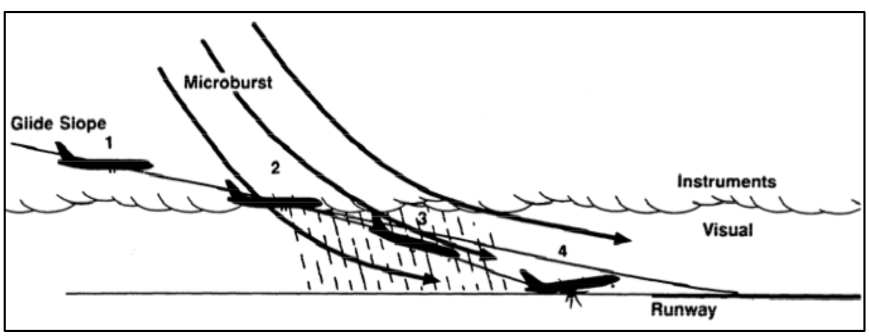

Figure 6: Wind shear encounter during approach. (1) Approach initially appeared normal. (2) Increasing downdraft and tailwind encountered. (3) Airspeed decrease combined with reduced visual cues resulted in pitch altitude reduction. (4) Airplane crashed short of end of runway (U.S. Department of Transportation, 1988)

The effect of wind shear varies depending upon the location the wind shear occurs relative to the ground, the rate of shear, and the magnitude. When wind shear occurs very close to the ground, the aircraft will hit short of the runway, whereas, if it occurs a reasonable distance above the ground, the aircraft will tend to overfly the touchdown zone. To better understand the dangers of wind shear, and how to properly respond, mathematical analyses can be performed.

Wind shear speed is calculated using the following equation:

$$\frac{v}{v_0} = \left(\frac{h}{h_0}\right)^{\propto}; \qquad equation\ 1$$

$Where;$

$v = the\ velocity\ at\ height\ h\ \left(\frac{m}{s}\right)$

$v_0 = the\ velocity\ at\ height\ h_0\ \left(\frac{m}{s}\right)$

$\alpha = the\ wind\ shear\ exponent$

Equation 1 determines the speed of wind shear using the wind shear exponent, which changes with respect to the surrounding terrain. Higher wind shear exponents imply an increased density of obstructive elements leading to lower wind shear velocity. The higher the altitude, the greater the wind shear velocity due to its reference point at ground level. Table 2 evaluates wind shear exponent values according to their respective terrain characteristics.

Terrain	Wind Shear Exponent - α -
Open water	0.1
Smooth, level, grass-covered	0.15
Row crops	0.2
Low bushes with a few trees	0.2
Heavy trees	0.25
Several buildings	0.25
Hilly, mountainous terrain	0.25

Table 2: Wind shear exponents for different terrains (The Engineering Toolbox, 2013)

Vertical shear magnitudes are derived by subtracting the wind speed at a lower level from the speed at an upper level, and dividing by the distance between those levels. This relationship is shown using Equation 2:

$$\frac{V_{upper} - V_{lower}}{d_{u-l}} = \frac{\Delta V}{\Delta d}; \qquad equation\ 2$$

$Where;$
$v = wind\ velocity$
$d = distance\ between\ anemometer\ height$

The horizontal wind shear is the change of wind speed with respect to horizontal distance. The horizontal wind shear magnitudes can then be derived algebraically by subtracting the wind speeds at each device and dividing by distance between devices. This mathematical process can be seen in Equation 3:

$$\frac{v_1 - v_2}{d_{1-2}} = \frac{\Delta v'}{\Delta d}; \qquad equation\ 3$$

The vertical and horizontal wind shear directions are calculated in similar fashion, using direction instead of wind speed, as shown in Equation 4:

$$\frac{WD_1 - WD_2}{d_{1-2}} = \frac{\Delta WD}{\Delta d}; \qquad equation\ 4$$

$Where;$
$WD = wind\ direction$
$d = distance\ between\ devices$

The equations presented in this section illustrate how wind speed is calculated at various heights to determine whether wind shear is present (Alexander & Camp, 1984). This analysis is the foundation of the PAWS design and will be further discussed in the Technical Aspects section.

3- Literature Review Supporting Design of PAWS

3.1- Overview of Research Process

The design team used a number of resources to gather as much information as possible to design a system that would effectively increase situational awareness of pilots during wind shear episodes. In the earlier conceptual stages, most research was focused on existing technology literature. As the design evolved, the team consulted publicly available conference proceedings and patents to determine the types of wind shear detection systems already in existence. Information on the TDWR, and other related systems, helped to provide the team with design goals and objectives. The design team also used academic courses and textbooks to investigate appropriate mathematical models for analyzing wind shear using the designed system.

3.2- Wind Shear Detection Systems Currently in Use

As specified earlier, there are a number of ground-based wind shear detection/warning systems in place today. Notably among these is the LLWAS, the acoustic Doppler system, laser system, and pulsed microwave Doppler radar system. Upon further investigation, there are advantages to these systems, but also disadvantages that the PAWS system addresses.

The LLWAS detects the presence of wind shear in the vicinity of the airport at the surface using anemometers and microcontroller for data transmission, however, this system cannot guarantee protection in all cases. It was designed to detect horizontal wind shears that move across the airport, thus is better suited for cold frontal passage and thunderstorm gust fronts than for outflow portions of microburst events. Moreover, it proved unable to detect the downdraft associated with microbursts and other forms of vertical winds (Airbus, 2013).

The acoustic Doppler system determines wind speed and direction by measuring frequency shift in signals reflected by the atmosphere. However, the system is expensive and unable to operate under heavy precipitation, in zones of aircraft noise, or detect clear-air turbulence. The laser systems lacked the ability to scan within the range of the glide slope and takeoff flight path for wind shear detection.

The pulsed microwave Doppler radar and TDWR systems are perhaps the most efficient and effective systems in place today, however, these systems cannot properly measure the vertical component or downdraft. To utilize such a system the airport must be equipped with a Doppler radar which is considered a substantial expense to airport operations managers. These systems are also out of the price range for GA Airports, at $6 million (National Research Council, 1983).

Although all the previously cited wind shear detection and warning systems have value, no one system has proven to be fully adequate for fail-safe detection of low-level wind shear. Consequently, there is a need for an inexpensive, simplified system that can detect vertical and horizontal low-level wind shear and communicate the real-time data to ground control towers or ATIS communication channels for continuous updates to incoming and outgoing pilots in range.

4- Problem Solving Approach for Design Process

Upon initial assessment of the technical design challenge and problem statement, several theoretical designs were brainstormed. At first, the defined problem focused on wind shear and clear air turbulence at the runway level. This idea emerged from a discussion of airport operations and technology that require improvement and have not yet been thoroughly investigated. The first few weeks of the fall semester were spent on wind shear research, factors that affect it, specifications, and potential solutions for the issue it imposes on aircrafts at takeoff and landing. After extensive research on this topic, the design team began focusing on GA Airports that lacked the wind shear detection technology due to airport and fleet sizes.

4.1- Team Composition

With various backgrounds in engineering, FAACT was motivated to undertake individual research as well as group brainstorming to introduce new design concepts to weekly meetings and utilize constructive feedback from each member and faculty advisor as a means of overall design improvement. Major areas of focus for the team included: consumer needs, safety and risk assessment, cost analysis, and communication with industry experts. With a broad range of categories set forth by the FAA Design Competition, FAACT explored creative, unique, and feasible solutions to relevant aircraft/airport issues. The team decided to focus on smaller airports and fleet sizes that lack the capabilities or budget to install expensive, complex systems for tracking wind shear. The reason for this focus is because smaller aircrafts have a higher risk of accidents due to drastic wind pattern changes and pilots with less experience than commercial pilots. Therefore, the PAWS design is an inexpensive and simplified alternative to current systems such as the multi-million dollar TDWR's in place at large, commercial airports throughout the U.S. Collectively, the team's design tasks for PAWS included research, risk management, risk and safety assessment, engineering analysis, prototyping, conceptualized SolidWorks modeling, scaled fabrication, and experimentation.

