2008 FAA AIRPORT DESIGN COMPETITION FOR UNIVERSITIES

Light Emitting Diodes: An Efficient Choice for Airfield Lighting

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6th April 2008

17th April 2008

Ms Debbie Ross, Program Assistant
Virginia Space Grant Consortium
600 Butler Farm Rd, Suite 2200
Hampton, Virginia 23666

Dear Ms. Ross:

Enclosed is the final report on “Light Emitting Diodes: An Efficient Choice for Airfield Lighting” prepared by a student team of Lannie Marsh (student team lead), Ryan Cole, Michelle Lanning and Nicole Sellers from the Aeronautics Program in the College of Technology at Kent State University.

The report on “Light Emitting Diodes: An Efficient Choice for Airfield Lighting” is submitted under the 2008 FAA Airport Design Competition for Universities’ broad category of Airport Environmental Interactions Challenges. The enclosed report is the culmination of eight month’s work by the second student team from Kent State University.

Thanks for your efforts in furtherance of aviation education at the tertiary level.

Sincerely,

I. Richmond Nettey

I. Richmond Nettey, Ph.D.
Associate Dean, College of Technology
and Senior Academic Program Director of Aeronautics

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Executive Summary

Current airfield lighting, which is typically incandescent, is inefficient in terms of energy consumption and associated costs for illumination. A reduction in consumed energy would decrease the environmental impact of airfield lighting through the reduction of greenhouse gas emissions. Using a light source with a greater intensity will help increase the situational awareness of pilots due to improved quality of airfield lighting. The increased situational awareness will improve the level of guidance given to pilots traveling between the ramp and runway, which could help decrease the amount of runway incursions and accidents during periods of darkness and low visibility. All modifications to airfield lighting will be done in compliance with standards set by the Federal Aviation Administration (FAA).

Throughout the scope of this project, many alternatives were examined and modifications assessed when attempting to improve the efficiency of airfield lighting. The group decided that replacing incandescent lighting with light emitting diodes (LEDs) would be the brightest choice. LED lights have average life expectancies of 35,000–50,000 hours or more, as compared to only 5,000 hours for the currently used airfield lights. The life expectancy allows some to believe that the LED bulbs will outlast the fixtures; allowing for a decrease in maintenance required.

When examining implementation strategies, the Advisory Circulars were consulted to ensure that new LED fixtures would meet FAA requirements. The existing circuitry would be more than sufficient to support the LEDs; and, with a switch in fixtures, the LEDs would become operational. The covers should be made of an approved substance, such as borosilicate glass, tinted the same color as the LEDs. Problems arose when attempting to meet the requirement of the light remaining clear of frozen accumulation, due to the relatively cool nature of LEDs. Additional research revealed a solution by modifying the light cover to maximize performance.

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Problem Statement

Runway and taxiway edge lights are the primary means for visual navigation at night and during periods of low visibility on the airfield. Lighting, that is bright with easy color recognition, enables users to properly navigate the airfield resulting in safe operations and fewer runway incursions. Current airfield lighting is inefficient and expensive.

Background on the Design Challenge

Airfield lighting should be easy to recognize by pilots and other persons navigating the field; as well as efficient to operate in terms of costs and energy consumption. Unfortunately, the currently used airfield lighting is expensive to run, inefficient in terms of energy consumption, and certain colors are often hard to differentiate. The lack of efficiency and reliability prompts the need for a change. In the replacement of existing airfield lighting, light emitting diodes (LEDs) would be a bright and efficient choice. The FAA has chosen test airports, such as Prescott Municipal Airport, for the initial installation of LEDs. Tests have produced favorable results; although, some improvements are still required before the FAA will approve implementation at cold-weather airports due to the requirement of the fixture remaining clear of snow and ice.

Summary of Literature Review

The advantage offered by LEDs over incandescent and halogen light sources is not luminosity or brightness; it is efficiency through less energy consumption. LEDs differ radically from traditional light sources in that there are no glass bulbs or filaments to break, or electrodes to decay. Instead, LEDs are solid state light sources – basically, a chemical chip embedded in a plastic capsule (Design Lab 2008). With LEDs' solid state construction comes durability and exceptionally long life. They also offer small size, lower maintenance costs, and many color options.

