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Title of Design: Utilizing Wind Energy to Provide Runway Lighting at Remote Airports

Design Challenge Addressed: Airport Environmental Interactions

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Number of Undergraduates: 24
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I. Executive Summary

Title: Utilizing Wind Energy to Provide Runway Lighting at Remote Airports

Team: Twenty-four undergraduate students from the Department of Computer Science, Thomas J. Watson School of Engineering and Applied Science

University: Binghamton University – State University of New York (BU)

The Federal Aviation Administration (FAA) recognizes the need for increased safety precautions for runways that experience power disruptions due to climatic conditions, little to no daylight due to location, and remote runways without access to an electrical grid. Such obstacles either provide grave conditions for landings and takeoffs or prevent flight completely. Because the need for solutions to these problems is so important, the FAA addresses these issues in the 2009-2013 Flight Plan and Portfolio of Goals.

Proposed herein is a system that provides a cost effective and environmentally friendly solution to these problems. The system utilizes wind energy to charge batteries that will consequently power runway lights. The system provides redundancy for reliability and is comprised of two wind turbines, two battery packs each consisting of two 12 volt (V) automotive style batteries, an inverter/charger, and a constant current regulator. An optional second redundant system is included in the design consisting of a backup gasoline or diesel powered generator. The system is capable of providing enough energy to power 60 runway lights continuously for approximately 10 hours. Sixty lights will provide the lighting capacity necessary for runways of up to 4,400 feet in length, assuming the runway has 22 lights per side, spaced 200 feet apart, and eight threshold lights on each end of the runway

This system can provide a solution to the FAA goals of keeping remote runways properly lit, while being environmentally friendly and financially competitive.

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II. Problem Statement and Background

Remote locations off the power grid present severe logistical challenges for airfields in varying locations across the United States. There is a need to provide runway lighting in areas that are so remote that no electricity is available to power runway lights, areas where climatic conditions have created power disruptions, or where daylight landings may be impractical depending on location or need. Some areas of Alaska, for example, are so remote that the availability of electricity is limited [3], severe weather conditions inhibit maintenance (Chad Nixon), or experience darkness 24 hours per day during some periods of the year [4]. In addition, recent emergency aid efforts in Haiti were aided by the availability of lit runways at the airport in Port-au-Prince. In the aftermath of a natural disaster, power could be disrupted for days or weeks at a time, thus takeoffs and landings are limited to daylight hours.

Proposed here, is a method to provide 100 percent (%) of the energy required to power remote runway lighting for general aviation runways via batteries charged by wind energy through a wind turbine system. The highlights of this system include easy installation and transport to remote locations, energy efficiency, and environmentally safe practices. The proposed system is small and portable, and can provide energy when standard means are infeasible due to location, climatic conditions, or other inhibiting factors. It is ideal for installing during emergencies to facilitate rapid responses by providing the energy necessary to provide power to the runway lighting infrastructure. In addition, the proposed system is energy efficient and environmentally friendly. No power will be drawn from existing sources of energy, because this system has the potential to provide lighting to remote runways and to replace existing systems that burn fossil fuels. This system will not only allow remote airports to power their runway lighting systems completely from wind energy, but also utilizes Light Emitting Diode

(LED) lighting rather than traditional incandescent lighting, which is less energy efficient.

The ease of deployment to remote runways and environmentally safe energy grid independence of the proposed system directly addresses the criteria of the "Airport Environmental Interactions" section of the Technical Design Challenges for this competition [5]. Furthermore, it is an expressed goal of the FAA to lower accidents in Alaska, where many remote runways exist, and become a world leader in environmental standards for airports, as stated in the FAA Flight Plan for 2009 – 2013 [6].

In the past, emergency lighting systems have relied primarily on fossil fuel burning generators to power remote runway lighting. A complete system, such as the Emergency Airfield Lighting System (EALS), produced by Multi Electric Manufacturing, provides runway edge, approach, threshold, taxiway, and distance-to-go marker lighting [7]. The EALS system requires diesel fuel to power quartz-halogen lamps through a generator [7]. Diesel and gasoline powered generators, present a host of difficulties including the task of providing fuel during harsh weather conditions, especially to remote locations, such as many runways found in Alaska, and the impact of burning fossil fuels on the environment. If a generator fails and the runway is not lit, catastrophic events could occur. In 2006, a Comair regional jet crashed and killed 49 of the 50 passengers, because the runway was not properly lit [8]. Events such as this show the importance of runway lighting.

Addressing and improving runway lighting systems at remote and small runways is a step towards fulfilling several stated goals of the FAA. In the FAA‟s 2009 Portfolio of Goals, it states to "enhance our [its] ability to respond to crises rapidly and effectively" [9]. Recent events in Haiti have made it clear that down time in airports can have serious consequences for the delivery of relief efforts and aid [10]. Runway lighting is of the utmost importance for planes to land; planes were able to land in Port-au-Prince, Haiti despite the lack of communication with the radar control tower, because the runway lighting system was working effectively [11]. Although the focus of this proposal is on general aviation airports, events have shown that emergency power for runway lighting systems is also an issue for major air hubs [12].

Boston‟s Logan Airport has experimented with the idea of harnessing wind power by constructing a wind farm consisting of 20 small wind turbines that will provide an annual electrical output of approximately 100,000 kilowatt hours (kWh) and save $13,000 annually in utility costs [13]. Wind turbines can generate a significant amount of energy, and as this proposal will show, even a very small wind turbine can produce enough energy to light an entire runway. Where Logan Airport is using wind turbines to provide power to their building facilities, this system proposes to charge and store energy in 12V batteries, exclusively for powering runway lights, which will enable landings and takeoffs at remote runways 24 hours per day in an environmentally sound manner. This system has the potential to help rural airports run more efficiently and allow planes to land at night, which is another goal of the FAA, as referenced in the FAA Flight Plan 2009-2013, "Improve rural airports to permit 24-hour Visual Flight Rules (VFR) access" [6].

Utilizing wind turbines to power runway lights has the potential to move the industry forward in several areas, notably providing access to remote runways, where electricity is not available, and providing environmentally friendly energy efficiency. By using a wind turbine system to power runway lighting at remote airstrips, the airline industry could accomplish three of its goals for the future [6]. First, this system is capable of powering runways lights, regardless of the condition or availability of the general electrical power grid. Secondly, this system provides a renewable energy solution and can reduce emissions typically associated with traditional power sources. Finally, the portability of our system presents a good opportunity for lowering the cost of expanding airfields. The proposed system is small and thus can be transported and installed with minimal time and cost.

III. Summary of Literature Review

To understand how to provide runway lighting or obstruction lighting to remote runways using wind energy required research in four key areas; the FAA requirements for obstruction lighting and runway lighting, wind turbines, battery technology, and safety.

Various FAA documents as well as other outside sources were analyzed to gain knowledgeable information in such areas. Originally, research was centered on both runway lighting and obstruction lighting. As work progressed, however, the project was narrowed to runway lighting rather than obstruction lighting. This literature review is a culmination of research for both runway lighting and obstruction lighting.

i. FAA Requirements and Electrical Properties for Lighting

Runway lights are an essential part of an airport in order to allow for aircrafts to safely land and takeoff. There is a vast array of different lights and the FAA has specific requirements as to how they must be implemented in order to minimize hazards. The runway lights are classified into three categories as shown in *Table 1*:

Runway In-Pavement Lights	L-850A, L-850B, L-850C, L-850D, L-850E, L-850F, L-850T
Taxiway In-Pavement Lights	L-852A, L-852B, L-852C, L-852D, L-852E, L-852F, L-852G, L-852J, L-852K, L-852S, L-852T
Elevated Lights	L-804, L-860, L-860E, L-861, L-861E, L-861SE, L-861T, L-862, L-862E, L-862S

Table 1. The three categories of runway lights determined by the FAA [14].

These light fixtures must meet strict environmental standards, as runway in-pavement (see *Figure 1*) and taxiway in-pavement lights must be able to operate in temperatures ranging from negative 40 degrees Fahrenheit (˚F) to 131˚F. These lights must also be able to perform under temperature shock, salt fog (exposure to a corrosive salt atmosphere), extreme wind conditions (velocities of up to 300 miles per hour (mph) for built in fixtures and 150 mph for elevated fixtures), precipitation (rain, snow, ice), and solar radiation. The lights must also meet specific electrical requirements. For example, all L-862 fixtures as well as all in-pavement light fixtures must use a constant current of 6.6 amperes (A). All L-860 light fixtures must use a constant voltage of 120/240 volts alternating current (VAC). The L-861 fixtures and the L-804 fixtures can use either a constant current of 6.6A, or a constant voltage of 120/240V AC [14].

Figure 1. A runway in-pavement light at the Greater Binghamton Airport in Binghamton, New York.

Obstruction lights are another necessary requirement for safe operation of airports and the FAA recommends that any tower higher than 200 feet, be lit 24 hours per day. The FAA also has explicit requirements as to how obstruction lights must be implemented. There are currently seven different types of obstruction lights: L-810, L-856, L-857, L-864, L-865, L-866, and L-885 [15]. Like runway lights, these light fixtures must meet similar environmental standards. Obstruction lights must be able to operate in temperatures ranging from negative 40˚F to 130˚F, as well as humidity of up to 95% relative humidity, wind speeds of up to 150 mph, wind-blown rain, salt fog, and solar radiation. All seven obstruction light fixtures have the same electrical requirements, as they all must use a constant voltage of 120/240VAC [15].

To monitor the conditions of runway and obstruction lighting, the Airport Lighting Control and Monitoring System's (ALCMS) minimum requirements establish a network-like system by which all auxiliary services feed off a central controlling unit called, "The Electrical Vault Computer/Processor." This system is responsible for sending and receiving data and commands from various nodes, which have been established around the airport. Implemented as a touch screen interface, a master Human Machine Interface (HMI) is used by Airport Traffic Control (ATC) to display and control all available nodes connected to the ALCMS [14].

The functionality of these nodes accomplish a variety of tasks, the most crucial of which are: airport power monitoring/management, airfield ground lighting control, beacon and obstruction lighting control (if the surrounding environment requires it), and a stationary HMI for all airport ground lighting control/information display. The model presented by the ALCMS allows room for expansion; optional and new systems can be added to an existing configuration as long as an appropriate interface to the ALCMS is specified [14].

Figure 2. The Binghamton University wind turbine (Photographer Jonathon Cohen)

Current state-of-the-art airport lighting-systems demonstrate the ability to utilize low power lights to provide the required lighting. The ADB L-810 model utilizes LED technology, which provides a robust, durable, and cost-efficient solution that meets all FAA standards for runway and obstruction lighting [16].

Monitoring the conditions of runway and obstruction lighting is especially important at remote runways. The northernmost location in the United States is Point Barrow, Alaska. The closest airport to Point Barrow is the Wiley Post-Will Rogers Memorial Airport in Barrow, Alaska. According to the Astronomical Applications Department of the United States Naval Observatory in Washington, D.C., Barrow has 24-hour sunless days from the end of November through the end of January [4]. In order to support continuous airport operation at Barrow, the lighting system would need to be capable of operating 24 hours per day.

ii. Wind Turbines and Wind Speeds

In order to provide electrical power using a wind turbine, it is crucial to select the right turbine. It must be able to provide enough power with the given wind speed at the desired location and it should be able to withstand maximum wind speeds at that location.

A wind turbine, built by a BU group of students, (see *Figure 2*) has a maximum power output of 1kilowatt (kW) that can be achieved at wind speeds of 25 mph and is used to charge a regular 12V car battery. With the wind speeds at BU, it has the capability of producing roughly 1,220 kWh every year. The cost for building and installing the wind turbine was a mere $3,680 [17].

Bergey Windpower offers several wind turbine models. One of which is the BWC XL.1. This 1kW turbine is currently available only as a 24 volts direct current (VDC) battery-charging system. Its low wind speed performance is greatly enhanced by a low-end-boost circuit that optimally loads the wind turbine down to wind speeds as low as 5.6 mph. The XL.1 is capable of producing 6,000 hours of useful energy a year at a "typical" site. It is offered with a tubular tilt-up tower in heights from 18 meters (m) to 29 m, and XL.1 includes the BWC PowerCenter controller, which controls the battery charging. The cost of the XL.1 is $2,790 plus an additional $2,000 to $3,000 for the tower [17].