4.2- Research Process

Due to the significant impact that the FAA has had on safety advancements in the aviation industry, the literature review and research was an important on-going process throughout the entire project. The review ensured full team comprehension of existing solutions, present problematic areas, and background history. The fall semester was focused on studying runway safety risks due to wind shear and developing potential formal solutions through extensive research, various system designs, engineering analysis and communication with local airports. As the concept became more refined, the research and conceptual design process evolved in several simultaneous paths.

FAACT partnered with Tweed New Haven Regional Airport located in New Haven, Connecticut. While on site, the team met with airport safety operations manager Kurt Rodman and pilots at the Airport, toured the control tower, viewed their ATIS communication system, and explored runway equipment to gain a better general knowledge of runway safety at smaller airports. Kurt Rodman became the main point of contact at HVN for the team. FAACT introduced the concept for an affordable system that would detect low-level wind shear events during takeoff and landing with various GA pilots and airport operations managers. In response, the team received constructive feedback from pilot, ATC, and FAA perspectives. In addition, a survey introducing the design group objectives, the conceptual design, and wind shear inquiries was sent to national airport managers, FAA expert advisors, and AAAE members to solicit a broader range of advice. As the concept moved to design, various techniques such as functional flow diagrams, planning Gantt charts and system modeling tools were integral elements employed throughout the design process to aid in the full-scale, commercialized design and scaled prototype version.

4.3- Development Methods

The evolutionary progression of conceptual designs is presented in Figure 7. Due to regular contact with faculty and technical mentors within the aviation industry, FAACT developed a final, functioning prototype after several design and development iterations. After much research, contact with FAA affiliates, and airport site visits to HVN, an initial design concept was conceived. This concept grew into a formal

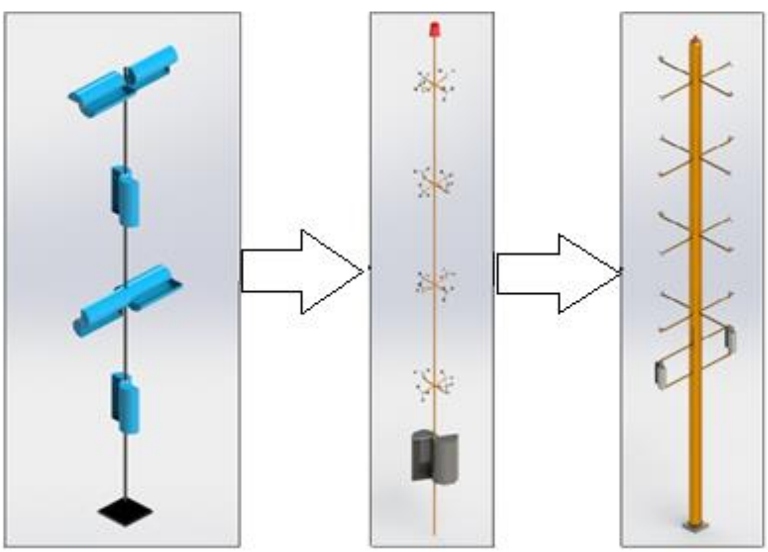

Figure 7: Conceptual design development, from Savonius wind turbine tree, to anemometer tree, to PAWS system

design and was modeled using a photorealistic simulation in SolidWorks and constructed at a one fifth scale for testing at HVN.

The fully functioning prototype was evaluated based on safety, cost, effectiveness, efficiency, and ergonomics which resulted in modifications that better addressed the team's objectives. The final anemometer tree design shown in Figure 7, suggested further analysis of the structural integrity of the 50 ft tower pole. Following in accordance with FAA airport equipment regulations, lighting system, color codes, and safety precaution advisory circulars, the team finalized a design. FAACT was able to complete the development of the scaled PAWS system through continuous modification and refinement until it met all acceptable criterion for implementation at HVN. Using feedback from pilots, FAA expert advisors and airport operators, the prototype models evolved to represent a reliable system.

4.3- Safety and Risk Management

FAACT employed a thorough risk assessment to comply with the FAA Safety Management System Manual (SMS). Each PAWS system will be integrated into cooperating airports based on number of runways, runway length, layout of taxiways, and prevailing wind patterns. Due to wide variations in location and environment, FAACT focused on a general framework for operational procedures that measures wind speed and direction, interpret data in real-time, and report potential risks to ground control operations. The PAWS system acts in accordance with safety considerations detailed in various advisory circulars, FAR AIM, and the FAA SMS.

FAACT has identified certain safety considerations that apply universally. The modern aviation system is characterized by increasingly diverse and complex networks of business/governmental organizations as well as increasingly advanced aircraft and equipment. According to AC No: 120-92A: Safety Management Systems for Aviation Service Providers, the important characteristics of systems and their underlying process are their safety attributes when related to operational and support processes. These attributes have safety requirements built into their design to provide improved safety outcomes. These attributes include: responsibility and authority, procedures and controls, process measures, and interfaces (ATOS). FAACT followed AC protocols when analyzing the safety and risk of the system. As a result, the team has assumed responsibility for accomplishing required precautions, providing clear instructions for members to follow, providing organizational and supervisory controls on the involved activities, measuring processes and products, and recognizing the important interrelationships between processes and activities within the airport as well as with consumers and other stakeholders. As directly stated by SMS principles, the four essential components of a safety management system provided in Table 3:

Principle	Description
Policy	All management systems must define policies, procedures, and organizational structures to accomplish their goals.
Safety Risk Management (SRM)	A formal system of hazard identification and SRM is essential in controlling risk to acceptable levels
Safety Assurance (SA)	Once SRM controls are identified and operation, the operator must ensure the controls continue to be effective in a changing environment
Safety Promotion	Finally, the operator must promote safety as a core value with practices that support a sound safety culture

Table 3: Four essential components of safety management system

PAWS complies with all SMS, FAA, and specific airport operations safety protocol and was commercially designed with a factor of safety of 4.4.

5- Description of Technical Aspects of PAWS

5.1- Development of PAWS

The PAWS system fully functioning prototype was designed at one-fifth scale and constructed using PVC pipe, as seen in Figure 8. PVC is designed to be a strong, waterproof, and weather resistant material. Safety was a major concern when developing plans for the system model. The FAA has a multitude of rules and regulations regarding runway equipment, installation, lighting, system location, height restrictions, and color codes all identified and outlined in the FAR AIM Manual and FAA advisory circulars.

Figure 8: Initial testing of PAWS at HVN

Following regulation standards, the full-scale commercialized design will be made of galvanized steel to avoid weathering and to maintain structural integrity. The pole will be 50 ft. tall, meeting the height requirements set forth by HVN Airport Operations. An L-810 red obstruction light at the top of the pole will act as a warning alert to incoming and outgoing pilots when wind shear occurrences have been detected by the system. The entire system will be a bright orange color, following FAA code. To demonstrate proof of concept, the prototype model has been tested within the pre-approved area of the segmented circle where the wind socket resides at HVN. This avoided interference with airport operations and maintained a safe distance from the.

The overall objective of the PAWS system is to aid in safety precaution procedures taken by airport operations and pilots which lack specific equipment dedicated to episodes of low-level wind shear. Though this system was designed for smaller airports, fleet sizes, runways, and annual traffic, PAWS can be theoretically implemented in any type of airport. It is inexpensive, ergonomic, easily-maintained, and uses simple data acquisition and alert system output to provide a marketable device for airports and pilots on a global scale.