While LEDs are an efficient alternative to using incandescent lights, some modifications are needed before implementation in cold weather regions. Mr. Dana Ryan, Chief of Planning for the Cleveland Airport System, expressed his interest in the implementation of LED lighting. When working on a runway extension project at KCLE, Mr. Ryan considered using LED lighting but ultimately decided that the technology was not yet ready for airfields. Research was conducted to see where and how LEDs are currently being used in other industries, especially in billboard signs. The modified light design presented in this project is based on technology used by Lamar Digital, manufacturer of digital outdoor billboards (Ripp 2007).

One incandescent bulb unit costs much less than an LED unit with comparable luminosity; however, LED bulbs can last more than four times as long as an incandescent bulb with less energy use (U.S. Department of Energy). A study of prototype LED lighting systems at Prescott Municipal Airport (PRC), provided by OPTIMUS Corporation compared the different lighting technologies and analyzed power use (Journal of Air Traffic Control 2007). The results showed a substantial decrease in energy consumption and an increase in capital savings when using LED technology.

Even though LEDs are considered quite an improvement over incandescent lighting, there are still inherent disadvantages associated with them. There are two major drawbacks of LEDs; these include the narrow ambient temperature zone for operation and the high initial cost of installation (LEDTronics). Since LEDs have recently gained tremendous momentum, there are no extensive industry or performance standards on which to build on (Gu 2007).

Research continues with the goal of further increasing LED efficiency. Researchers at Glasgow University have developed a technique to make LEDs brighter, and use less power than comparable light bulbs on the market, through nano-imprint lithography. This process imprints microscopic holes on the surface of LEDs very rapidly; the result is an increased level of light (see BBC News, 2007).

The safety analysis portion of the research was conducted by researching airports that have implemented or tested LED lighting systems. Airport Technology (www.airport-technology.com) has reported valuable information in the form of press releases from various airports that are equipped with LED technology. The safety analysis also includes the weather conditions that the LED lights would be subjected to when implemented in high latitude airports. An almanac was used to gather information about Cleveland Hopkins International Airport and the snowfall and seasonal temperature averages. These issues are important to relate to the proposed design concept of LED bulbs due of the wide temperature variations across the United States.

The maintenance component of electricity costs and electrician wages was viewed as a national average to take into account the differences in the standard of living. Graphs from the United States Energy Information Administration were used to present the average retail price of electricity as spread across numerous economic sectors. It is important that the sectors be differentiated in the graph to give a more accurate depiction of consumption and costs associated with the quantity of use. Electrician wage information was also taken as a national average as provided by the United States Department of Labor in their annual statistics. The graph depicts annual and weekly earnings, along with their respective mean and median information to make it a generalization across the entire United States.

Problem Solving Approach

Current lighting systems are inefficient due to the high maintenance costs and low life expectancy; also, the bulbs consume a great amount of energy and then expel heat energy into ambient air having a negative impact on the environment. LED lights provide an attractive alternative to lighting sources that provide low maintenance costs and very high life expectancy. By analyzing airports[1] that have already implemented LED technology this group understood how reviews were conducted and the overall reliability of the LED bulbs. From there, information was gathered about regulations governing lighting systems on the airfield during poor visibility conditions and snow accumulation. LED bulbs have demonstrated their ability to project far above lumen minima requirements, and still meet mandatory requirements for airfield operations.

The greatest barrier when converting from the existing airfield lighting to LED lighting is the ability to do so in a cost-effective, energy-efficient manner while still meeting all of the requirements stipulated by the FAA. LEDs are typically thought of as cool light sources, which were thought to create problems when implemented in colder regions. Previously, it was thought that the only way to install LED fixtures at airports that are susceptible to snow, freezing rain, or ice was to use a heater along with the fixture. This team's goal was to come up with an alternative fixture design when switching to LEDs that would still allow airports to benefit from implementation in regions that are susceptible to frozen precipitation.

[1] Airports using LED technology, analyzed in this report, include the following: Truckee-Tahoe Airport, Naval Air Station North Island, Cartagena Airport, Newcastle International Airport, Manchester International Airport. A more complete list of airports using LED technology is presented in Appendix G.