According to annual wind data, provided by the National Climatic Data Center (NCDC), over a period of 50 years through 2002 the average wind speed throughout the entire United States (US) was 9.1 mph [19].

iii. Storage Battery Technology

When using a wind turbine system to provide electrical power to a battery, choosing the correct storage device is critical. Storing energy allows the system to deliver stable power by using the battery as a buffer. The battery must be able to handle continual charging and discharging. Reliability and low maintenance are key attributes as well.

According to ABS Alaskan, lead acid storage batteries are a cost effective way to store generated power for reuse. These batteries can be charged from various sources such as wind generators and Pulse Tech conditioning systems can be used to extend battery life in demanding conditions [20].

Wind & Sun of Arizona offers an alternate to wet lead acid batteries. They have developed Absorbed Glass Mats (AGM) technology. AGMs are spill proof and can be mounted in unstable conditions, like buoys and towers. These units have a charge energy conversion of over 99% and have high charge retention with low charge heating. AGMs are a good match where high reliability conditions exist [21].

In order for a direct current (DC) battery to supply alternating current (AC) power, its electrical output must pass through an inverter. Analytic Systems builds inverters with low input capacitance that are military grade. The inverters can input a battery voltage from 12-24V and produce a stable output of 120V AC and 300-1,000 watts (W). This type of inverter will work well in outdoor low maintenance conditions [22].

According to "Introducing Wind Power to SUNY Binghamton," the BU wind turbine system uses a Lifeline GPL-31T deep cycle marine battery. This battery was selected due to its ability to withstand repeated charge and discharge cycles. The most important attribute is the battery‟s capacity, which is rated at 105 amp hours (Ah) at a 20-hour rate [17].

iv. Computer Systems and Battery Charging

A computer interface between the system and airport operators is important for efficiency. Present-day processors have a wide range of utility, and in turn have a wide range of operating power consumptions. Since a powerful processor is not necessarily required for a battery charging system, a low voltage processor would be enough to handle the task of managing the power that the wind turbine produces. Such low voltage processors are rated at anywhere from 0.65W to 13W in Thermal Design Power (TDP), while more powerful processors can be rated at 55W TDP. The Thermal Design Power rating determines how much heat energy needs to be dissipated by the system, not necessarily energy consumption, as different machines may have different energy requirements [23].

Currently, PassMark Software offers a software suite that can monitor the information of a laptop's battery. The software can track the charge, energy dissipation, as well as log information on one or many batteries [24]. It is possible to build a micro-controlled circuit that can automatically determine where to direct the electrical output produced by the wind turbine and to transmit it to any number of destinations. Software would not be necessary in determining where the energy is directed, merely a microcontroller [25].

v. The FAA and Safety

The FAA provides specific steps to ensure the reliability and safety of all airports and aircraft. Procedures are in place for identifying hazards, analyzing risk, assessing risk, and treating risk. Risk analysis includes identifying existing mitigations and controls, as well as how large the impact of the risk could be. Risk assessment includes ranking hazards by severity and selecting which hazards require treatment. Finally, the treatment of risk is the process of identifying options to deal with hazard(s) and developing a treatment plan to mitigate the hazard [26].

Safety Risk Management (SRM) is at the heart of the Safety Management System (SMS). It is through this that hazards, risks, and design risk mitigation strategies are identified. Safety assurance is also an important aspect of a SMS, which involves numerous activities: oversight and audits; working with those directly responsible for analyzing hazards, and providing feedback to the SMS group. Both SMS and SRM need to be utilized in the process of deploying wind turbines for lighting. In fact, lighting is directly addressed as, "a comprehensive SMS using SRM will develop layers of safety built upon the measures taken to mitigate risk. These layers are examples of implemented protective measures such as ... marking and lighting standards" [27].

The goal of the FAA is to limit the general aviation fatal accident rate to no more than 1.11 fatal accidents per 100,000 flight hours [9]. In order to ensure that this goal is met, it is necessary to address proper lighting of runways and obstructions towers. For those airports that do not have the means or ability to light their runways or place obstruction lighting in their surrounding area, a new solution will need to be implemented to achieve this goal. For example, in Alaska 128 accidents occurred during the calendar year of 2005 [6]. In order to reduce this number, more aggressive safety measures must be implemented.

IV. Problem Solving Approach

Finding a cost effective method to illuminate areas vital to air traffic and safety is a challenging task. The focus of the team since the beginning of our discussions revolved around using a wind turbine built by former students from the Thomas J. Watson School of Engineering and Applied Science at BU as a primary component to provide power for runway and obstruction lighting. The team considered mainly three situations in which a wind turbine would be most applicable. First, the team considered providing runway lighting to remote airstrips where a power grid is not available. Second, the condition in which an airport has lost power from its primary source. Third, providing electricity to obstruction lights in remote areas, where a considerable investment would be required to provide electricity.

The team for this project consisted of 24 undergraduates, shown in *Figure 3*, and for efficiency, four project teams were formed, each with different requirements and tasks assigned to them. The teams were aptly named "Engineering and Graphics," "Design," "Risk Assessment and Research," and "Strategies and Ethics." The "Engineering and Graphics" team held the responsibility of obtaining photos to document our interactions with industry professionals and airport officials, along with producing all the graphics and visuals needed for the project. The "Design" team‟s focus was to construct all the drawings, mockups, software etc. needed. "Risk Assessment and Research" worked on gathering information on previous or similar projects that could be used to improve our product, along with what technologies would be best to use and certain limitations that may arise in terms of implementing our plans. Finally, "Strategies and Ethics" documented the strategies used by the team, including problems and solutions, discussed maintenance of the product after completion, and included the team‟s evaluation of the project.

Figure 3. The entire team at the Greater Binghamton Airport on the main runway.

Along with these four teams, there was also a Project Leader and an Assistant Project

Leader. The Project Leader began been working on the project in October 2009, and while working with industry professionals and airport officials, she obtained the initial information for the teams to begin work in early 2010. Both the Project Leader and the Assistant Project leader contributed considerable amount of time and effort outside of the classroom to ensure the project proceeded as planned. This included their weekly visits to McFarland Johnson, Inc. to gather information.

Each team met weekly to discuss methods in which to approach the problem, which involved discussions of overall design as well as detailed information regarding the design. The teams followed a schedule to ensure completion of the project in a timely manner. Since the first meeting, where the project was discussed, the team prepared initial questions and planned a visit to the Greater Binghamton Airport (BGM). The team brainstormed on solutions involving a wind turbine developed by students at BU. Another solution we considered was the use of solar power as a primary source of power, but it was decided that solar power would be less applicable in areas such as Alaska, that lack exposure to sunlight during certain periods of the year.

The team then decided to seek advice from experts on whether to use the system for runway or obstruction lighting. Once the decision was made to concentrate on runway lighting for remote airports, the primary focus then moved to devising a solid design and process for implementation of the system. Additionally, the team made sure that any designs strictly followed FAA regulations and guidelines relating to placing components such as wind turbines at airports.

Figure 4. Chad Nixon and Carl Beardsley holding an in-pavement LED light at the team‟s meeting at the Greater Binghamton Airport.

Another issue that required attention was the technical requirements and the type of lights required for use on the runway and on obstructions. In addition to the lights, the team also discussed the type of battery to use and decided to use conventional 12V automotive batteries due to their ready availability and low cost.

To resolve these issues, the team visited BGM to meet with experts for information and knowledge regarding the project (see *Figure 4*). The experts included Chad Nixon, Vice President and Aviation Director of McFarland Johnson, Inc., who provided information regarding engineering concepts and limitations to the design. Also consulting was Carl Beardsley, Jr., the Commissioner of Aviation for BGM and Broome County, who helped clarify any FAA regulations and guidelines this project must adhere to.


Figure 5. Commissioner Beardsley elaborating on in-pavement lights at BGM.

During the visit to the airport, the team spent much of the time discussing initial strategies in solving the problem. In addition to the discussion, the team observed the conditions of an airport runway and the runway lights by inspecting the main runway at BGM (see *Figure 5*). Two weeks after the visit, the industry experts were invited to meet with the team on the BU campus for finalizing the design schematics and implementation strategies. The meeting involved an in-depth discussion of the turbine-powered system and a presentation of the schematics. With the help of the experts in the meetings, the team was able to arrive at a complete design. After finalizing the design of the system, the team immediately began working on the final stage by preparing the necessary formal documents for the project.

The original concept of using a wind turbine as a source of power for runway lights was very abstract, but evolved into a detailed final design specification. Wind turbines, standard 12V car batteries, and several types of lights were considered. After careful review with the expert engineers at McFarland Johnson, Inc., the concept was finalized into a design where the wind turbine system can serve as a primary source of power to provide lighting to remote runways.

For a case study of the design, the team targeted airports in areas such as Alaska, which are remote locations without access to a primary source of electricity. It was concluded that the proposed system would work well in that environment.

V. Safety & Risk Assessment

Whenever implementing a new system, it is critical to assess the potential safety and risks that could occur. The following analyzes the safety and risks associated with the proposed system.

i. The Impact of Wind Energy on Wildlife and Human Health

The main impact that wind turbines have on wildlife is the number of bird kills. However, while birds do collide with wind turbines at some sites, modern wind power plants are collectively far less harmful to birds than are radio towers, tall buildings, airplanes, vehicles, and numerous other manmade objects. In the past at many wind farms, avian studies conducted show that bird kills per megawatt (MW) average one to six per year or less, with the exception of a single 3-turbine plant in Tennessee that has recorded 11 per MW per year. These include sites passed by millions of migrating birds each year. In fact, several sites reported no bird kills. The National Academy of Sciences estimated in 2006 that wind energy is responsible for less than 0.003% of bird deaths caused by human (and feline) activities [28].

At this point, the American Wind Energy Association (AWEA) is not aware of any scientifically peer-reviewed information demonstrating a link between wind turbines and negative health effects. Thousands of people around the world live near wind turbines without ill consequences [29]. In fact, wind energy has been shown to improve air quality having a direct impact on human health [29]. The generation of electricity from the wind does not result in any air emissions. By offsetting more polluting forms of energy generation, wind energy can actually improve air quality and human health.

Lastly, there is the issue of shadow flicker. Shadow flicker occurs when the blades of a turbine pass in front of the sun to create a recurring shadow on an object. Computer models in wind development software can determine the days and times during the year that specific buildings in close proximity to turbines may experience shadow flicker. Based on the knowledge of shadow flicker patterns, mitigation measures such as setbacks or vegetative buffers can be taken in order to avoid the effects of shadow flicker. Issues with shadow flicker are less common in the United States than in Europe due to the lower latitudes and the higher sun angles in the United States. Shadow flicker has also been shown to not affect persons with epilepsy because shadow flicker from wind turbines occurs much more slowly than the light "strobing" associated with seizures. The strobe rates necessary to cause seizures in people with photosensitive epilepsy are three to five flashes per second and large wind turbine blades cannot rotate this quickly [29].

ii. Daytime Lighting Requirements for Wind Turbines

The FAA recommends that any structure exceeding 200 feet above ground level (AGL), or less near airports, to be marked and/or lighted. Standards for marking and lighting are set forth in FAA Advisory Circular 70/7460-1K [30]. These standards apply to communications towers, water towers, bridges, wind turbines, or any other large structure exceeding 200 feet, unless the structure can be proven to not interfere with flight. The wind turbine used in this project stands a mere 30 feet high, making it low enough to comply with FAA regulations.

iii. The Effects of Weather on the Wind Turbines

In order to take advantage of electricity generated by wind turbines, to light a runway in a remote area, many safety concerns need to be addressed. Wind turbines, built in cold climates, are prone to ice throw. The structural integrity of the wind turbine as well as the flicker effects produced from a rotating wind turbine are two aspects of the wind turbine that need to be examined. Furthermore, wind turbines have the ability to produce interference with radar. Without safety precautions taken to address these factors, it would be impractical and dangerous to use wind turbines near a remote runway to power the runway lights.