5.2- PAWS System Technical Analysis

Each component of the commercialized design required thorough engineering analysis for structural integrity, power generation, and ability to measure and communicate data to ground operations. The 50 ft galvanized steel structure was designed with careful consideration of drag forces, imposed moments, and weathering. As seen in Figure 9, a preliminary Free Body Diagram (FBD) was utilized for analyzing these factors.

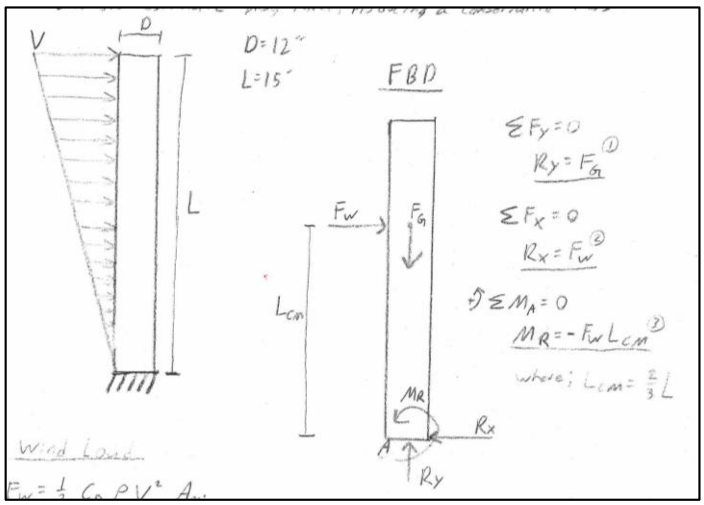

Figure 9: Free body diagram of system pole structure

In order to calculate these elements with considerations on safety and operation, an over-estimate was implemented. Thus, the pole was modeled as a cylinder with a 1-foot diameter, as opposed to the tapered design of the pole. Initially, the structure was analyzed for reaction forces at the base of the system's structure, the moment about the structure, and center of gravity.

The summation of forces in the vertical direction (y-axis) must equal zero according to static equilibrium. This is mathematically represented in Equation 5:

$$\sum F_y = 0 \quad \therefore The\ reaction\ force\ in\ the\ y - direction\ (R_y) = F_G \qquad equation\ 5$$

The summation of forces acting in the horizontal direction (x-axis) must equal zero also to prove the structure will remain stable during applied loads. This relationship can be seen in Equation 6:

$$\sum F_x = 0 \quad \therefore The\ reaction\ force\ in\ the\ y - direction\ (R_x) = F_w \qquad equation\ 6$$

Once reaction forces were calculated, the structure required allowable wind load analysis. Equation 7 depicts the wind load analysis:

$$F_w = \frac{1}{2} C_D \rho {V_{avg}}^2 A_{proj} \qquad equation\ 7$$

$Where;$
$F_W = wind\ load\ (lbf)$
$C_D = Coefficient\ of\ drag$
$\rho = density\ of\ air; 2.42 * 10^{-3} slug/ft^3$
$V_{avg} = 110mph\ (161\ ft/s)$
$A_{proj} = L * D = 50ft^2$

The V_{avg} term refers to a three-second gust wind speed that has been determined as extremely dangerous wind shear conditions (ASCE ISEI 7.05). The reason for applying a significant wind gust velocity was to ensure the structure could handle the load applied in such a scenario. The coefficient of drag is dependent upon the Reynolds Number, thus the Reynolds Number was required for evaluating the system's structure, and was calculated as follows:

$$R_e = \frac{U_\infty \rho D}{\mu} = \frac{(161mph) * \left(2.42 * 10^{-3} \frac{slug}{ft^3}\right) * (1ft)}{(3.82 * 10^{-3} \frac{lbf * S}{ft^2})}$$

$$R_e = 1.06 * 10^6$$

$Where;$
$U_\infty = V_{avg} = 161 \frac{ft}{s}$
$\mu = 3.82 * 10^{-3} \frac{lbf*s}{ft^2}$
$D = 1\ ft$

Once the Reynolds Number was calculated, the coefficient of drag, C_D, could be determined. For a Reynolds Number in the range $10^{-5} < Re < 1000$, the $C_D \sim 1$, and when Re > 10^5, the C_D = 0.4. Thus, the wind load is calculated as:

$$F_w = \frac{1}{2}(0.4) * \left(2.42 * 10^{-3}\frac{slug}{ft^3}\right) * \left(161\frac{ft}{s}\right)^2 * (50ft^2)$$
$$F_w = 627.3\ lbf$$

The moment about the fixed point of the system's base with the ground was then calculated using the wind load force, as shown using Equation 8:

$$M_R = (F_w) * \left(\frac{2}{3}L\right) \qquad equation\ 8$$
$$M_R = (627.3\ lbf) * \left(\frac{2}{3} * 50ft\right)$$
$$M_R = 20{,}910\ lbf * ft = 20.91\ kip * ft$$

$Where;$
$M_R = moment\ about\ the\ base, (R);$
$L = 50ft$

As a final consideration for the pole structure, a stress analysis was conducted. The risk of structural failure is greatest at the base as a result of the largest moment generated at that point, thus the actual and yield stresses were calculated to provide a factor of safety (FOS). The specifications of the 50 ft. tapered, galvanized steel pole manufactured by LightMart is guaranteed with a minimum yield strength, of σ_y = 55ksi. The top diameter is 5.2" and the bottom diameter is 12". The bottom section is a 7 gage, top section is 11 gage. With these specifications, the actual stress (σ_{act}) was calculated using Equation 9:

$$\sigma_{act} = \frac{-M * r}{I} \qquad equation\ 9$$
$$\sigma_{act} = \frac{-(20.91kip * ft) * (0.5\ ft)}{0.00585\ ft^4}$$
$$\sigma_{act} = 1787.1795\frac{kip}{ft^2} = 12.41\ ksi$$

$Where;$
$M = Moment = 20.91\ kip * ft$
$r = radius\ of\ pole\ at\ bottom\ section = 0.5\ ft$

$$I = Moment\ of\ Inertia = \frac{\pi}{64}\left({D_0}^4 - D_i^4\right);\ D_0 = 1ft, D_i\ = 0.96875\ ft$$

$$I = \frac{\pi}{64}(1^4 - 0.968754^4) = 0.00585\ ft^4$$

With the actual stress and yield stress, the factor of safety was determined:

$$FOS\ = \frac{\sigma_y}{\sigma_{act}} = \frac{55\ ksi}{12.41\ ksi} = 4.4$$

Another significant element to the system is the vertical axis wind turbine ("Seabird" VAWT). This 100-Watt VAWT starts and operates at wind speeds of approximately 3.8 knots. The turbine has a high capacity factor (C_F) over the average annual wind velocities of HVN. Figure 10 illustrates the REM Enterprises "Seabird" vertical axis wind turbine that will be integrated into the commercial PAWS system. The solidity of the turbine face will prevent birds from flying into it and being harmed. This particular turbine will obtain torques in low winds, enabling it to extract energy from wind at a higher percentage of the time than other competitive market products. Table 4 details the benefits associated with the utilization of the Seabird VAWT. In addition to the functional benefits, it is COTS (commercial off-the-shelf) and convenient to purchase for the commercialized PAWS system. According to HVN wind pattern statistics, the average wind speed is approximately 10.4 knots (Weather Observations for New Haven/Tweed). As a result of the VAWT mechanical design, these average wind speeds will engage the device and actively store energy. A factor of safety was implemented to ensure the

Figure 10: REM Enterprises "Seabird" VAWT

system is always powered, continuously transferring data collected by the DAQ with sufficient energy stored in the battery to power the obstruction light when necessary.