<u>**Lighting Comparison: Current vs. New Technologies**</u>

<u>*Incandescent Lighting*</u>

Incandescent bulbs were the original electric light sources used in airfield lighting and, with some refinements, still employ basic technology that is over one hundred years old. A tungsten wire filament is placed inside a glass bulb, an electric current is passed through the filament, and resistance in the filament causes it to heat and "incandesce" or glow. Most modern light bulbs feature a coiled filament that improves efficacy (the lighting industry's term for efficiency) and reduces heat loss. Whereas early light bulbs contained a vacuum to prevent the filament from combining with oxygen and "burning out," most of today's bulbs use various mixtures of inert gases for the same purpose (Sylvania 2008).

Incandescent bulbs are affordable, can be controlled by inexpensive dimming circuits, and are available in a wide range of sizes, configurations and wattages. Unfortunately, incandescent bulbs are inefficient. Compared with the other major light sources, incandescent is the least efficient. Because they produce light by heating a solid material until it glows, most of the energy they consume is given off as heat. Approximately 90% of the energy that is consumed in an incandescent bulb is released in the form of heat, while only 10% is converted to visible light. Incandescent bulbs operate at shorter lives than most other lighting sources.

<u>*Halogen Lighting*</u>

Tungsten Halogen bulbs are a refinement of incandescent technology that offer up to 20 percent greater energy efficacy (lumens per watt), longer service life and improved light quality. Nevertheless, halogen lighting still only converts 30% of the energy to visible light; this, by no means, is considered efficient. In a standard incandescent bulb, tungsten from the filament evaporates over time and is deposited on the walls of the bulb, thus reducing light output

(Sylvania 2008). The filament gets thinner and thinner and eventually breaks, causing the bulb to fail. The halogen gas inside a halogen bulb causes the evaporated tungsten to redeposit on the filament. This process, along with high pressure inside the capsule, slows down deterioration of the filament, improves lumen maintenance and extends the bulb's service life. Other advantages include instant start-up with no flickering and they are operational at any temperature, including sub freezing temperatures. However, these lights, along with incandescent lights, are prone to failure in high vibration environments.

Light-Emitting Diodes

Light-emitting diodes (LEDs) are a relatively new technology that has advanced from use in numeric displays and indicator lights to a range of new and potential new applications, including airport ground lighting. LEDs differ radically from traditional light sources in that there are no glass bulbs or filaments to break, or electrodes to decay. Instead, LEDs are solid state light sources – basically, a chemical chip embedded in a plastic capsule. When the chip is energized by applying a voltage, it emits visible light. The light can then be focused, routed, or scattered using lenses, waveguides or diffusers. The color composition of the light being emitted by the LED is based on the chemical composition of the material being excited. With traditional light sources, colored filters must be used to create colored light, absorbing and wasting much of the bulb's light output. LEDs are available that can produce colors including white, deep blue, blue, green, yellow, amber, orange, red, bright red and deep red. For red, amber, yellow, green and blue LEDs, new materials have been developed that are more efficient than traditional materials, thus producing efficacies greater than incandescent bulbs.

With LEDs' solid state construction, comes durability and exceptionally long life. LEDs are highly rugged (Design Lab 2008). They feature no filament that can be damaged due to shock and vibrations. LEDs are also low-voltage, low-current devices and highly efficient light sources. For example, a properly operated red or yellow LED can maintain up to 50% of its initial brightness after 100,000 hours (Sylvania 2008). Also, in traffic signal lights, a strong market for LEDs, a red traffic signal head that contains 196 LEDs draws 10W versus its incandescent counterpart that draws 150W. Various estimates of potential energy savings range from 82% to 93%. With the red signal operating about 50% of the day, the complete traffic signal unit is estimated to save 35-40% (Design Lab 2008). Even though LEDs are more efficient than incandescent lights now, they are always improving and becoming more advanced than traditional lighting. "In 1993 an array of 200 LEDs was required whereas only 18 LEDs achieve the same performance today, with prediction of further reduction to only 10" (Design Lab 2008).

LED units are small, typically 5mm, therefore produce little light overall. However, this weakness is actually its strength. LEDs can be combined in any shape to produce desired lumen packages as the design goals and economics permit. In addition, LEDs can be considered miniature light fixtures; distribution of light can be controlled by the LEDs' epoxy lens, simplifying the construction of architectural fixtures designed to utilize LEDs. A controller can be connected to an LED fixture to selectively dim individual LEDs, resulting in the dynamic control of distribution, light output and color while producing energy savings.