Ice throw is a major concern for wind turbines that operate in cold climates. Ice accretion occurs several ways on wind turbines, the most dangerous of which is rime icing occurring when the wind turbine is subjected to sub-zero temperatures, incident flow with significant velocity, and liquid water present [31]. Ice fragments in the range 0.1kilogram (kg) to 1kg in mass can travel a minimum of 15 to 100 m from the wind turbine posing a threat of ice flying into the engines of planes taking off and landing [31]. Most ice shedding occurs when the temperature rises and the ice begins to thaw, loosening it from the rotor [31]. Ice can accumulate on top of the nacelle housing and fall directly to the base of the turbine due to the heat from the generator and gearbox, posing a threat to maintenance workers [32].

These safety issues regarding wind turbines constructed near airport runways is solved by placing wind turbines at a safe distance away from the runway. As long as the turbine is far enough away from the runway, such issues will not cause a problem to the safety and continued use of wind turbines for airport runways in remote areas. Fortunately, the wind turbine proposed for this project stands only 30 feet off the ground. Since the turbine is so small and close to the ground these safety issues do not apply to the wind turbine used in this project.

iv. Airspace Issues in Wind Turbine Sites

One of the most important milestones in any wind turbine project is securing a determination from the FAA that the project does not adversely affect air traffic or radar systems. The FAA has oversight of any object that could have an impact on the navigable airspace or communications/navigation technology of aviation (commercial or military) or DOD operations. There are several types of airspace impacts: (1) imaginary surface penetration, (2) operational impacts, and (3) electromagnetic interference [33]. Following an analysis of these FAA Regulations by professional aviation consultants at McFarland Johnson, Inc, it is evident that at a height of 30 feet and placement near an already existing building at the airport, which houses the system‟s batteries and other hardware, the wind turbine proposed here is unproblematic for these issues.

VI. Technical Aspects Addressed

The proposed system provides a portable, environmentally friendly, and cost effective solution to providing runway lighting at remote airports where a standard electrical grid is not available. In a simplified sense, the system converts wind energy from wind turbines to electricity, which charges two battery banks consisting of two 12V batteries each. The batteries then provide 24V DC to an inverter, which converts the 24V DC into 240V AC. The 240V AC provides power to a constant current regulator (CCR), which in turn provides the necessary power to light the runway lights.

As seen in the *Figure 6* (below), there are ten required components of the proposed system with one optional piece. The components consist of: two wind turbines, two battery packs, two smart switches, one inverter/charger, one constant current regulator (CCR), LED runway lights (including 44 edge lights and 16 threshold lights), and an optional back up gasoline or diesel powered generator.

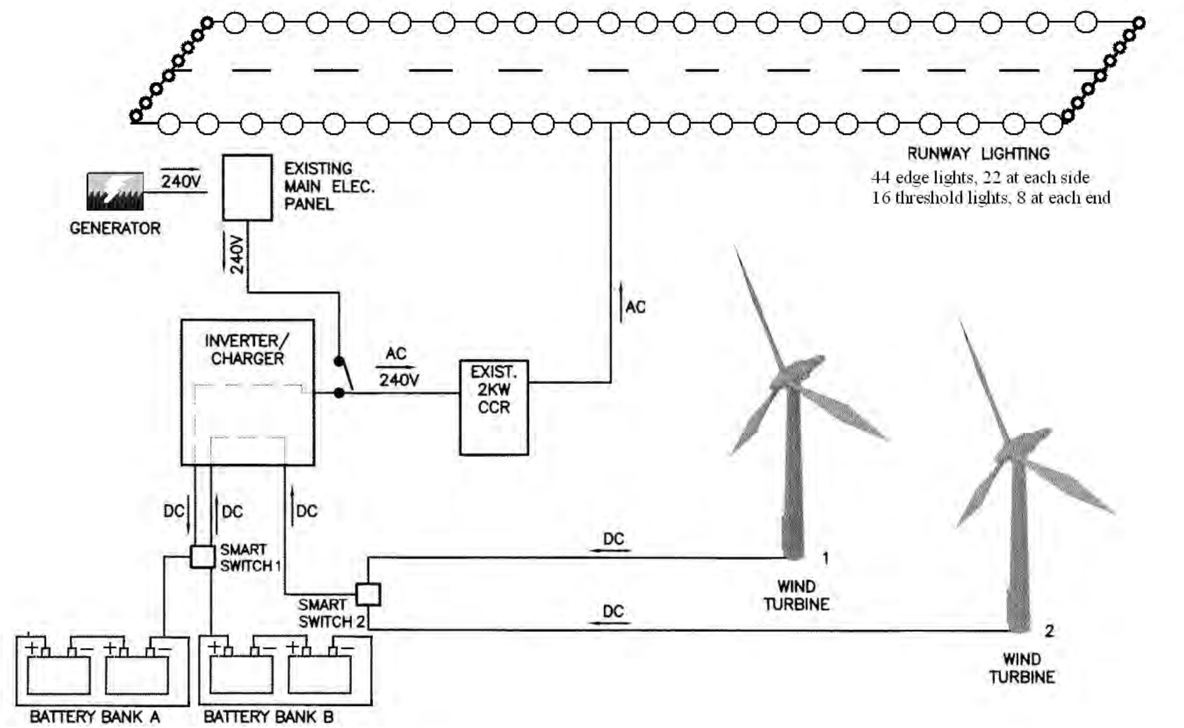

Figure 6: Proposed wind turbine system (shown larger in Appendix K)

By using two wind turbines and two battery packs, the system is redundant. Therefore, if one wind turbine or one battery pack fails, the system can still perform effectively. An optional gas or diesel generator provides additional measures to ensure stability. Often times, remote runways already have a generator system in place. All required and optional components are listed in *Table 2* (below).

REQUIRED	
2 BU Wind Turbines	-only one is necessary for the system, two creates redundancy
2 Battery Banks	-each bank includes 2 „27 TMX 12V Deep Cycle Batteries" -only one is necessary for the system, two creates redundancy
Inverter / Charger	-charges both battery packs and converts 24 VDC to 240VAC
Constant Current Regulator (CCR)	- manufactured by Manairco, Inc.
LED Edge Lights	-22 L-861 LED Elevated Taxiway Edge Lights"spaced 200 feet apart on each side of the runway -44 in total
LED Threshold Lights	-8 L-861 LED Elevated Taxiway Edge Lights"on each end of the runway -16 in total
Smart Switch 1	-enables the management of battery usage by controlling the 24 VDC between the inverter/charger and batteries
Smart Switch 2	-enables the management of wind energy by controlling the flow of 24 VDC from the turbines using an "and" or an "or" operation
Customized Software	-specialized software designed to control and monitor the system
Customized Hardware	-a specialized low power controller to support the necessary software
OPTIONAL	
Gasoline/diesel powered generator	-provides power for additional redundancy

Table 2. System components.

The design makes the following assumptions:

- We assume the FAA will adapt medium intensity LED runway lights soon, following on recent FAA certification of other LED intensities. This system utilizes medium intensity L-861 LED elevated taxiway edge lights, which are equivalent to low intensity LED runway edge lights, with only a different lens color (Chad Nixon).

- We assume that a 240V CCR, appropriate cables, facility to store the battery packs, 60 L-861 LED lights (or comparable), and a gas or diesel generator are already in place, or could be placed, at the designated airports. This system will tie into the existing AC system (Chad Nixon, Charles Howe).

- We assume that the L-861 LED lights have white, red, and green lenses, thus eliminating the need to change lens colors.

The proposed system is able to provide electricity for runways up to 4,400 feet in length. The following text and calculations describe the system based on a 4,400-foot runway, thus maximizing the system. However, these calculations may be extrapolated to runways less than 4,400 feet.

i. Wind Turbines

Two wind turbines, designed by BU students [17], are used as the primary source of power. The blades of each turbine are 8.5 feet in diameter. The start up speed for the blades is 6.7 mph, where the blades are most efficient at 18 mph wind speeds. The blades incorporate a furling mechanism allowing them to turn out of the wind at a desired wind speed, preventing the generator from overheating and eliminating resistance on the blades. The following formula is used to calculate the power (P):

Equation 1 $$P = 2\,D^2\,V^2$$

Where: *D* is the diameter of the blades
V is the wind speed.

Each turbine has the capability of producing roughly 1,220 kW per year, where the maximum power output of 1kW can be achieved at wind speeds of 25 mph. Each turbine supplies a 12V DC output that flows through smart switch 2, when permitted, through the inverter/charger, surpassing any modification, and finally through smart switch 1, when permitted, to charge the battery banks.

ii. Smart Switch 2

Smart switch 2, located at the junction of the cables extending from the wind turbines, manages the connection of the wind energy, produced as 12V DC, to the inverter/charger. One or both wind turbines may provide wind energy, decided by a negative or positive charge within the switch. The wind energy then flows from the switch through a single ground wire into the inverter/charger, where it is unmodified and utilized to charge the battery banks via the charger.

iv. Smart Switch 1

Smart Switch 1 located at the junction of the cables connecting both battery packs and the inverter/charger, manages the input of power to the battery packs. The switch will provide power to each battery pack until fully charged. Without this switch, the batteries may be overcharged and explode. Consequently, either battery pack may be chosen to charge.

v. Batteries

Figure 7: Bank of two Trojan Deep Cycle Batteries.

The energy produced by both wind turbines is stored in two battery banks (see *Figure 7*), each consisting of two 27 TMX 12 V Deep Cycle Batteries connected in series to provide 24V DC in total [34]. The output of the charger side of the inverter/charger, charges both battery banks, one at a time.

The capacity of each battery is 105 Ah, meaning each battery can supply 105A to the system for one hour. The basic formula is as follows:

Equation 2 $$t = \frac{Q}{I}$$

Where:

- t is the discharge time
- Q is the capacity of the battery when discharged at a rate of 1A
- I is the current drawn from the battery (also known as rate)

It is inferred from *Equation 2* that the discharge time (t) of each battery depends upon the available capacity of batteries and the rate at which it is discharged (I). If the batteries are charged at a high rate then the available capacity will be lower than expected. Since the CCR in the system requires 8.5A, using 80% of the batteries (105Ah * 80% = 84Ah), each battery bank can supply power to the system for approximately 10 hours (hours = 84 Ah/8.5A = 9.88h). Using a Xantrex inverter/charger, which is discussed in the following section, the charger provides 4,000W when 240V is provided. Since:

Equation 3

$$P = I * V$$
$$4000 = 240 * I$$
$$I = 166.6\ A$$

Where:

- I = current
- V = volts
- A = amps

We can conclude that 166.6A will be produced by the charger. Charging the batteries to 80% of their capacities (105Ah * 80% = 84Ah), the charging time of one 12V battery will be half an hour (84Ah/166.6 A = 0.5 hours). Using two batteries for each battery bank, the total charging time of each battery will be an hour. The duty cycle of batteries is shown in *Figure 8* (below).

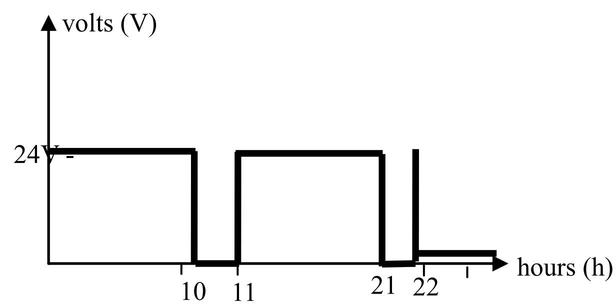

Figure 8. The duty cycle of the batteries

vi. Inverter / Charger

The energy produced by the wind turbines is transmitted into the inverter/charger, where it is utilized by the charger to charge the batteries. After the batteries are fully charged, the electricity then flows back into the inverter/charger. At this point, the inverter transforms 240V AC from 24V DC to power the CCR and consequently the runway lights. The Xantrex Hybrid Inverter/Charger provides 4,000W at 240V [35].

vii. Constant Current Regulator

The CCR provides a constant current to all runway lights, maintaining the required brightness of each light. It is assumed that a CCR similar to that provided by Manairco, Inc., 240V CCR [36] (or equivalent), which exceeds FAA performance requirements, is already in place at the airports in question (Chad Nixon & Charles Howe). Due to its properties, the smallest unit of Manairco, Inc., CCR is able to produce 2kW (2,000W), and it requires 8.5A input from the inverter/charger to deliver a 6.6A constant current.

viii. Runway Edge Lights and Threshold Lights

The Siemens, L-861T Elevated Medium Intensity Taxiway Edge Light [37] with a heater (Model ETES- XX11) was chosen for the lighting system (see *Figure 9*). These lights are designed to be controlled thermostatically, where the heater is turned on when temperatures drop below freezing. However, for safety considerations, the calculations for this system presume that the heaters are always on. The "FAA has certified LED medium intensity taxiway lights as well as obstruction lights. Recently the FAA has also certified low intensity LED runway lights. Medium intensity taxiway lights are used for the basis of our design, which are very similar, if not identical to the anticipated specifications for medium intensity LED runway lights. The underlying assumption therefore is that the evolution of LED lighting certification will lead to the near-term certification of medium intensity runway lighting (Chad Nixon)."