Benefits of “The Seabird” Vertical Axis Wind Turbine
Starts and operates at wind speeds of approximately 3.8 knots (4.4mph, 2 m/s)
Very high capacity factor (CF) over average annual wind velocities on site
Solidity of turbine face will prevent birds from flying into it and being harmed
Obtains useful torques in low winds to enable turbine to extract energy from wind at a higher percentage of the time than other competitive market products
Obtains high values of C_P, maximizing amount of energy to be taken from wind at any velocity
Has no “dead band”; this component will self-start
High capacity factor reduces problem with storage power during low demand
Direct drive generator-no slip rings, belts or gears to wear out. Only moving part is the rotor
VAWT takes advantage of its ability to harvest energy from regions of low wind

Table 4: Benefits of using the "Seabird" VAWT

5.3- PAWS System Electrical Components

The function of the PAWS system is to retrieve wind measurements from multiple fixed heights in both vertical and horizontal planes to determine the rate of change of wind speed as a function of height and slope. In order to achieve this, the system employs 16 calibrated anemometers located at three different heights, placed both vertically and horizontally on the tower pole to measure and transduce wind speed into an AC voltage signal. Figures 11 and 12 show SolidWorks renderings of a single vertical and horizontal anemometers. To transduce wind speed, the AC signal is passed through a positively biased non-inverting operational amplifier. The reasoning for this is that the original AC signal from the anemometer has a peak-to-peak voltage of one volt, which is not sufficient voltage to trip the transistor-to-transistor logic (TTL) used by the Arduino microcontroller. The Arduino is responsible for receiving the signal which requires a minimum of 3.5 volts to register a “HIGH” signal. The positive bias was implemented to

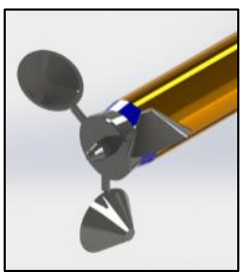

Figure 12: Vertical anemometers

Figure 11: Horizontal anemometers

translate the AC signal to a DC offset, which would effectively remove any negative voltage signals. The team's custom designed PAWS circuit details each component of the electrical design for the scaled PAWS System. Figure 13 shows the full circuit schematic.

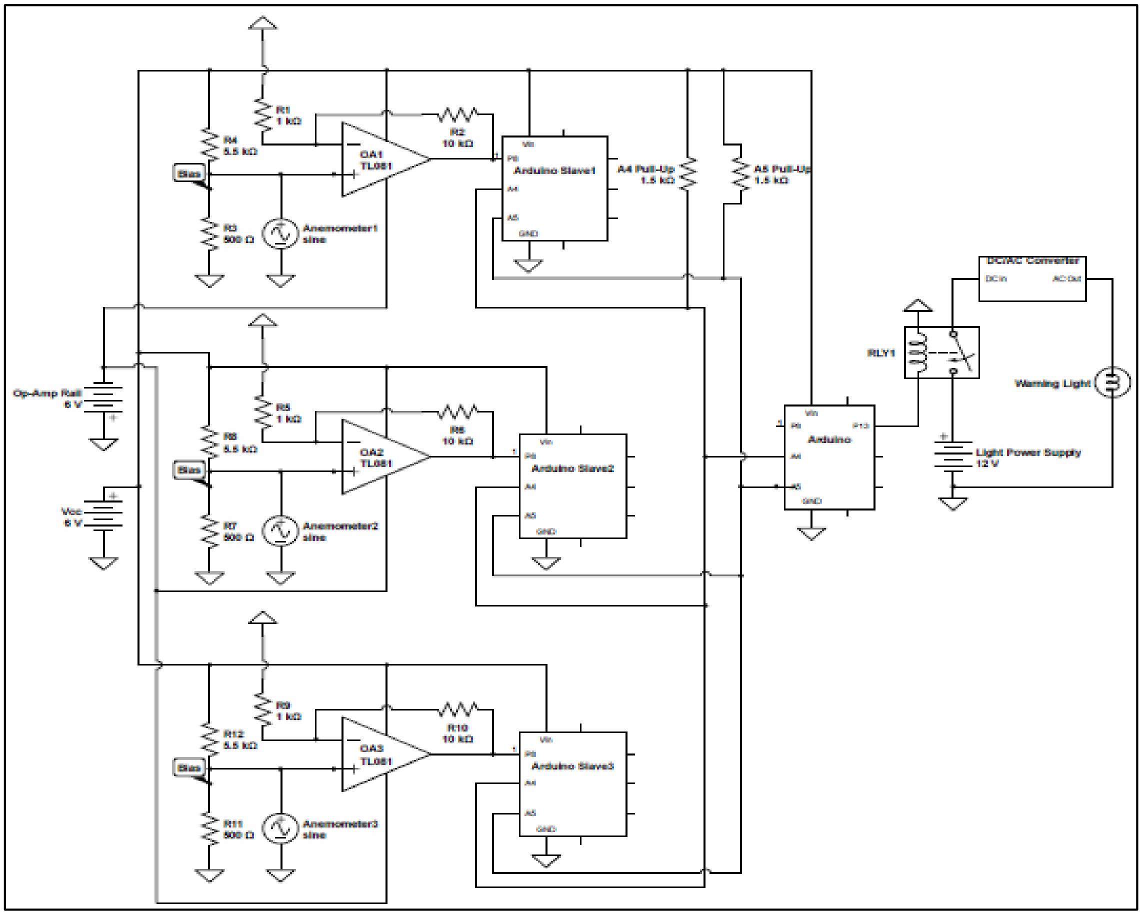

Figure 13: Full circuit schematic for scaled PAWS system

The Arduino translates the AC signal to a frequency output using the frequency library of Arduino found on an open source website. This frequency library functions using the on-board clock of the Arduino to time the span between impulses from the AC signal while simultaneously

Figure 14: Scaled PAWS System Electrical

counting the number of impulses. This information is then used to determine frequency. The frequency is then fed into a transfer function taken from the data sheet of the anemometers to yield the correlating wind speed in MPH.

5.4- PAWS System Programming

To translate and communicate information to ground operations, the separate wind speed measurements taken at the various fixed heights are used to calculate a slope. A linear regression equation in Excel is used to generate the slope of the wind speed measurements. To capture all frequency outputs, each anemometer was paired with a single "slave" Arduino because the Arduino measures one frequency at a time due to its single on-board clock per unit. Each Arduino-anemometer pair sends its data to a single "Master" Arduino which utilizes the collected data to generate a single slope calculation. The programming process involved two separate codes to distinguish between slave Arduinos and the Master Arduino functions. Figure 15 displays partial code for the "slave" Arduinos which monitor their paired anemometer frequency outputs continuously. Figure 16 illustrates the Master Arduino code.

```
#include <FreqMeasure.h>                    //Library to measure frequency
#include <Wire.h>                           //Library needed to use I2C
#include "I2C_Anything.h"                   //special library for sending float variables over I2C
void setup() {
  Wire.begin(#);                                // join i2c bus with address
  Wire.onRequest(requestEvent);    //When master makes a request, run method "requestEvent"
  FreqMeasure.begin();                         //Initialize frequency measure
  pinMode(8,INPUT);                          //Pin 8 is where signal comes in
}
double sum=0;                     //adds up frequency over time
int count=0;                      //keeps track of how many times frequency is counted
volatile float frequency;         //variable to hold frequency output
void loop() {
  if (FreqMeasure.available()) {            //Check for incoming frequency
                                          // average several reading together
    sum = sum + FreqMeasure.read();         //Add measured frequency to current sum
    count = count + 1;                      //add to count
    if (count > 10) {
      frequency1 = F_CPU / (sum / count);   //calculate frequency
      sum = 0;                              //resent sum and count to zero
      count = 0;
    }
  }
}
void requestEvent()                          //method for sending data to master
{
  I2C_singleWriteAnything(frequency);  // When master requests data, send frequency

}
```