LED runway and taxiway fixtures can reduce airport maintenance costs because of the extended bulb life LEDS offer. Some LEDs are projected to produce a long service life of about 100,000 hours. For this reason LEDs are ideal for hard-to-reach/maintain fixtures; because of the reduced energy requirement, there are reductions in sizes and ratings for cables or other circuit components. Therefore, airport installation costs can be reduced. If needed, during the summer, the LED current can be reduced to save energy further and reduce the junction temperature to extend life. LEDs, in turn, offer a more affordable lighting alternative for smaller airports.

Even though LEDs are considered quite an improvement over incandescent lighting, there are still inherent disadvantages associated with them. There are two major drawbacks, among others, of LEDs; these include the narrow ambient temperature zone and the initial cost. Since LEDs are current driven, each degree the ambient temperature changes affects the LED's (including its components) operating temperature (LEDTronics 2000). In order to maintain the projected longevity (100,000 hours) of LEDs, the LEDs need to be operated within the desired temperature range of 35°C - 45°C. LEDs can operate at the FAA's requirement of -40°C and 55°C by increasing or decreasing the current through the LED. This will allow the LED to stay in the desired temperature zone. Since the current needs to be regulated, LEDs need a power supply to do so. LEDs have a risk of being overdriven by this power supply. The other major disadvantage is the initial cost of LEDs. As compared to traditional lighting devices, an LED system would be more of an investment at installation. This is easily outweighed by the continuing decline in costs compared to incandescent lighting. Considering the long-term costs, reliability, and safety, an LED lighting system should be a preferable alternative.

LEDs have recently gained support for their replacement of conventional lighting. Since this is true, there were no industry standards for this technology in its advent years (Gallagher 2001). Therefore, the development of performance standards is needed in order to publish appropriate advisory circulars/specifications. Installation procedures also need to be refined and standardized.

Safety Risk Assessment

A safety risk assessment for the use of LED bulbs at airports around the nation requires an in-depth look at the overall reliability of the lighting system. This can be discussed in terms of overall success rate of current systems, and an evaluation of current airports that are equipped with LED bulbs. In addition, one must also analyze the intensity of the bulb with respect to a variety of weather conditions. This will be broken down by analyzing the effect of snow accumulation on the lights, and how different weather trends and visibility conditions affect the overall lumen output of the LED bulb.

Reliability

The reliability of the bulb is the first step in the safety risk assessment, which will be broken down into an evaluation of current airports with LED systems and their success rate at those airports. Airports across the world are implementing LED's to test the efficiency and cost benefit as they are viewed over a respective time period. A list of known airports that have experimented or permanently adopted LED's on the airfield can be seen below.

Airports that are already using LED lighting:

1. Truckee-Tahoe Airport – California (Efficient lighting takes off at California airports)
2. Naval Air Station North Island (Efficient lighting takes off at California airports)
3. Cartagena Airport – Columbia (New LED AGL and Infrastructure Saves Power for Colombian Airport)
4. Newcastle International Airport - (LED Stop Bar AT Newcastle Airport)
5. Manchester International Airport – United Kingdom (First Sale of New LED Technology)
6. Oxford (Kidlington) Airport - United Kingdom (First Sale of New LED Technology)

7. Liverpool John Lennon Airport – Liverpool, united Kingdom (Liverpool Airport Creates New Taxiway with Carmanah Solar Taxiway Lights)

The Truckee-Tahoe and Naval Air Station North Island airports reported more efficient operations as a result of energy and maintenance savings (Efficient lighting takes off at California airports). The Cartagena airport reported that the simplified electrical infrastructure has reduced the power consumption to 10%. In addition, the tests proved that the total number of ZA216LED fixtures only consumed 500 watts at the output of the CCR, compared with 5000 watts that would have been required with Tungsten Halogen bulb type products. Also, the power factor and harmonic content was much improved when LED's where operated in this fashion (New LED AGL and Infrastructure Saves Power for Colombian Airport).