Figure 9. A Siemens, L-861T Elevated Medium Intensity Taxiway Edge Light

The CCR load on each light (the power consumption on the CCR) is 32.5W due to the properties of the lights. Since the system uses a 2kW CCR and LED lights with 32.5W on the CCR, the system can power up 60 lights. See *Equation 4*.

Equation 4 $$\text{number of lights} = \frac{\text{power provided by the CCR}}{\text{light's load}}$$

$$61.5 \text{ lights} = \frac{2{,}000\text{W}}{32.5\text{W}}$$

As shown in *Equation 4*, the proposed system supports 60 lights connected in series. Sixteen runway threshold lights are segmented in pairs of four lights, on each side of the centerline, on each end of the runway. Lens colors of white, green, and red are utilized per FAA requirements for threshold lights. Forty-four elevated white edge lights run the length of the runway on either side. Each light is spaced 200 feet apart per FAA standards.

ix. Customized Software

The design employs software to control and monitor the system. *Figure 10* (below) shows the graphical user interface (GUI) of the developed software.

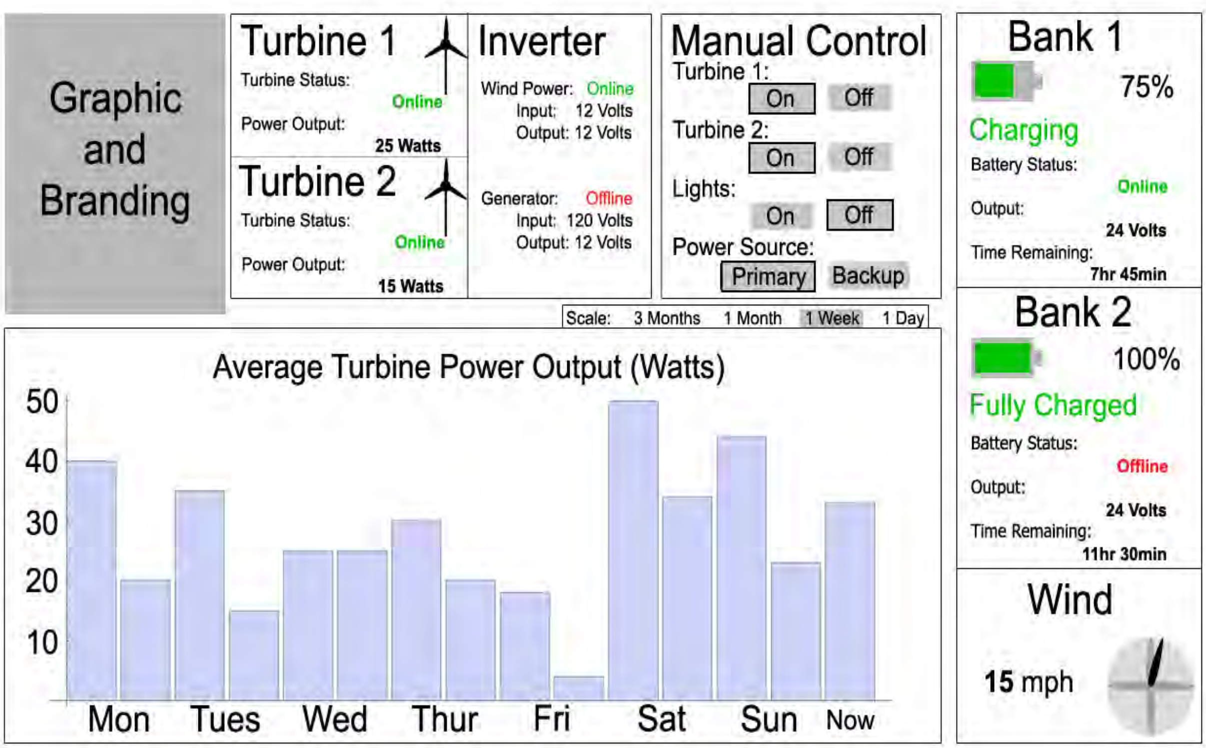

Figure 10. Graphical User Interface

By using the developed software, the user is able to:

- Monitor the entire system including, turbine status, inverter status, power produced by each turbine, battery discharge time, wind speed, and weekly power output from the turbines.
- Control both batteries and turbines. The user can easily switch between battery bank 1 and battery bank 2, and between turbine 1 and turbine 2. This option gives the user control over the smart switches and the switch between the generator and the lighting system.
- Switch to the gas or diesel powered generator in case of failure in the primary system.

x. Customized Hardware – Low Power Controller

A customized low power controller, essentially a very basic computer, will support the necessary software. Specifications of the hardware system are listed on *Table 3* (below).

Motherboard/Processor	-Intel BOXD945GCLF -Intel Atom processor 230 -Intel 945GC Mini ITX Motherboard/CPU Combo
Random Access Memory (RAM)	- G.SKILL 1GB 240-Pin DDR2 SDRAM
Hard Drive	- RiDATA Ultra-S Plus 2.5" 32GB Internal Solid State Drive (SSD)
Case	- APEX MI-100 Black / Mirror finish Steel Mini-ITX Tower Computer Case with 250W Power Supply

Table 3. The hardware used to monitor the system.

xi. Case Study: Alaska

As previously mentioned, the calculations shown in this document are determined for a runway length of 4,400 feet; however, the calculations can be extrapolated for all runway lengths 4,400 feet or shorter. There are 121 Airports in Alaska, of which 61 can benefit from the proposed system. For example, Emmonak, Point Hope, Nuiqsut, Egegik, and Haines, shown in *Figure 11*.

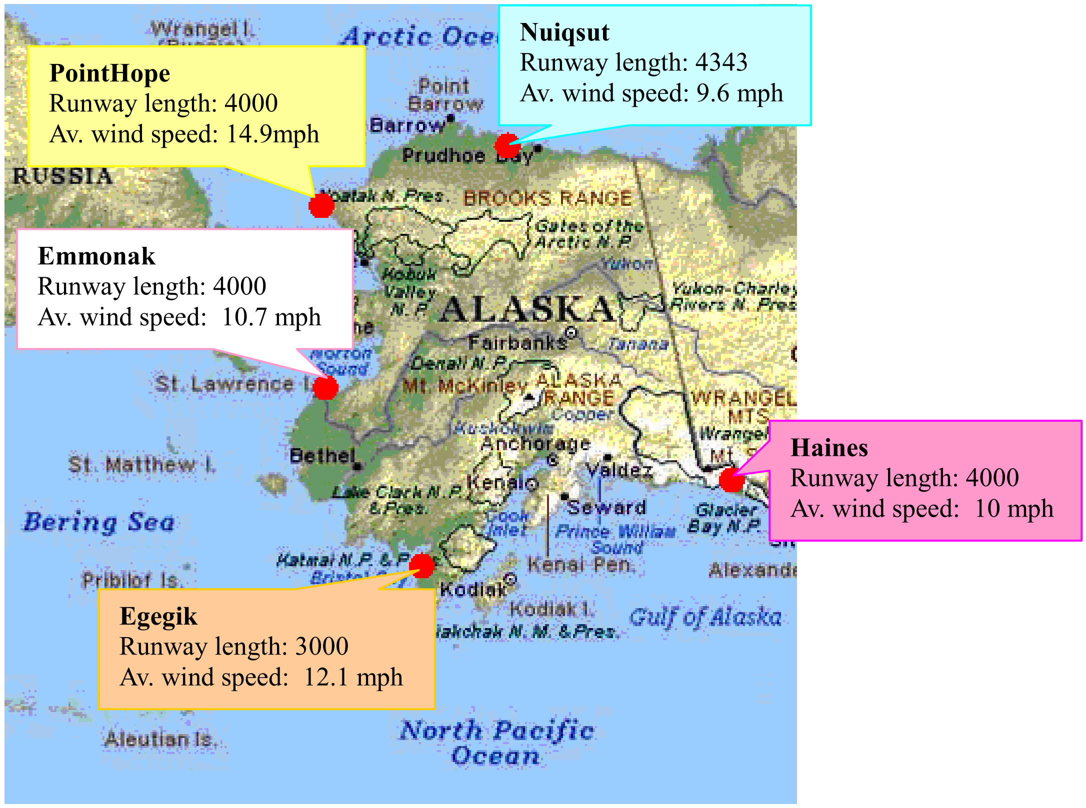

Figure 11 Five example airfields that can benefit from the proposed system [38].

Dillingham and Manokotak airports have remote runways that are less than 4,400 feet.

Figure 12. Dillingham airport [40].

Dillingham airport, shown in *Figure 12*, is located in Dillingham Alaska, southwest of Anchorage. Runway 19 is 1,954 feet in length, thus making it a good candidate for this system [40].

Manokotak airport, show in *Figure 13*, located in Manokotak, Alaska, has two runways, Runway 3 and Runway 21, both of which are under 4,400 feet in length [41]. Manokotak airport sits in a remote location west of Dillingham. It too is ideal for this system.

Figure 13. Manokotak airport [39].

As shown in *Figure 14* (below), the average wind speed in Alaska is 7.58 mph, which is consistent with the wind speed needed for the BU wind turbine to operate efficiently. With higher wind speeds, the system will produce more energy.

Wind- Average Wind Speed- (MPH)

DATA THROUGH 2002	YRS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
ANCHORAGE, AK	49	6.4	6.8	7.1	7.3	8.5	8.4	7.3	6.9	6.7	6.7	6.4	6.3	7.1
ANNETTE, AK	38	11.6	11.8	10.5	10.6	9.0	8.5	7.7	8.1	8.8	11.2	11.7	12.0	10.1
BARROW, AK	69	11.9	11.3	11.3	11.5	12.0	11.5	11.7	12.4	13.2	13.3	12.5	11.7	12.0
BARTER IS.,AK	33	15.1	14.4	13.7	12.0	12.7	11.6	10.9	11.8	13.2	14.8	14.9	13.9	13.2
BETHEL, AK	44	14.5	14.7	13.7	12.9	11.5	11.0	10.6	11.0	11.6	12.3	13.2	13.6	12.6
BETTLES,AK	27	5.8	6.3	7.0	7.4	7.2	6.8	6.5	6.2	6.4	6.4	5.8	5.6	6.5
BIG DELTA,AK	26	11.2	10.2	8.8	8.0	8.2	6.9	6.1	6.6	7.6	8.7	10.2	10.0	8.5
COLD BAY,AK	47	17.5	17.9	17.4	17.5	16.2	15.8	15.6	16.2	16.2	16.6	17.5	17.5	16.8
FAIRBANKS, AK	51	3.0	3.9	5.3	6.6	7.7	7.1	6.6	6.1	6.0	5.3	3.8	3.0	5.4
GULKANA,AK	14	5.0	4.9	6.3	8.5	8.7	8.1	7.7	7.7	7.3	6.0	4.1	3.3	6.5
HOMER, AK	28	7.8	7.7	7.8	8.1	8.2	7.8	7.1	6.6	7.0	7.3	7.7	7.8	7.6
JUNEAU, AK	57	8.1	8.2	8.4	8.5	8.3	7.7	7.5	7.4	8.0	9.5	8.4	8.8	8.2
KING SALMON, AK	47	10.5	11.0	11.3	10.9	11.0	10.5	9.9	10.0	10.4	10.3	10.4	10.1	10.5
KODIAK, AK	49	12.7	12.5	12.5	11.6	10.6	9.3	7.7	8.4	9.7	11.4	12.5	12.6	11.0
KOTZEBUE, AK	56	13.9	13.0	11.9	12.0	10.7	11.9	12.7	13.2	13.2	13.5	14.4	12.9	12.8
MCGRATH, AK	52	3.2	4.2	5.3	6.5	6.7	6.4	5.9	5.8	5.9	5.4	3.7	3.2	5.2
NOME, AK	55	10.8	11.0	10.1	10.1	9.9	9.7	9.7	10.4	11.0	10.5	11.5	10.3	10.4
ST. PAUL ISLAND, AK	28	19.9	20.0	18.8	17.4	14.9	13.6	12.1	13.7	15.4	17.4	20.0	20.1	16.9
TALKEETNA, AK	19	6.0	5.5	5.5	4.7	4.9	5.1	4.2	3.7	3.7	3.8	5.0	4.9	4.8
VALDEZ, AK	22	7.5	7.8	6.7	5.2	5.8	5.9	4.9	4.2	4.3	6.3	7.5	7.0	6.1
YAKUTAT, AK	54	7.2	7.3	7.0	7.1	7.5	6.9	6.6	6.3	6.9	7.8	7.2	7.8	7.1

Figure 14. Average wind data for Alaska [38].