Figure 15: Coding snapshot for "slave" Arduinos

```
#include <Wire.h>                //Library needed to use I2C
#include "I2C_Anything.h"        //special library for sending float variables over I2C
const int light=13;              //Pin for warning light relay
void setup()
{
  Wire.begin();                 // join i2c bus (address optional for master)
  Serial.begin(115200);         // start serial for output
  pinMode(light,OUTPUT);        //Pin for relay set to output
digitalWrite(light,LOW);        //Turn light off
}
volatile float frequency[3];  //array of variable to hold frequency information from anemometers
volatile float windSpeed[3];  //array of variable to hold frequency information from anemometers
volatile float t1;             //Variables used in slope calculation
volatile float t2;
volatile float b1;
volatile float b2;
volatile float slope;          //Variable for slope
void loop()                    //Main code
{
  Wire.requestFrom(1,4);                //Set I2C connection to request data from 1st anemometer
  if(Wire.available())                  //Check for connection
  {
   I2C_readAnything(frequency[0]);      //Request data from Slave arduino and save data to frequency variable
  }
  Wire.requestFrom(1,4);                //Set I2C connection to request data from 2nd anemometer
  if(Wire.available())                  //Check for connection
  {
   I2C_readAnything(frequency[1]);      //Request data from Slave arduino and save data to frequency variable
  }
  Wire.requestFrom(3,4);                //Set I2C connection to request data from 3rd anemometer
  if(Wire.available())                  //Check for connection
```

Figure 16: Coding snapshot for "master" Arduino

The Wire library of Arduino was utilized to communicate the collected data. The Wire library used a technique known as “Inter-Integrated Circuit” (I2C). This technique employs a connection of all analog 4 ports (A4) of each Arduino which then connects to all analog 5 ports (A5). The A4 and A5 ports act as serial clock lines (SCL) and serial data lines (SDL). Each Arduino requires a common ground with two pull-up resistors spanning from the SDA node to power, and the SLC node to power. The code displayed in Figure 16 defines each anemometer as a variable. When an impulse signal is detected at any of the variables, data filters through a built-in linear regression formula. This data will determine if the calculated slope is considered a threat. That information is requested by the Master Arduino which combines all slave Arduino readings and sends them through the DAQ.

Once the data has reached the Master Arduino and the slope has been calculated, the program will automatically compare the generated slope with a preset threshold. When the calculated slope is higher than the threshold, the Arduino writes a specified port to "HIGH." The port sends a voltage to a connected relay, and the relay trips and completes a circuit. The circuit consists of a 12V battery power supply, DC to AC power converter, and an obstruction light. The DC to AC converter is necessary because the only available power to the system is derived from DC, however the obstruction warning light runs off of AC voltage. In the event that the calculated slope is less than the threshold, the Arduino writes the port connected to the relay to "LOW." This disables the relay and opens the circuit, consequently turning the warning light off. This programming strategy has proven successful after testing the scaled prototype to turn the warning light on and off. Figure 17 represents the SolidWorks model for the warning light component.

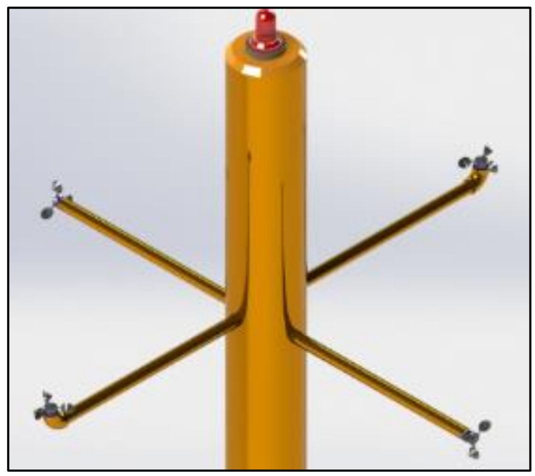
Figure 17: Warning light rendering in SolidWorks

6- Interactions with Airport Operators and Industry Experts

6.1- Tweed New Haven Airport

As the team was conducting the initial literature review, there was a simultaneous effort to find an appropriate airport to work with. After contacting several airports, Tweed New Haven Regional Airport (HVN) became the team's partner. The contact at Tweed airport was Kurt Rodman, the Airport Operations Supervisor. When asked about his job description Kurt said, "I am an Aircraft Rescue Firefighter and am first to respond to aircraft emergencies. Also, I ensure that the airport and all persons on it comply with FAR Part 139. This includes runway/taxiway inspections, lighting inspections, FOD removal, wildlife control, security, general coordination and enforcement, work orders, emergency management, escorting, airport/airline/FBO personnel training, etc." Kurt has worked with the team to develop PAWS and has provided contact information for other individuals relevant to the project. Kurt has helped the team present the design to pilots and other airport operations employees to maximize feedback. Kurt also facilitated the prototype testing of the PAWS system at HVN.

6.2- Survey Results

In an effort to collect information and feedback from industry experts, the team also conducted an electronic survey using Survey Monkey to introduce the design. The survey was sent to over 1,000 U.S. airport operations managers and industry experts listed on the World Airport Database. Although the response rate was low, valuable information was provided by many airport operations managers, industry experts and technical mentors.

The first wave of the survey was sent to the list of technical mentors provided to the team by the design competition. This survey consisted of questions about challenges related to the design, suggestions for improvement, projected costs, and information about the respondents' area of expertise. This first wave of the survey received a number of responses that suggested some areas of the design would need improvement. When asked if there were any challenges related to the current design that the advisors could identify, a respondent replied, "One unit is insufficient. As in the LLWAS you need a ring of these around an area because it is very important to monitor the variance between wind intensity between locations, not just in one area so as to be able to predict wind shear migration." FAACT took this into consideration when deciding how many units to use at an airport. The team decided that one unit per runway would be sufficient. This was concluded after identifying the average length of runways for GA airports and knowing that wind speed can change horizontally between 2 and 4 km (1.2 to 2.5 miles). Since the runways are less than one mile long the horizontal changes in wind shear would not be sufficient to warrant multiple systems. Another comment to the question of challenges related to the design stated, “Unless your team has someone with some expertise in meteorology, or an industry expert on meteorology, this project would appear to be beyond the level of a college team to interpret the impacts of wind shear and protocols for offering guidance.” To address this concern, the team has undertaken an extensive amount of research into the topic of wind shear. The team has reviewed publically available course material, textbooks, and scholarly articles in order to understand a wind shear episode. FAACT is confident that the team’s technical background, research, and testing has allowed for an accurate interpretation of the impact of wind shear.

The second survey was sent to airport operations managers throughout the U.S. This survey also yielded a number of helpful responses that the team took into consideration throughout the design process. This survey focused on determining how many airports, of the ones surveyed, had incidents related to wind shear and the types of systems the airports may, or may not, have in place to detect wind shear. The survey concluded that approximately 25% of the airports surveyed had at least one accident that was caused by low level wind shear, and only 15% of the surveyed airports had a system in place to detect low level wind shear. When the respondents’ airports were considered, none of those that had some type of system in place to detect low level wind shear had any accidents to report that were related to wind shear. This indicated that when the proper measures are taken to detect wind shear, pilots can react accordingly to avoid a potentially fatal accident.

6.3- Stakeholder Considerations

There were many stakeholders involved in the implementation of PAWS. Understanding the potential users and other participating constituencies of the PAWS system was carefully considered to deliver a product design that proves beneficial, safe, and adheres to FAA regulations. These stakeholders include; the FAA, pilots, private aircraft owners, non-towered airports, airports which operate tower-closed during overnight hours, installation personnel (i.e., airport lighting technicians, facilities management), airport maintenance personnel, airport lighting system manufacturers, airport anemometer device manufacturers, and the public in general. Each stakeholder involved in the implementation of the PAWS system has varying interests and levels of authority on each matter throughout the development of the system. Their influence has been accounted for in creating a successful low-level wind shear detection system.