The Newcastle airport implemented the LED technology with a Stop bar, that can be seen as "... one of the most critical roles for airfield ground lighting." At busier airports, stop bars are active for the majority of the day with only a few hours of down time. According to the News Release, LED Stop Bar at Newcastle, the intense lighting cycles can significantly reduce ordinary tungsten halogen bulb life to a few months especially in <u>CAT III</u> conditions. This results in increased maintenance time because under Civil Air Patrol rules, no more than two stop bar lights are allowed to be non-operational. The implemented LED stop bar has a rated life in excess of 30,000 hours for its respective wattage, and is forecasted to operate 14 hours a day providing an expected six years of maintenance free service. (LED Stop Bar AT Newcastle Airport)

The Manchester International and Oxford Kidlington airports, "...have installed 80 of the new ZA216L taxiway-edge lights, and pilots have already reported an improvement." (First Sale of New LED Technology) The Liverpool airport, also located in the United Kingdom leaned towards solar powered LED's for a quick install for taxiway lighting purposes. The Carmanah solar taxiway lights require no additional digging or cable installation and still provide the illumination needed for all weather conditions. Solar LED's are rated at up to 300 hours of operation and can go five years without battery replacement or routine maintenance. (Liverpool Airport Creates New Taxiway with Carmanah Solar Taxiway Lights)

Adverse Weather Conditions

The test airport, Cleveland Hopkins International Airport (KCLE), is located in northeast Ohio at Latitude 41.4˚ N and Longitude 81.8˚ W. This region is well known for its ever changing weather conditions with Lake Erie situated nearby. Snow accumulations and temperature fluctuations need to be analyzed over time, with respect to LED lights, in order to evaluate the risks associated with implementation.

Average snowfall for KCLE can be seen in Figure 1 with last year (2007) in red ink.

Figure 1: Average Snowfall for KCLE (2007)
Source: "Season Weather Averages for Cleveland-Hopkins International," *Weather Underground Inc.*

As indicated in Figure 1, snow fall can extend past 10 inches and probably more in northern latitudes. Snow, cold temperatures, and poor visibility conditions can also affect LED lights on a lumen output level and an overall operating level. Figure 2 displays the temperature range that was observed over the past year at KCLE.

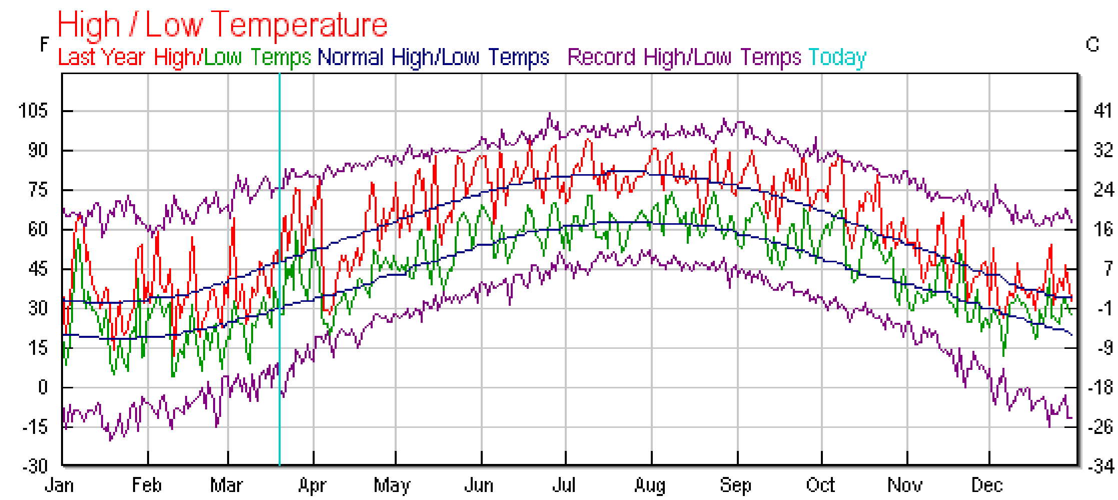

Figure 2: Range of Temperatures Experienced at KCLE (2007)
Source: "Season Weather Averages for Cleveland-Hopkins International," *Weather Underground Inc.*