VII. Description of Interactions with Airport Operators

The opportunity to collaborate directly with industry professionals provided a means for answering a large number of the team‟s questions. Most of the project team‟s collaboration was divided between representatives from BGM and McFarland Johnson, Inc. Commissioner of Aviation Carl Beardsley from BGM and Vice President Chad Nixon from McFarland Johnson, Inc. served as the team‟s central contacts during the design process. In addition to these two contacts, the team sought professional advice from several other independent resources as listed in *Table 4*.

Airport Operators and Industry Professionals		
Carl Beardsley	Greater Binghamton Airport	Commissioner of Aviation
Blair Dury	McFarland Johnson, Inc.	Electrical Engineer
Donald Harris	McFarland Johnson, Inc.	Project Manager
Charles Howe	McFarland Johnson, Inc.	Electrical Engineer
Chad Nixon	McFarland Johnson, Inc.	Vice President
Rosemary Aures	McFarland Johnson, Inc.	Environmental
Chris Fales	McFarland Johnson, Inc.	Planning Team
Rick Lucas		
Zachary Staff		
Suleyman Kurucay	Consultant	Electrical Engineer
Prof. Dr.-Ing. M. Mohsen Saadat	South Westphalia University of Applied Sciences, Department of Mechanical Engineering	Mechanical Engineer

Table 4. Industry professionals who provided advice to the project team.

Lauren Hillengas, the project leader, shown in *Figure 15* maintained contact with Chad Nixon by directly working with him and others at McFarland Johnson, Inc. every week. Through her contact with Nixon and the company, the team was able to extend their knowledge base to include electrical engineers, airfield lighting specialists, and appropriate product managers. Beardsley provided his working knowledge of the current light and power configurations found at BGM. In conjunction with Nixon, feasible and professional decisions were made, starting with the decision to concentrate efforts on providing full runway lighting to remote airfields, rather than providing power for standalone obstruction

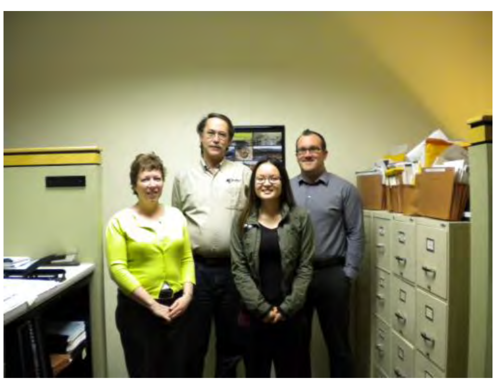

Figure 15. (from the left) Rosemary Aures, Chris Fales, Lauren Hillengas, and Rick Lucas.

or tower lighting. With the assistance of Charles Howe (see *Figure 16*), the possibility of lighting an entire runway was deemed feasible when powered by a bank of only two series-wired industrial strength batteries.

The team considered the prospect of solar powered lights, from Prof. Dr.-Ing. M. Mohsen Saadat‟s advice. However, with the assistance of Mr. Nixon, we concluded that with a target area of Alaska, solar power would not be practical in areas that have 24-hour darkness during certain periods of the year.

Figure 16. (from the left) Charles Howe and Irem Kurucay at McFarland Johnson, Inc.

The entire team met at BGM with Carl Beardsley and Chad Nixon. The goal was to conceptualize the base set of ideas for a wind-driven lighting system and to inspect, first-hand, the runway lighting system at BGM. At this meeting, the team primarily focused on various approaches to providing runway lighting at remote airports that do not have access to electrical power. Providing power to obstruction lighting was originally discussed, but ultimately the team decided to design a runway lighting system using the existing student-built wind turbine at BU. While at BGM, the team toured the runway and inspected the runway lights, as shown in *Figure 17*. Nixon noted that the cost of the BU wind turbine was negligible compared to the expenses currently required to provide energy to remote airports. Alaska was designated as the target service location. The professionals were consulted regarding extreme cold weather effects on lighting and turbines, but further investigation was


Figure 17. Inspecting lighting fixtures on BGM's runway.

needed. The meeting adjourned with the intention of finding out more information about the feasibility of runway lighting with a wind-driven power source.

Commissioner Beardsley and VP Nixon met with the team at BU to finalize the selection of the design solution (see *Figure 18*). Beardsley emphasized that LED lighting was the best solution for the project‟s lighting needs, given its benefits. The most important aspects of LED lighting are longevity of the product and the low energy consumption compared to other lighting solutions. When discussing the cold Alaskan environment, Beardsley commented that BGM‟s LED lights emit enough heat to keep any snow under three feet off the lights, thereby minimizing the use of heaters. Beardsley also pointed out that a drawback of LED lights is their tendency to overheat when used in constricted areas. For a runway however, he added that this would not be an issue. The specific type of lighting chosen was a medium intensity elevated taxiway edge light with a white lens, an equivalent alternative to incandescent lights.

Figure 18. Nixon advising on lighting at Binghamton University

Nixon addressed the question of whether or not the team‟s system should be a primary or emergency source of power. Because of these prospects and the amount of power produced by the turbines through the inverter/charger system, Nixon helped the team conclude that this would become the primary power source of any existing lighting configuration. The low cost of the design prompted the inclusion of a redundant system for

Figure 19. A demonstration of the system using a standard 12V car battery and inverter, used to power a 120 V AC L-861T Elevated Taxiway Edge LED light.

added reliability and FAA compliance. Because of this, two battery banks are included. Alternating these battery banks will avoid deterioration from inactivity. To accommodate this rotation, an embedded system would be used to switch between battery banks, as well as between primary and backup power supplies, when necessary. When leaving the meeting, we decided that our system would be a primary source of runway lighting with an optional complementing backup generator powered by diesel or gasoline. The meeting concluded with a demonstration, shown in *Figure 19*.

VIII. Projected Impacts

The FAA"s goals, as outlined in the FAA"s 2009-2013 Flight Plan and Portfolio of Goals, were a primary consideration in the design of this system. In particular, the devised system meets four FAA goals: increased safety, greater capacity, international leadership, and organizational excellence [9].

i. Increased Safety

First, and most importantly, the proposed system meets the FAA goal for increased safety. The FAA states that its "first commitment is to safety" [6]. This measure aims to constantly strive for the lowest possible accident rates. For the system proposed here, Alaska is used as a case study, and according to the FAA Portfolio of Goals, lowering accidents in Alaska is a primary component of this goal. The FAA continues to work closely with the Alaskan general aviation community to "reduce accidents in Alaska for general aviation and all part 135 operations to no more than 99" [9].

Runway lights are synonymous to road signs for pilots; lights are necessary for both takeoffs and landings [42]. It is of particular importance to ensure that the runway is well lit. This may seem like a trivial issue, but there are many remote runways, in Alaska and elsewhere, that lack an independent power source and do not have access to electrical power [5]. Some existing systems, such as gasoline or diesel powered generators, create dilemmas when fuel supplies are depleted at remote runways. The proposed system eliminates the reliance on generators, while providing a redundant system of wind turbines and battery packs to ensure dependability. In the event that the proposed system was to fail, the existing generator is used as an additional backup system.

ii. Greater Capacity

The proposed system satisfies the FAA goal intended for greater capacity, to increase operational performance by expanding to better meet the projected demand, because "America's airports are the access points for the Nation to the air transportation network" [6]. Because the proposed system has the capability of powering 44 runway lights and 16 threshold lights for 10 hours on one charge, airports without access to electricity can now have lighted runways, permitting increased air traffic at remote airfields. Furthermore, the portability of the proposed system could bolster development of new airfields at remote locations, which are currently not a realistic option, because of the lack of electricity.

iii. International Leadership

Utilizing wind turbines provides an environmentally friendly energy alternative for lighting runways at remote airports. The FAA proposes, "to increase the safety and capacity of the global civil aerospace system in an environmentally sound manner [6]" so that America may continue to be the "gold standard for aviation safety" [6]. Using a natural and renewable energy source, the proposed system shows the international community that the US is committed to increased air capacity to remote locations in an environmentally responsible manner.

iv. Organizational Excellence

Finally, the proposed system meets the FAA goal to provide organizational excellence, which, "is the „how" in executing all other goals" [6]. This can be accomplished with "advanced cost control measures" [6]. *Table 5* provides the total costs of proposed system.

	Unit cost	Quantity	Total Cost
LED Lights	$260.00	50.00	$13,000.00
BU Wind Turbine	$3,680.00	2.00	$7,360.00
Xantrex Hybrid Inverter/Charger	$1,300.00	1.00	$1,300.00
Smart switches	$200.00	2.00	$400.00
MX 12V Deep Cycle Batteries	$157.00	4.00	$628.00
Underground Cable 10 gauge 100'	$104.00	1.00	$104.00
12 Gauge 3 wire 50'	$30.00	1.00	$30.00
Computer system	$477.00	1.00	$477.00
System Software	$200.00	1.00	$200.00
Total System Cost			**$23,499.00**

Table 5. Initial total cost for the system. References: LED lights [17], BU wind turbine [17], Xantren Hybrid Inverte /Charger [43], smart switches (Charles Howe), MX 12V Deep Cycle Batteries [34], wire 10 gauge [44][45], 12 gauge 3 wire [46], computer system and system software based on employee manpower.

The total initial cost of the proposed system is $23,449.00. This is an insignificant amount when compared to the cost of running electricity to the runway from a nearby power grid (Chad Nixon). The cost of entrenching power cables to a remote runway, especially airfields in Alaska, is almost one hundred times more than the cost of the lighting itself. For example, it would cost as much as $56,000 just to trench 9,400 linear feet for power cables, which is approximately $5.95 per linear foot, neglecting labor costs [47]. Labor costs would easily bring the entire project cost over $100,000.

Furthermore, it is estimated that the cost of gasoline to power a generator is approximately $1,575 per year.

Year	Costs	Cumulative Costs	Benefits	Cumulative Benefits
0	$10,499	$10,499	$2,143.84	$2,143.84
1	$524.95	$11,023.95	$2,186.72	$4,330.56
2	$734.93	$11,758.88	$2,229.59	$6,560.15
3	$941.91	$12,700.79	$2,272.47	$8,832.62
4	$1,154.89	$13,855.68	$2,315.35	$11,147.97
5	$1,364.87	$15,220.55	$2,358.22	$13,506.19
6	$1,574.85	$16,795.40	$2,401.10	$15,907.29
7	$1,784.83	$18,580.23	$2,443.98	$18,351.27
8	$1,994.81	$20,575.04	$2,486.85	$20,838.12
9	$2,204.79	$22,779.83	$2,529.73	$23,367.86
10	$2,4514.77	$25,194.60	$2,572.61	$25,940.46

Table 6. Return on investment to ten years.

While the primary goal of the proposed system is to provide lighting to remote runways where electricity is not available, the system is also cost effective. *Table 6* shows a cost-benefit analysis, and compares the costs of the proposed system and the financial benefits over a ten-year period. The maintenance costs are calculated as 5% of $10,499 and increases by 2% each year. The benefit costs are calculated at $2143.84 initially and increase by 2% each year. Maintenance costs are factored in as low percentages, because of the stability of the system. To be conservative, the increase in the percentage of maintenance costs and the increase in percentage of benefits are equal. Beginning at Year 0, the year of installation, the system will provide incalculable benefits of providing access to remote airports. Additionally, at Year 7 the proposed system provides direct financial benefits as well.