The close collaboration with HVN allowed for operating within the scope of non-towered airports or airports that function without control operators during overnight hours. With consideration for GA Airports, the lifespan and reliability of the PAWS design is vital in terms of associated cost and maintenance. One unique benefit to the system is its energy conservation. PAWS can be considered an environmentally-sound product as it will operate using self-stored energy conserved in a battery that is charged by the vertical axis wind turbine components. Therefore, the system will have no need to tap into the electrical grid of the runway. This self-sufficient device will power the microcontroller, wireless transmitter, and warning light when necessary.

7- Commercial Potential & Projected Impacts of the PAWS System

7.1- Manufacturability

The PAWS system is designed using off-the-shelf components. The motivation for this was to increase convenience for obtaining materials and optimizing production and manufacturability while maintaining low-costs. The PAWS system is designed in accordance with FAA regulations for weather detection equipment. In order to meet these regulations, the PAWS system uses a 50 ft. galvanized steel pole as the support structure of the design. This type of pole is rigid enough to withstand extreme weather conditions and is currently used for other airport runway systems.

The cross-sections that house the SecondWind C3 Anemometers are 3 ft. long, 2 in wide pieces of galvanized steel pipe. The pipes can be ordered pre-cut to reduce manufacturing time. The SecondWind C3 anemometers have been chosen for this system because they have been tested to be accurate and are calibrated. Furthermore, they were used during the testing phases of the scaled prototype and the code to control them has already been developed. The obstruction light employed at top of the PAWS system is the Honeywell L810 Red Obstruction Light developed for airport use and is compliant with FAA regulations. In addition, the micro-controller and onboard DAQ system come pre-assembled and ready to be placed into a weatherproof box enclosure. The VAWT also comes pre-manufactured and ready for attachment to the system.

To manufacture the system, FAACT tested the ease of assembly by building a 1/5 scale model out of PVC and other pre-manufactured parts. The scaled PAWS system was constructed in a matter of days with basic hand tools. If the PAWS system were to move to full scale commercialization, assembly time would decrease.

7.2- Testing

To validate the PAWS system operation, testing was required on the prototype and code. To test the system, FAACT brought the prototype to HVN. Figure 18 shows the prototype, in operation, next to the HVN wind sock. The prototype is made of PVC and stands ten feet high. Three of the calibrated SecondWind C3 anemometers were used to take measurements at different fixed heights.

Figure 18: 1/5 scaled prototype being tested at HVN

At the time of testing, the prototype showed different wind speeds at the varying heights where anemometers were placed. To validate the results gathered from PAWS, wind speeds that were recorded by ground traffic control at the time of the testing were compared to the results gathered by the PAWS system. When these results were compared, PAWS reported identical wind speeds of 18 mph to ground traffic control. This successful proof of concept was necessary to showed that this system can be used to accurately detect wind speeds. However, the primary objective of the system is to identify and measure wind shear conditions that ground traffic control could not measure.

The next step in testing then was to ensure that if wind shear was present, the warning light at the top of the system would turn on. To test this, FAACT created a wind shear like event using fans at various speeds and heights in addition to the wind already present. The team used a Boolean statement to tell the light when to turn on and off. When the system observed wind shear, the light at the top of the pole turned on. The light remained on until 10 minutes after the wind shear simulation ended. This 10 minutes was used as a “safe-zone” in the event that wind shear was observed again during that time. This would give pilots enough time to react to wind shear. The testing validated that the design worked as intended.

7.3- Operation

The detection system is distinctive based on the self-powered nature and automated transmission of real-time data measurements to the automated computers in the control tower. In the control tower there are separate instruments for measurements such as dew point, temperature, wind, etc. Each piece of information is then broadcasted and consolidated onto a shared screen. It is the duty of the controller to read these measurements via recorder microphone onto the ATIS. The ATIS is then recorded and broadcast repetitively on a discrete frequency that pilots tune into before contacting ground control for initial descent. This procedure is followed universally so the pilot can prepare for any oncoming weather behavior before reducing altitude and becoming vulnerable to a dangerous and unrecoverable situation.

For the system to be integrated into ground control operations, the micro-controller, which acquires and transmits wireless data, needs to be compatible with the airport's ground control software. Once communication with the micro-controller is established, information will be continuously transmitted to ATC. Ground control will then place this information onto the ATIS which will communicate updated conditions directly to incoming pilots. The ATIS is an integral component to the safety and precautionary actions taken by all aircrafts and pilots. The system is designed to be independent and allow airports to obtain information easily without the struggle of complex integration into the large network of runway equipment and instrumentation.

7.4- Maintenance

The maintenance required for PAWS is minimal. The components requiring the most attention will be the anemometers and wind turbines. The turbine blades and gear train need to be well maintained to guarantee an extended life cycle for the system. The Seabird VAWT used for this system has a 5 year warranty. The SecondWind C3 Anemometers come with a 10 year manufacturer's warranty and are fully weather resistant. These anemometers have been tested in all types of weather and have proven to last well beyond the warranty period. The electronic components of the system will likely outlast the mechanical components as they are not exposed to external factors such as solar radiation, wind, rain, sleet, snow, etc., and are therefore not a lifecycle concern. Since the system will stand 50 ft. tall, servicing could be complicated. The system is designed to mitigate any need for servicing the higher components. The PAWS system will require servicing about once a year to ensure working quality. The major servicing will test all of the attached batteries to ensure that they are in proper working condition and will continue to hold a charge.

7.5- Financial Analysis

As previously noted, cost is a significant factor in any potential upgrade at a small airport. The economic rationale of public investment decisions concerning project implementation requires the identification and measuring of benefits and costs during the life of the project and calculating the net present value of this flow. Due to the downturn in the recent economy, airport development projects have been the first to experience budget cuts by local governments. FAACT has conducted a cost-benefit analysis using an annual equivalent cost methodology to provide a detailed economic analysis for implementing the PAWS system.

As previously mentioned, a unique feature to the PAWS system is the self-powered element provided by two VAWTs. The system does not use electrical power from the airport runway grid which will eliminate electric bill costs. Thus, the cost of PAWS is comprised of initial cost, installation, maintenance, testing and evaluation, and training.

The cost of PAWS' installation is the sum of the initial cost of the structure, associated wiring costs, and the installation of the system and obstruction light. The team estimated an average of $5,000 for annual maintenance and training costs. To further develop the costs associated with the system, the team chose to outfit a single PAWS system for small airports which typically have only one or two runways.

The service life of PAWS will be measured in terms of a decade. The majority of the galvanized steel structure is warranted for 10 years with associated components (anemometers, VAWTs) having 5 to 10 year life spans. Aside from annual safety checks, the system would only require major maintenance every 10 years. The itemized budget of the PAWS system construction and implementation is introduced in Table 5. As shown, the initial investment costs are less than $10,000. All necessary components and tools were included in this cost estimation. Further considerations include the minimum acceptable rate of return (MARR). The MARR was determined to be 5% as it is the minimum acceptable rate of return that prospective airports would be willing to accept before starting the implementation of the PAWS system after risk and opportunity costs were accounted for.