The return on investment (ROI) is incalculable because the system‟s intent is to provide access to remote runways. However, from a strictly financial perspective, the ROI can be calculated as:

$$\frac{TotalBenefits - TotalCosts}{TotalCosts} \qquad \frac{25940.46 - 25194.60}{25194.60} = 0.0296$$

This system has an ROI of approximately 3%, which makes for a very small capital risk.

Furthermore, the net present value (NPV) is $1,543, as shown in *Table 7* (below). The following calculations show how the values in *Table 7* were determined:

$$\sum_{x=0}^{n} \frac{C_x}{(1+r)^x}$$

Cash Flows:	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Benefits	$2,143.84	$2,186.72	$2,229.59	$2,272.47	$2,315.35	$2,358.22	$2,401.10	$2,443.98	$2,486.85	$2,529.73	$2,572.61
Discounted Total:	$17,930.69										
Costs	$10,499.00	$524.95	$734.93	$941.91	$1,154.89	$1,364.87	$1,574.85	$1,784.83	$1,994.81	$2,204.79	$2,414.77
Discounted Total:	$19,473.69										
NPV	$1,543.00										

Table 7: Net Present Value (NPV) Calculation

C_x is the cash flow for a given year *x*. In order to discount it to the present period, it must be divided by $(1+r)^x$ where *r* is the interest rate, and r = .08, or 8%. We divide C_x by $(1+r)^x$ to subtract all the interest that has built up over the years to what the value was before any interest was accumulated. Thus, in summary, compared to the installation costs of electricity, assuming that was even possible, installing the proposed wind turbine system is convincing from a financial standpoint.

v. Funding

Airports in the US can benefit from financial support in the form of grants, which are offered by the government. One such grant is the Airport Improvement Program (AIP), sponsored by the Federal Aviation Administration (FAA). Airports in Alaska suffer from low traffic density and tend to lack sufficient internal monetary resources needed for efficient operation [6]. The AIP can provide funding for public and some private airports. Small airports and airfields are eligible for funding up to 95% of costs. The proposed system falls under the airport lighting category for project eligibility [43]. The classification for justifying funding is airport safety enhancement. Award of funds are based on national priority first. Remaining funds are distributed by discretion according to a national prioritization formula. The durability and environmental practices of the proposed system create a strong candidate for the AIP program.

Because many airports in Alaska tend to have short runways, with over 60 runways falling under 4,400 feet, the proposed system has the ability to make many airfields accessible, more environmentally friendly, and more cost efficient [48]. The benefits are immeasurable in terms of accessibility, human safety, and environmental effects. The system‟s portability, the minimal changes necessary to install the system, environmentally friendly nature, and safety factors contribute to make this design realistic and logical.

IX. Summary and Conclusion

Providing runway lighting to remote airstrips that lack the necessary infrastructure to connect to the local energy grid is an important priority of the FAA. Many locations, especially in remote areas such as northern Alaska, cannot rely on daylight landings due to 24-hour darkness during certain months of the year. Existing solutions utilize generators, which require delivery of fossil fuels to maintain lighting availability. However, in the event of a lack of fuel, the airfield must close, because no daylight landings are possible. Another alternative, solar power is not feasible in areas of 24-hour darkness. In addition, in the case of an emergency such as a natural disaster, a portable and reliable lighting solution would potentially allow an airport to maintain continuous operation in the absence of reliable electricity from the grid or availability of fuel to power lighting generators.

Working with industry professionals from McFarland Johnson, Inc., and the Commissioner of Aviation at BGM, the team has proposed a solution that consists of providing a small wind turbine and associated infrastructure to power runway lights at remote airports. Calculations and demonstrations resulted in the conclusion that it is feasible to light a runway using a wind turbine and two 12V batteries to power the infrastructure. The factors that drove this design were its relatively low cost, low environmental impact, and its reliability. Wind turbines are a simple and inexpensive method to generate power, and turbines emit no greenhouse gasses, unlike diesel or gasoline generators. The system proposed herein, includes a failsafe redundant system consisting of two wind turbines and two battery packs to keep the runway operating safely even if one of the turbines or battery packs fail. Additionally, an optional second redundant system consisting of a diesel or gasoline powered generator is also included in the design. The proposed wind turbine system is capable of providing enough energy to power 60 runway lights continuously for up to eleven hours. Sixty lights will provide the lighting capacity necessary for runways of up to 4,400 feet in length, assuming the runway has 22 lights per side spaced 200 feet apart and 8 threshold lights on each end of the runway. If implemented, this system can provide a solution to the FAA goal of keeping remote airways properly lit, while being environmentally friendly and financially competitive.

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Appendix B: Description of the University

Binghamton University (BU) is one of 64 campuses that make up the State University of New York (SUNY) system of higher education and is one of only four university centers within the SUNY system. BU ranked 1^{st} in 2010 as a best value school among the nation‟s public colleges according to *Kiplinger's Personal Finance* [49]. It ranked sixth based on academics, cost of attendance, and financial aid according to *The Princeton Review Best Value Colleges for 2010*. *Forbes 2008,* ranked BU 4^{th} in the nation and 1^{st} in the Northeast for top-starting salaries of graduates; it also ranked BU 16^{th} among public universities and 57^{th} among the nation overall. *U.S News & World Report(2010)*, declared BU one of the nation‟s top 50 public universities for the 13^{th} consecutive year; also declaring BU to be among the top 25 schools nationally whose students graduate with the least amount of debt. BU ranked 9^{th} out of almost 130 colleges in New York for the enrollment of international students. BU is one out of only 15 colleges in the nation to receive the highest score on *The Princeton Review's* second annual "green rating" (2009). Corporate recruiters ranked BU 11^{th} among the nation for the quality of its graduates [50]. The Fisk Guide to Colleges deemed Binghamton as, "The Premier Public University in the Northeast" [51].

Binghamton currently has a very diverse student body. Out of the 11,821 undergraduate and 3,077 graduate students, all the 50 states in the U.S and 100 countries around the world are represented. However, still 86% of students are New York State residents. At Binghamton, there are more undergraduate males, but more graduate females. In total though, only 47% of the population is female, while 53% are males. In terms of ethnicity, almost half (45%) of students are White/Non-Hispanic, 13% Asian, 9% Hispanic, and 5% are Black/Non-Hispanic. Academically, 48% of Binghamton‟s students graduated in the top 10% of their high school class (85% in top 25% of their class), and 50% of students have a GPA of 3.75 or higher [52].

Appendix C. Description of non-university partners involved in the project

Greater Binghamton Airport (BGM)

The Greater Binghamton Airport (BGM) is a medium-sized regional airport located in Maine, New York that serves the Southern Tier of New York, primarily Broome and Tioga counties. The airport was originally named Broome County Airport and that name remained through the 1970‟s. It was later renamed to honor Binghamton resident Edwin A. Link, the inventor of the aircraft instrument simulator, the Link Trainer, as Edwin A. Link Field-Broome County Airport, a name it kept until the 1990‟s when it was again renamed to the Binghamton Regional Airport. The name Greater Binghamton Airport was chosen in 2003 to match the area's new marketing campaign under a unified name. The field on which the airport lies is still named in Link's honor.

The main runway, which is oriented north northwest-south southeast, was 5,600 feet in length initially, but was later extended by about 700 feet to the south to 6,298 feet in 1969. In 1988, the main runway was extended again, this time on the north end, to 7,500 feet (2,286 m). The crosswind east-west runway is 5,002 feet long [53].

In recent years, the main runway was shortened to 7,100 feet to add engineered materials arrestor beds to both ends of the runway. The arrestor beds, also known as Engineered Material Arresting Systems (EMAS), are a crushable concrete surface that slows an aircraft in the event of an overrun. Given that the airport was built on a mountaintop, the terrain drops off abruptly shortly after the runway ends, prompting the need for the EMAS beds. Fifty years after its opening, the airport finally received a major renovation in 2001. In July 2004, the airport opened four new jet bridges that can accommodate regional and mainline jets. BGM now operates an average of 57 aircrafts per day in which 43% has been commercial, 36% transient general aviation, 17% local general aviation, and 4% military [53].

McFarland Johnson, Inc.

McFarland Johnson, Inc. provides expertise planning and design for a wide variety of projects. Since its inception in 1946, McFarland-Johnson has grown not only in size but in reputation as well. With a diverse and multi-disciplined team, McFarland-Johnson is capable of taking on projects dealing with airports, bridges, highways, and much more. In the past McFarland-Johnson has worked with the Aviation Council of Pennsylvania, the FAA, the Pennsylvania Department of Transportation Bureau of Aviation, and they have been published in Airport Business and Aviation Week Newsletters [54]. In New York alone, McFarland Johnson has worked with the Binghamton Regional Airport, the Elmira/Corning Regional Airport, the Buffalo International Airport, the Albany International Airport, and the Niagara Falls International Airport [55]. This list greatly expands when considering work that McFarland Johnson has done in fields other than airports as well as airports outside of New York State.

Located in Binghamton, NY – their corporate headquarters – McFarland Johnson has grown in size and now has six branch offices located throughout New York, Vermont, New Hampshire, Connecticut, and Pennsylvania. McFarland Johnson has both the skill and number of employees to handle any size project as well as a stellar reputation within the industry.

Appendix E: Evaluation of Educational Experience Provided by the Project

<u>Student Evaluation</u>

1. *Did the FAA Design Competition provide a meaningful learning experience for you? Why or why not?*

The FAA design competition provided a meaningful learning experience and helped develop numerous skills that will be useful later on in life. We learned to work as a team and collaborate on a sizable project. On several occasions, the team held meetings and group discussions with both, Carl Beardsley and Chad Nixon, including actually inspecting the runways and runway lighting at the Greater Binghamton Airport. From the meetings with Chad Nixon and Carl Beardsley, the team learned about runway lighting procedures and technical aspects as well as the realistic viability of having a wind turbine as a primary energy source to power runway lights.

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

This competition provided many challenging problems that we overcame with hard work and perseverance. Being in a class of nearly 25 students, communication and coordination became a problem at times. To solve this problem we split up into four separate teams with each team having a leader and designating one person to oversee the entire project. Each team leader was responsible for submitting completed work to the professor and the project leader. The teams exchanged e-mails between each other to ensure deadlines were met and the proper work was being completed. Another challenge the group of students faced was deciding if the group should focus on using a wind turbine as a primary source of energy to power obstruction lights at an airport, or power the runway lights at remote airports. Each team did research on both obstruction lighting as well as runway lighting. The information obtained from the research, coupled with the insight and knowledge of Chad Nixon and the engineers from McFarland Johnson Inc., Professor William Ziegler of Binghamton University, and Carl Beardsley led to the group deciding to do research on wind turbines powering the runway lights at remote airports. Further technical challenges arose from the fact that none of the team members are electrical engineers. Oftentimes the students designed a system or examined an existing system, but could not determine the technical specifications, because this turned out to be a task for electrical engineers. Fortunately, each team found and referenced different quality documents on wind turbines, runway lighting, batteries, and FAA regulations dealing with the safety and risk assessment. Furthermore, the students worked with and received assistance from Carl Beardsley and Chad Nixon on the different technical aspects that troubled each team.

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

When the competition first began, we realized that we had all the resources necessary on the Binghamton University campus to develop a solution to light runway lights in remote areas. The team‟s development of a hypothesis was a straightforward process. In the academic year of 2008 - 2009, a group of engineering students at BU developed, in the context of a senior project, a relatively small and thus inexpensive wind turbine in order to charge the Global Electric Motorcars (GEM) operating on the university‟s campus, which are small 100% battery-powered vehicles. The team recognized that wind energy would fulfill the requirement of being applicable to charge batteries, which in turn would provide power to runway lighting in remote locations.

After a thorough study of the wind turbines technical specifications, the team members were prepared for a first meeting with Chad Nixon and Carl Beardsley. The meeting took place at the Greater Binghamton Airport, and included a tour of the airport‟s runways, where the team could examine the various kinds of runway lights. After a discussion of these runways lights and their technical specifications, we knew that we would need to calculate how much energy would be required to provide power to all lights on an entire runway. This was an electrical engineering question, which the engineers at McFarland Johnson, Inc. helped us examine. By working with electrical engineers at McFarland Johnson, it was determined that it would take only one wind turbine and two 12V batteries to light an entire runway. Initially, the team had a system in mind that would work as a backup or emergency energy source. However, it became evident that a wind turbine system could operate as a primary energy source. This surpassed all expectations and the team then focused on writing the details of using a wind turbine as a primary source of power, and even using a second wind turbine and second set of batteries to create a redundant system to insure system reliability.

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

Carl Beardsley and Chad Nixon were both instrumental in helping gather the necessary information required to develop the team‟s idea of using wind turbines as a primary energy source to light remote runways. Thanks to Carl Beardsley, the team went to the Greater Binghamton Airport to see how runway lights were used and constructed. McFarland Johnson, Inc. was a great asset and provided much needed engineering expertise. The engineers helped the team find out the power consumption of the FAA regulation lights, and how much energy wind turbines would need to produce to power the runway lights. Carl Beardsley and Chad Nixon also provided significant guidance to the team regarding the FAA regulations required to make this hypothesis a reality.

Another major contributor, who dedicated himself to this project, was Charles Howe of McFarland Johnson, Inc. Mr. Howe assisted the team in finding an appropriate battery and inverter, and calculated the estimates of how many runway lights could be lit with the system we designed, which dictated the maximum length of the runway where our system could be used

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

As mentioned earlier, we learned to be part of a team, while we worked on a large-scale project. The team members learned to be responsible for a personal task. The project required the team members to develop and improve their interpersonal communication skills in order to coordinate the necessary teamwork. Furthermore, we learned how to engage in formal meetings and conversations due to the interaction with various industry experts in which we had to scientifically express and justify ideas and procedures. Without communication with Carl Beardsley and Chad Nixon, this project would not have been possible. We learned that it is extremely important to collaborate as college students with people who work in industry to get a preview of what is in store for us after we graduate. Another experience most students gained from this project was to conduct cost analyses, and to keep the costs of a newly developed system feasible. We also learned a great deal about the FAA, how airports operate, and the regulations needed to light runways at these airports in a safe and efficient manner. In addition, we learned how wind turbines produce energy, and we learned about battery technology as a means to store this energy.

<u>Faculty Evaluation</u>

1. *Describe the value of the educational experience for your student(s) participating in this Competition submission.*

Real world experience can never be gained by sitting in a classroom. Many of my students participating in this competition have never even been on a plane; most have never consulted with experienced professionals, nor ever had to solve an engineering problem that did not come out of a textbook. Certainly none of them ever experienced the once-in-a-lifetime experience of standing in the middle of a runway and examining pavements and lighting. They have never had to perform real research on a topic they began knowing nothing about, they have rarely worked in teams, and they have never had to collaborate with so many individuals. When they can learn and experience all of those lifelong skills in less than one academic year, then they truly have had an educational experience that is simply immeasurable in value.

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

The competition was undertaken as a class project in a required senior level undergraduate course titled Professional Ethics and Communication. The course is intended to bridge academe and professional practice within the themes of communication and ethical decision making. The students in this project are stretched far beyond their comfort zone, but the learning experience presented by the FAA competition is exactly what should be expected of all students.

3. *What challenges did the students face and overcome?*

There were three primary challenges. First, the students are all undergraduate Computer Science seniors with no experience relating to air travel, airports, aviation, etc. However, they are experienced at problem solving, research, and communication, which are the foundations of the competition. Their lack of experience relating to the aviation industry took them far from their comfort zone and that was quite a challenge for them.

The second challenge was that of communication. The student team consisted of about 24 students, far too many for such a project. However, as the students learned, sometimes you have to seize the moment when opportunity arises, and the FAA competition was such a moment. As I tried to explain to the students, you do not always get to work on the ideal team, the perfect team size, or the perfect project; the idea is to learn and adapt as you go. They will realize later that the technical and communication challenges they faced on the FAA project prepared them well for the future.

The biggest challenge was that of motivation, and the methods to deal with the students who fall into the category of the *weakest links*. Some students are content to just, *get by*, while others are striving for perfection. The challenge is how to deal fairly with the two extremes, especially in a competitive situation, where the weakest links can bring down the entire team. As a professor, I am usually content to let students rise or fall to their own motivations. However, for this competition, my role as professor turned into more of the role of a coach. I refused to allow the unmotivated students to bring down the rest of the team to their level, which required several very uncomfortable discussions with various individual students and teams during the project. There were times when I am sure that some of the students were not happy that I was making them rise to their true abilities. In the end, I hope they have learned the true meaning of teamwork, responsibility, and to take pride in their work.

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

I am already making plans to enter my students in the competition next year. This has been a fabulous experience for not only the students, but also our aviation partners who assisted us in the competition, our local community, the university, and of course for me. I have reviewed and analyzed every action and decision throughout the competition with the goal of making the experience for my students even better the next time around.

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

The FAA competition is by far the best-organized competition I have seen in my 32 years in higher education. Because my students are computer scientists, this competition was quite a stretch for them. However, the educational value and experiences presented by participating in the competition is simply unmatched anywhere else, so I am willing to go the extra effort to bring my students up to speed, just to be able to participate.

My only concern is that it seems that most of the suggested topics had been covered in previous years, so it was difficult to come up with a twist on a topic because we did not want it to appear that we were copying ideas that had already been presented at some earlier time.

I am looking forward to having my students compete again next year.

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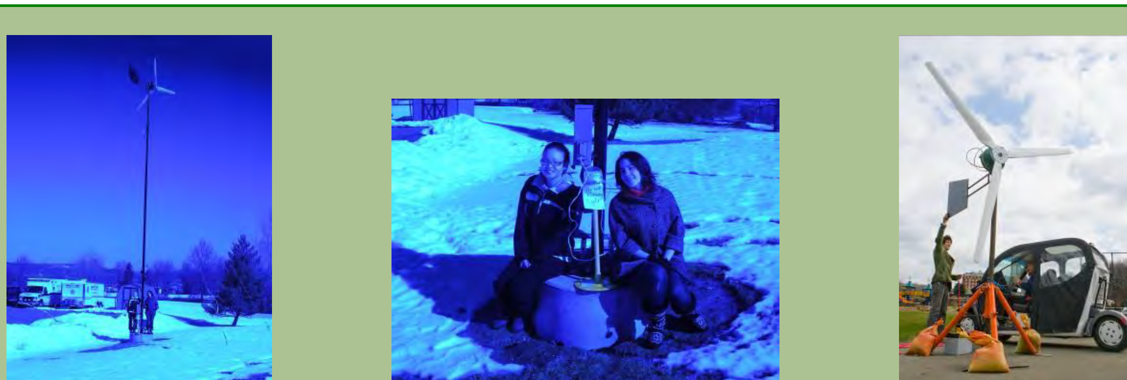
Appendix G: Photo Gallery of Participation in the FAA Competition

Students working on runway lighting systems with Industry professionals at the Binghamton Airport (BGM)

Student team inspecting runway lighting at BGM

Industry professionals work with students at Binghamton University



Students work at the wind turbine at Binghamton University

Appendix H: Ethical Considerations

The use of wind turbines as a source of renewable energy has minimal drawbacks. In its simplest form, the wind turbine converts kinetic energy into mechanical energy. This mechanical energy is then converted into electricity. The acknowledgement of this process is important because no significant byproduct or waste is produced. The combination of this clean energy source with the lower energy requirements of LED lighting on runways constitutes an environmentally friendly lighting system. Additionally, the use of scaled down wind turbines, such as the one proposed for this design allows this system to be relatively portable, making it especially useful for emergency systems. In recent events, this proposed system could have provided remote runways, such as those in Haiti, with the ability to land more planes in a shorter amount of time during the aftermath of a devastating natural disaster.

In contrast, the use of wind turbines has been reported to have side effects on surrounding populations. Reports have indicated that wind turbines have caused people to become ill. It has been reported that the illnesses caused by the noise a turbine generates include headaches, dizziness, and nausea [56]. A recent article documents the illnesses suffered by an entire town after a wind farm was installed the town of Waubra in Australia. However, no medical evidence suggests the wind farm as the cause [57]. Additionally, other ecological and environmental downsides exist. There is evidence to show that wind turbines are a significant contributing factor to the death of birds. However small this may be in magnitude, the issue must be addressed even though studies have also shown wind turbines to be one of the least significant causes of mortality in avian creatures [58].

Wind Energy Ethics, LLC provides numerous reasons for the avoidance of wind turbines as a source of power. Among these reasons are view pollution, poor efficiency, noise pollution, and wildlife detriment, as previously mentioned [59]. These reasons should all be considered, but their relevance is highly circumstantial. Since the target destination for these small-scale wind turbines is at an airport, issues such as noise and view pollution can typically be dismissed; small-scale turbines allow for less view obstruction and produce only 30-45 decibels (dBA) of sound, while an airplane can produce levels of up to 90dBA. A 10dBA increase is equivalent to a doubling of loudness, making an airplane approximately fifty times louder than a wind turbine.

Appendix I: Biographies

Josh Banyasz

Josh Banyasz is currently a senior attending BU. He is majoring in computer science but plans to enter the IT field after graduation. In his time off from school he works part time as a technical intern at an IT Consulting firm in Brooklyn where his responsibilities range from help desk work to assisting in large scale deployment of equipment and networks.

Daniel Chan

Daniel Chan is currently studying for his BS in computer science, from BU. His research interests include cryptography, network security, and software design. He has experience writing search bots and multi-threaded web crawlers. He is currently a member of ACM and Theta Tau, professional engineering fraternity.

Yin K. (Jack) Choi

Yin K. (Jack) Choi is an undergraduate student in BU studying computer science. Choi has been active in internships throughout campus and the local Binghamton area. His main career focus is in the Information Technology field. Some of his future goals include being a Network or Systems administrator and web development. Jack grew up in Brooklyn, New York, where he attended Mark Twain Junior High School and Brooklyn Technical High School for his secondary education. He is currently in the last semester of his undergraduate studies in BU and is expected to graduate May 2010. His interests include pool, bowling, guitar, and basketball.

Dimitri Derose

Dimitri Derose is currently a senior at BU. He is a dual-degree major studying both computer science and mathematical sciences. He is also the secretary of the Haitian Student Association as well as an IT intern for the Church Pension Group. Dimitri Derose wants to improve the lives of people around the world by finding ways to enhance technologies. He is currently the leader for the written work of the Risk Assessment and Research Team for BU‟s "Wind Turbines as a Primary Energy Source to Light Runway Emergency Lights at Remote Airports" project. He hopes that the experience he gains from this project will jump-start his career in helping improve the lives of people with the help of technology.

Louis Fata

Louis Fata was born in Connecticut, but was raised in Rockland, New York. Louis Fata is a computer science major with a minor in mathematics at BU and is expected to graduate in May 2010. As a member of the design team, he was involved primarily with the feasibility of this proposal. His personal and academic interests include programming, mathematics, and baseball.

Milind Gawande

Milind Gawande is majoring in computer science at BU. He prefers learning on his own instead of going to classes, a habit not much appreciated by his professors. In his free time, he enjoys watching movies, playing video games and irritating his roommates. He is sympathetic towards animals and is trying to turn vegetarian.

Joseph Harvey

Joseph Harvey is a computer science degree candidate for spring 2010 at BU. He has been ranked in the top ten in the ACM programming competition and ranked in the top three in the Freestyle Limited Archery State Championship. After graduation, he plans to begin employment at IBM Corporation as a System Test Engineer in Poughkeepsie, NY. His favorite hobbies include contributing to numerous web design projects, playing guitar, drums, and developing applications for the RIM Blackberry platform.

Lauren Hillengas

Lauren Hillengas is the project leader. She plans to graduate from BU in May 2010 with a Bachelor of Science in computer science. As a freshman, she attended Boston University‟s School of Engineering and later transferred to BU to carry out the remainder of her four years. Currently, she is looking for work in the cyber security industry, with many prospects.

Eric Jackson

Eric Jackson is from Rochester, NY and is a senior computer science major at BU. He is interested in networking technology and hopes to pursue a career in a related field after graduation. An active member of the University, Eric is a member of Pipe Dream, BU‟s “free word on campus,” as a staff photographer and news tech. He is also a Senior Rescon and a part of SnoCats, the ski and snowboard club at BU.

Alexander Jaspersen

Alexander Jaspersen is a senior from Long Island, New York. He is majoring in computer science and mathematics and plans to graduate in May 2010. His interests include programming competitions and swimming.