Item	Description	Unit Cost	Qty	Detailed Amount	Amount
PAWS tower materials and welding					$ 3,828.50
galvanized steel pole	12" round tapered steel	$ 3,341.99	1	$ 3,341.99	
galvanized pipe	2" SCH 10, 3' length Band Saw Cut-0" + 1/16"	$ 24.37	8	$ 194.96	
anti-rust paint	gallons	$ 11.91	2	$ 23.82	
box of welding electrodes		$ 9.00	1	$ 9.00	
welding labor	2-3 days	$ 210.00	1	$ 210.00	
bag of cement		$ 5.82	4	$ 23.29	
metal pipe adapter	1" to 2"	$ 1.59	16	$ 25.44	
PAWS parts and materials					$ 4,926.88
Obstruction Light	Honeywell L810 Red ObLight	$ 95.00	1	$ 95.00	
Paint	384-fl oz Orange Epoxy-Base Paint and Primer in One	$ 249.97	4	$ 999.88	
Anemometers	SecondWind C3 anemometer sensor	$ 145.00	16	$ 2,320.00	
Savonius Wind Turbines	250W DC Silent Wind Turbine	$ 750.00	2	$ 1,500.00	
Assorted hardware	bolts, washers, etc	$ 0.04	300	$ 12.00	
External Components					$ 1,170.95
Weatherproof Box Enclosure	Wiegmann-Junction Box Enclosure	$ 819.00	1	$ 819.00	
Micro-controller	PRO-Plus Board 100MHz	$ 29.95	1	$ 29.95	
Wireless transmitter	PocketWizard MultiMAX Transeiver	$ 295.00	1	$ 295.00	
electrical wire	18-Gauge, 75" multi-colored wire	$ 3.00	9	$ 27.00	
Total Cost of PAWS System and Implementation					**$ 9,926.33**

Table 5: Itemized budget of the PAWS System

Another significant factor in the cost-benefit analysis was the equivalent annual cost (EAC); or the cost per year of owning, operating, and maintaining this asset over its lifetime. The EAC acted as a screening method for this capital budget decision for evaluating the PAWS investment. EAC analyzed the investment beyond its initial lifetime, providing an annualized cost for budgeting purposes. With the use of Excel, the EAC was calculated below using a MARR of 5%, 10 year service life and net present value. (NPV)

$EAC = PMT(rate, nper, npv) = \$5{,}632.35$ annualized cost per year of operation

$Where;$
$PMT = payment$
$rate = MARR\ (5\ \%)$
$nper = 10\ years$
$pv = present\ value, -(\$9{,}926.33)$

Net present value and annualized equivalent cost analyses were calculated using Excel, as shown in Table 6. A ten year service life of the PAWS system will generate a total NPV of -$43,491.52, accounting for initial construction costs, annual maintenance and salvage value of $1,500 in year ten. The NPV is negative in this case because this analysis only considers outflows or costs.

Service Life (years)	Cash Flow
0	$ 9,926.33
1	$ 5,000.00
2	$ 5,000.00
3	$ 5,000.00
4	$ 5,000.00
5	$ 5,000.00
6	$ 5,000.00
7	$ 5,000.00
8	$ 5,000.00
9	$ 5,000.00
10	$ 3,500.00
Net Present Value (NPV)	$43,491.52
Annualized Equivalent (AEC)	$5,632.35

Table 6: Excel spreadsheet used to calculate net present value and annualized equivalent cost

Capital budgeting decisions required distinct methods for determining costs and potential profitability of this new project. The EAC methodology proved most useful for evaluating the system's unequal, but repetitive life spans. As calculated previously, the EAC was calculated at $5,632.35. According to AirNav: *FAA Information Effective 03 April 2014*, an average of 114 aircraft operations occur at HVN daily, approximately 41,610 takeoff/ landings per year. Thus, dividing the annualized cost of system implementation by annual landings yields a system cost of only $0.14 per landing. When put into perspective, this AEC cost accounts for the entire wind shear detection system, increased alert warnings, and pilot and ground operations awareness while increasing the rating of the airport due to more advanced safety precautions.

When identifying the benefits of the system, it is difficult to assign a value on saving a life. FAACT proposes the PAWS system benefits should be measured in terms of preventing fatalities and aircraft damage. When considering PAWS total and annual costs, if just one accident is prevented, or one aircraft saved over the 10 year service life of PAWS, this cost is far less than a damaged or totaled GA aircraft, ($35,000 - $172,000). This significant expense does not even consider the potential loss of life.

During the process of construction and implementation, FAACT will institute a system to evaluate the frequency of times the system is engaged. At the end of the ten year period, the team will have sufficient evidence and data to evaluate the viability of the investment.

8- Conclusions

The PAWS system is intended to actively prevent the threat of wind shear for aircrafts at the runway level. The implementation of this system will mitigate runway incidents at smaller airports, especially those that lack ground control towers. The continuous updates of wind speed and directional patterns will prove beneficial for overall operational awareness of pilots and airport operators. For smaller airports which lack these types of alert systems or ground control towers, this system will prove essential for pilot awareness of low-level runway conditions by adhering to ATIS procedures and reacting to the PAWS visual aid.

PAWS is an affordable and sustainable concept addressing society's need for "green," next generation technology. The design was created considering a variety of technical discussions with airport operations managers and pilots. It is based on a simple and easy to assemble design to deliver efficient and effective data to ground control which will then update to the ATIS in real-time. As pilots approach their final descent, they will be able to call into the specific ATIS frequency of the airport for weather condition updates and alerts.

The team expects that the simplicity, affordability and sustainability of the PAWS system will provide optimal awareness of ground operations to pilots, prevent incidents due to low-level wind shear and increase overall safety of smaller airports. The benefits of PAWS and its ability to conform to current airport operations and FAA regulation procedures will provide a feasible and marketable product for commercial development.

Appendix A- Contact Information

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Appendix B- Roger Williams University

The principles and philosophies carried throughout the University date back to our namesake, Roger Williams. Founder of the State of Rhode Island and Providence Plantations, Roger Williams was the first major figure in colonial America to forcefully argue the need for democracy, religious freedom and understanding of America's native cultures.

Roger Williams University is an independent, co-educational institution with a focus on undergraduate learning, paired with strong, related master's degree programs. The University is also home to Rhode Island's only law school.

Roger Williams University School of Engineering, Computing and Construction Management offers a nationally recognized ABET accredited B.S. in Engineering program and an ACCE calculus/physics based B.S. in Construction Management program. Engineering students may choose among specializations in civil (structural or environmental track), mechanical, electrical, computer or a custom-designed engineering track. Approximately 20% of all engineering students graduating from Roger Williams University immediately enroll in graduate school with the many of these students accepted directly into Ph.D. programs. Five years after graduation, 65% of the school’s engineering graduates are either enrolled in a graduate program or have already completed one.

What is unique about the Engineering program is an underlying philosophy valuing a multidisciplinary approach to earning a professional degree, or education of the whole person. System-level thinking while achieving competence in specialized areas of engineering and construction is stressed. All students graduating from the Engineering program are excellent communicators both in their written as well as verbal skills. Team exercises and projects are incorporated into all classes. The programs in the School of Engineering, Computing and

Construction Management at Roger Williams University exist in an educational infrastructure that is flexible in its ability to address industry needs with regard to characteristics required in new graduates.

Appendix C- Non-University Partners

Tweed-New Haven Regional Airport (HVN)

Tweed New Haven Regional Airport (HVN) is a public airport located in New Haven, Connecticut. The airport resides partially in the city of New Haven, which owns the airport, and partly in the neighboring town of East Haven. This airport is one of only two in Connecticut to have air carrier service. Though not a high traffic airport, it falls within the National Plan of Integrated Airport Systems (NPIAS) for 2011-2015. According to the FAA, Tweed is categorized as a 'primary commercial service' airport because it has more than 10,000 enplanements per year.

US Airways Express the only passenger airline operating at HVN. The flights offered by US Airways Express are between Tweed New Haven and Philadelphia. This airport is, however, popular with private aircraft and companies providing flights to tourists of the Connecticut shoreline. During times of increased traffic due to local University student inflows, the general aviation portion of the airport becomes crowded with private jets.

Tweed New Haven airport covers 394 acres (159 ha) at an elevation of 12 feet (4 m) above mean sea level. HVN has two asphalt runways: 2/20 is 5,600 by 150 feet (1,707 by 46 m) and 14/32 is 3,626 by 100 feet (1,105 by 30 m). According to 2012 records, HVN had 41,598 aircraft operations, average 113 per day: 89.8% general aviation, 7.6% scheduled commercial, 1.6% air taxi, and 1% military.

AAAE

Founded in 1928, the American Association of Airport Executives is the world's largest organization for airport executives, representing thousands of airport management personnel at public-use commercial and general aviation airports. AAAE's members represent roughly 850 airports and hundreds of companies and organizations that support airports. AAAE serves its members through results-oriented representation in Washington, D.C. and delivers a wide range of industry services and professional development opportunities including training, meetings, conference, and a highly respected accreditation program (American Association of Airport Executives, 2013).

Appendix D- Sign-off Form

FAA Design Competition for Universities
Design Submission Form (Appendix D)

Note: This form should be included as Appendix D in the submitted PDF of the design package. The original with signatures must be sent along with the required print copy of the design.

University ____Roger Williams University____

List other partnering universities if appropriate__N/A______________________________

Design Developed by: ☐ Individual Student ☒ Student Team

If Individual Student

Name ____

Permanent Mailing Address ____

Permanent Phone Number ____________________ Email __________________________

If Student Team:

Student Team Lead ___Samantha Gildersleeve_______________________________

Permanent Mailing Address ___118 Commons Rd., Germantown, NY 12526_________

Permanent Phone Number (518) 610-1729_____Email _sgildersleeve663@g.rwu.edu___

Competition Design Challenge Addressed:

Runway Safety/Runway Incursions/Runway Excursions__________________________

I certify that I served as the Faculty Advisor for the work presented in this Design submission and that the work was done by the student participant(s).

Signed ____ *Date*______________________

Name _Dr. Linda Ann Riley____
University/College _Roger Williams University_______________________________
Department(s) _Engineering____
Street Address _1 Old Ferry Rd.____
City _Bristol__________ State _Rhode Island__________ Zip Code _02809_____
Telephone _(401) 254-3896_________________Fax _(401) 254-3562_______________

Appendix E- Educational Experience

Faculty Advisor- Dr. Linda Riley

As a faculty member and mentor to the team, I view the educational experience that the students gained over the past two semesters as extremely valuable to their development as practicing engineers and in their preparation for graduate school. The competition provides an excellent platform for the senior engineering capstone design project in that the open-ended nature of the challenge fits perfectly with the learning objectives of the class. What makes the FAA competition especially effective is that student teams have the ability to stretch their intellectual boundaries. This is especially important for a team such as this one since all four of the students are high-achievers and two will continue with their graduate studies in aerospace engineering. The open-ended nature of the challenge allowed the team to truly delve deeply into subject matter and bring fresh new perspectives to solving and addressing an FAA challenge. This particular team of students, in contrast to past teams of mine entering the competition, were very comfortable and in fact embraced the challenges associated with facing the unknown. With every challenge, they identified paths to solutions or actively pursued experts in the field to assist them in filling knowledge gaps. At this point, they truly are experts on the topic of low level wind shear. Furthermore, they used their expertise to conceptualize and fabricate a very innovative solution that not only is functional, but has been successfully tested at Tweed New Haven Airport.

As expected, at the beginning of the process the students spent a great deal of time researching and meeting with industry experts to ultimately decide on a direction for their problem statement. However having participated in the competition in the past, I had seen this phase before and did not force them into making a hasty decision by adopting a problem statement that may not have been entirely appropriate.

In the future, I see continued participation by RWU in the competition. I feel that this competition is one of the best defined from the perspective of expectations, deliverables and evaluation metrics. In addition, the expert resources made available for students and overall administration of the competition is outstanding.

Undergraduate- Samantha Gildersleeve

The FAA Design Competition has played a very significant role in my academic experience as a mechanical engineer. Not only has it given me the opportunity to exhibit professional and technical skills, but has provided a gateway to the aviation industry. Throughout this competition process, the team has been able to work together and explore solutions that would meet standards for the FAA, various stakeholders as well as our technical and academic mentors. One of the larger challenges faced by the team was the broadness of competition categories and constraints on time to determine a current issue within the industry and propose solutions that would fill a gap between current technology. Extensive research and team communication on our strengths, weaknesses and major interests were methods for overcoming this challenge. After several discussions, the team decided to focus on the issue of wind shear and its lack of detection technology at the runway level because we felt we could integrate our technical and academic backgrounds in mechanical and electrical engineering. Participation by industry was a key factor in our success as it was helpful to receive feedback from industry experts working in the field. Overall, the project has helped with our ability to communicate our ideas to various audiences, develop technical solutions to complex issues and provide insight into the aviation industry. More specifically, it has given me experience with the entry into this field and encouraged me to move forward in pursuing graduate study for aerospace engineering.

Undergraduate- Stephanie Norris

The FAA Design Competition provided a meaningful learning experience for me. This competition gave me, and the rest of the team, our first real chance at using all of the engineering we have been learning for four years. The competition also offered us the ability to work on our professional communication skills. The largest challenge that the team faced was gaining the technical knowledge of wind shear to be able to undertake this system design. This challenge was overcome by doing an extensive amount of research on the subject of wind shear. This resulted in the team knowing wind shear almost as well as professionals. In order to develop our hypothesis, we first had to know what wind shear was and why it was a problem. After figuring that out, the team then looked into technologies that are already in existence for wind shear detection. We discovered that a few different technologies had been developed but there was a niche missing, an affordable detection system. We then started contacting local, GA airports. After contacting Tweed, we began the modeling process of the design. Talking to, and working with, industry professionals was crucial to the project. The industry professionals gave us critical insight into the project and how we could improve our design. Through this project I learned about airport operations. This will be useful in my future career if I choose to go into aerospace engineering.

Undergraduate- Benny Tortorici

The FAA Design Competition provided a meaningful learning experience for me. It was a very unique competition that allowed me to sharpen and utilize my skills. In addition it was a project that offered a lot of freedom where we could identify and solve a problem of our choosing. Over the course of this competition our group faced a number of challenges. These challenges ranged from technical challenges to bureaucratic challenges. As far as technical challenges go, our group needed to understand the properties of various electronic components and combine these with mechanical components. The bridging of these two areas took a significant time and effort. Fortunately, our group was able to overcome these challenges by taking the time to understand the characteristics of each component and utilizing each group member's strengths. The team was able to develop our hypothesis by attempting to find a gap in some area of runway incursions. After many hours of research, the group noticed a significant gap in detecting low level wind shear. The current technology to detect low level wind shear is available but costs an enormous amount of money. Smaller airports cannot afford these types of technologies and so we decided to develop a cost effective and reliable wind shear detection system. Participation by industry was very important in the development of this project. Working in collaboration with Tweed New Haven Airport and Kurt Rodman proved to be imperative and essential to the success of this project. I learned a significant amount for this project. Such as working as a team, improving my technical skills and improving my communication skills. This project will help me in my future endeavors because this project offered an insight into the real world applications and how a problem is actually solved.

Undergraduate- Andrew Wilson

The FAA Design Competition provided a meaningful experience for me in several ways. It provided a valuable experience in communicating with industry professionals, it provided a platform to experience the engineering design process, and it was an excellent opportunity to experience group dynamics. The greatest challenge faced by my group was to come up with a design problem in the first place. This was overcome by research and many group brainstorming sessions. The process used to develop our hypothesis was to propose ideas and then research current solutions. We chose our hypothesis based on what our research yielded. The participation between our group and industry was a very important part of the project. Our industry connection provided critical insight into our project that we had never been exposed to. What I mainly learned from this project was an ability to work with others and communicate with industry professionals.

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