Josh Lambert

Josh Lambert is a senior at BU pursuing his BS in computer science. His primary interests are in computer architecture, parallel computing, and programming languages He Interned for the Chromalloy Gas Turbine Corp. Technology Group in Orangeburg, New York. He plans on starting a career in Java software development.

Matthew LeMar

Matthew LeMar is expected to receive his Bachelor of Science in computer science in May 2010 from BU. He is currently enrolled in Professional Ethics and Communication, Programming Languages, Systems Programming, Introduction to Security, and Data Communication & Computer Networks at BU.

Makbule Irem Kurucay

Irem Kurucay was born in Istanbul, Turkey on March 26, 1988 and attended a dual diploma program in Turkey. She is currently studying information systems engineering at BU. She is expecting to have a bachelor‟s degree in computer science in May 2010. She is a member of IEEE, Turkey and EESTEC, Turkey. Her personal and academic are project management, organizational behavior, jewelry design, dancing, snowboarding and horse riding.

Michael Ng

Michael Ng, from Brooklyn, New York, is currently studying for his bachelor's of science in computer science, expected May 2010. He has developed his passion for Computer Science since high school, and carried his love of learning with him into his college career. He is currently the tutoring coordinator of the Upsilon Pi Epsilon Computer Science Honor Society chapter at BU. He also tutors various math and computer science subjects at the university.

Miguel Nina

Miguel Nina is a double degree student working toward his Bachelor of Science degree in computer science from the Watson School and Bachelor of Arts degree in Mathematics from Harpur College. Miguel is a Hispanic American from New York City who received a technical honor society award while in high school. Miguel was an active member of his high school track and swimming team. He is an active member the Educational Opportunity Program (EOP), Society of Hispanic Professional Engineers (SHPE), Computer Science Honor Society (UPE), EOP National Honor Society (XAE), Louis Stokes Alliance for Minority Participation (LSAMP), and the Ronald E. McNair Post baccalaureate Achievement Program (McNair). The LSAMP program provides mentoring and a supportive network to underrepresented minority students in math, science and engineering. The McNair Program prepares participants for doctoral studies through involvement in research and other scholarly activities. Miguel‟s long term goal is to get a Master degree and then a PhD with computer science.

Richard A. Palacio

Richard A. Palacio received the AA and AS degrees, from Westchester Community College. He is currently pursuing a BS degree in computer science from BU. He has been a member of Phi Theta Kappa honor society since 2006. He is a former member of the 82nd Airborne Division, 307th Brigade Support Battalion. His research interests include computer graphics, and real-time simulation.

Chris Raulli

Chris Raulli is a senior computer science major at BU. He is enrolled in the Watson School/SOM Fast-Track MBA program as well. He attended the University of Delaware for two semesters originally as physics major, until transferring to BU at the beginning of his sophomore year. Chris lives in North Syracuse NY, and attended Cicero-North Syracuse high school. Along with being interested in computers, Chris is also an athlete. In high school, he was captain of his cross country, wrestling, and tennis team, and is now a member of BU‟s Division I cross country and track teams. He is a competitive distance runner, and competes with the best runners locally and nationally. Chris currently works for Leone Timing & Results Services, a race computing company which times a variety of track, cross country, and road race events using chip transponder technology, along with photo-finish cameras. He has helped time prestigious events such as the Penn Relays, and Millrose Games. Chris is one of four children He has a younger sister Lindsay, who is a freshman at BU, an older sister Melissa who just graduated from the

University of Richmond, and an older brother Stephen who attended The U.S Naval Academy, along with MIT and the University of Cambridge for graduate school. Upon graduation in December of 2011, Chris will have a bachelor degree in computer science and a Masters in Business Administration.

Sohrab Saadat

Sohrab Saadat grew up in Germany, where he graduated from high school and attended university before transferring to BU in spring 2008. He is a computer science student, graduating in December 2010. In addition to computer science, his personal interests include, among others, reading, soccer, traveling and walking his dog. His contributions to this project include literature reviews as well as risk and safety assessments.

Anatoliy Semchishin

Anatoliy Semchishin was born on September 3, 1988 in Ukraine and immigrated to the United States in 1998. Since the English language was unfamiliar to him when he first arrived, he developed an interest in mathematics and computers. He currently is a senior at BU and is expected to graduate in May 2010 with a bachelor‟s degree in computer science. After graduation, he is planning to enroll in the Engineering Leadership Development Program at BAE Systems, which will provide him with a full time job and allow him to work part time towards a master‟s degree.

Matt Spatola

Matt Spatola was born on a cold February night in the city of White Plains, New York. After spending the first years of his life becoming an avid ice dancer, he decided to study computer science and enrolled himself at BU. He is an Aquarius who enjoys long walks on the beach whose short but illustrious career has touched many lives.

Greg Stoddard

Greg Stoddard is a senior at BU who is studying mathematics and computer science. He will pursue his PhD in computer science beginning in fall 2010. His academic interests include theoretical computer science, algorithmic game theory, and social network theory. His personal interests include music and ice hockey.

Joseph Tabone

Joseph Tabone grew up in Syosset, NY and attended Syosset Senior High School. He is currently a senior attending BU, expecting to graduate in May, and is enrolled in the Watson School/School of Management Fast Track MBA program and will receive an MBA within one year of receiving his B.S in computer science. He is currently a member of IEEE and the computer science honor society Upsilon Pi Epsilon chapter at BU. Upon completion of his MBA he plans to return to school to obtain a Masters degree in computer science.

Chris Wright

Chris Wright is currently a senior studying computer science at BU. He is from Vestal, NY and attended Broome Community College before transferring to BU. He plans to move south to become a software engineer. His interests outside of computer science include watching sports and playing golf.

Ken Williams

Ken currently attends BU in a dogged pursuit of a BS in computer science. He has worked as a programmer for Celestica Corporation, Modern Marketing Concepts and New York State Electric and Gas. He has worked as an electrical technician for BAE and Harvard Custom Manufacturing. Hobbies include ski boarding, skiing, rollerblading, tennis, mountain biking, woodworking, alligator wrestling and RC trucks.

Appendix J. Interview Reports and Meeting Reports

Student Project Leader – Lauren Hillengas

Prior to the rest of the team being formed, Lauren had been already working out details of the project for two months. Because of the research, planning, and contacts that she had made with McFarland Johnson, Inc. the rest of the team had their goals laid out over a well-planned timetable. Having a well thought-out plan was a necessity due to the large size of the team.

Milestone 1

Location: **Binghamton University Science Library 302**

Date: January 26th 2010

Time: 8:30 am – 10:00 am

Speaker: Professor William Ziegler

This was the first time the entire group had met. Everyone was introduced to each other, the professor, and to the project leader who had been working on the project for two months already. After the introductions, Professor Ziegler then talked about the project and the project goals. Professor Ziegler then showed us the results of the competition from last year to show us how much of a big deal this project is. At the end of the meeting, we all took a small survey that would help determine what smaller group everyone would be placed in.

Milestone 2

Location: **Binghamton University Science Library 302**

Date: February 2nd 2010

Time: 8:30 am – 10:00 am

Speaker: William Ziegler

Once the group assignments were set up for the project, we started talking about what we did not know and what we did know. There were discussions about considering using LED lights, because they require less power consumption, but we did not know the price difference for LED lights and if LED lights were FAA approved. We did not know how we would connect an AC runway lights to a DC battery.

Although we did not know many parts of the project we did however, know where our starting point would be. We knew that we had to create a Literature Review regarding wind turbines, for wind reports around the US, and related FAA documents.

Milestone 3

Location: **Greater Binghamton Airport**

Date: February 9th 2010

Time: 10:30 am – 12:00 pm

Speakers: Professor William Ziegler, Commissioner of Aviation Carl Beardsley, and Chad Nixon, Vice President of McFarland-Johnson, Inc.

After being introduced to Carl Beardsley and Chad Nixon, we went over the FAA requirements for this project. We discussed whether we would concentrate our project on lighting remote airfields or obstruction lights. Although the decision was not finalized, the idea of working on remote airfields was favored.

There were discussions on how we should power the runway lights using the wind turbine. Powering the runway lights directly with the wind turbines was out of the question. So, the final idea was to have the wind turbines charge the batteries and have the batteries power the lights.

There were still questions about how long the runway lights have to be lit, how many batteries will need to be used and how many wind turbines will need to be used.

Milestone 4

Location: **Binghamton University Science Library 302**

Date: February 16th 2010

Time: 8:30 am – 10:00 am

Speaker: Professor William Ziegler

After a week to think about the visit to BGM, discussions took place regarding the plan. The decision to power runway lights over obstruction lights was finalized. There was discussion about what kind of system would be powered and some theoretical math was done. At first, it seemed that the wind turbine would only power a 20 light system, 10 per side, spaced 200 feet apart. This led to a conversation about power consumption problems and whether it would be possible to power a large remote runway in an area with no electricity.

In addition, there was discussion about writing mechanics and deciding to use standard US units over the metric system in order to keep it uniform throughout the reports.

Milestone 5

Location: Industry Experts visit **Binghamton University - Bingham Hall Lounge**

Date: February 23rd 2010

Time: 8:30 am – 10:00 am

Speakers: Commissioner of Aviation Carl Beardsley, and Chad Nixon, Vice President of

McFarland-Johnson, Inc., Professor William Ziegler,

Having finalized in the previous week that the project would deal strictly with runway lighting Carl Beardsley and Chad Nixon helped the team come up with a feasible approach. Mr. Beardsley answered a question of whether it would be a good idea to use LED lighting. He informed the team that BGM has been using LED‟s for taxiway lighting and that they are both cost effective and emit enough heat to keep snow off the lights, which was a consideration that was preventing LED‟s from being incorporated into the project.

Mr. Nixon came to the meeting with a diagram of the system that we had been discussing: A redundant system consisting of two turbines, two battery banks, and a method to switch between the two systems. It is important that both systems receive regular use and testing. The batteries will power the lights while the turbines constantly charge them. It was learned that without wind the fully charged battery banks would power the runway for 11.7 hours. In addition, it is assumed that most airports have a generator on site as an emergency backup although it is unlikely that the system will fail. This system will be able to tie-in to any existing lighting system easily and will not necessitate any major changes to the lighting infrastructure.

Milestone 6

Location: **Binghamton University Science Library 302**

Date: March 2nd 2010

Time: 8:30 am – 10:00 am

Speakers: Professor William Ziegler

Building upon the prior week, the discussion focused on changes that will be made to the diagram that Mr. Nixon introduced. After a lengthy and somewhat heated debate all issues were settled.

In addition, there was some discussion about the financial costs of the project. At this point we had a list of prices but they had not yet been analyzed.

Milestone 7

Location: **Binghamton University Science Library 302**

Date: March 9th 2010

Time: 8:30 am – 10:00 am

Speakers: Professor William Ziegler

Our project leader displayed the changes made to the design after week 6. In order to achieve 12 hours of power from a full battery charge it was necessary to change the number of lights to 44 along the runway as well as 8 on each end. This would be the final version of the design.

We discussed that our need to be finished in only two more weeks and as a result there were only minor changes that would be made to the existing design. There was also a discussion of changes that needed to be made to the Graphical User Interface for the system.

Further Contributions from McFarland Johnson, Inc.

Donald Harris, Project Manager and Joe Kellicut, Senior Designer

When the team was deciding on whether to use wind turbines to power runway lights or to power obstruction lights, they noted that wind turbines need a lot of space to set up and that each obstruction light would need its own turbine. They expressed concerns about the effect of wind turbines on flight.

Blair Dury, Electrical Engineer

Created our design schematic in AutoCAD.

Charles Howe, Electrical Engineer

Contributed the specifications for the inverter and battery to the design as well as supplied the equations used and some notes on Alternating and Direct Currents.

Chris Fales, Zachary Staff, and Rick Lucas of the Planning Team and Rosemary Aures from Environmental

Supplied notes on "Imaginary Surfaces" as described in part 77 of the FAA guidelines in reference to where to place the wind turbine.

Contributions from Independent Parties

Suleyman Kurucay, Electrical Engineer

Consulted with the design to make sure the plans were feasible.

Prof. Dr.-Ing. M. Mohsen Saadat

Advised the team during the brainstorming phase.

Appendix K. System Design