LED bulbs have been studied in conjunction with incandescent lights, and they have been found to meet the FAA requirements with respect to temperature fluctuations. LED fixtures, when exposed to colder temperatures, have a set time frame to increase the fixture temperature to a more appropriate level. Suiting FAA requirements, the temperature rise was observed in the fixture itself, but the optical surface temperature only increased a few degrees. Therefore, the northern regions of the country would not experience much difficulty when dealing with temperature fluctuations. However, a design change that would allow for an increase in the surface temperature would need to be implemented when dealing with cold weather airports and snow accumulation. This is due to the lack of heat generated from a filament inside the LED bulb, which prevents an increase in the optical surface temperature (Gu 2007).

Maintenance Components

Electricity Costs

To determine the average electrical cost per kilowatt hour at an airport, a generalization was realized by grouping sectors of users according to use. All airports can be grouped into the transportation sector as seen in Figure 3, obtained through the Energy Information Administration (U.S. Energy Information Administration p.1).

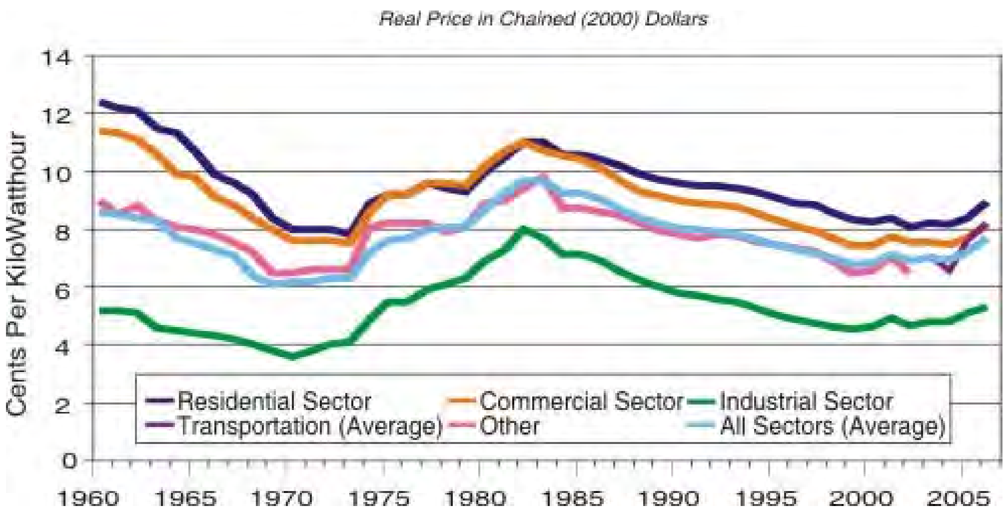

Figure 3: Average Retail Price of Electricity Sold by U.S. Electric Power Industry, 1960-2006
Source: Energy Information Administration, *Annual Energy Review 2007*, Table 8.10.

LEDs draw 1/10th the amps of incandescent bulbs, which allow for more power to be saved or utilized lighting more bulbs. Since LED's operate more efficiently than incandescent bulbs, maintenance costs, similar to electricity consumption, will be decreased after the implementation of LEDs. This results in an overall saving when dealing with electricity consumption costs.

Electrician Costs

To determine the average electrician wage in the U.S. for maintenance costs, an analysis of wages was considered across the continental U.S. The U.S. Department of Labor publishes statistics for all occupations, and Table 1 states the results of a survey taken in June of 2006 (U.S. Department of Labor).

Table 1: National Estimates: Employment and Wage Estimates for Electricians

Employment	Employment RSE	Mean hourly wage	Mean annual wage	Wage RSE
617,370	0.9 %	$22.41	$46,620	0.5 %

Percentile	10%	25%	50% (Median)	75%	90%
Hourly Wage	$12.76	$16.07	$20.97	$27.71	$34.95
Annual Wage	$26,530	$33,420	$43,610	$57,650	$72,700

Source: U.S. Department of Labor: Bureau Statistics. Occupational Employment and Wages: GPO, May 2006.

The maintenance aspect of the cost analysis reviews the bulbs operating lifetime and how efficient it is in the long run. Allen Enterprises addresses this topic by examining the long life expectancy of the LED bulb over the traditional incandescent. LED’s are referred to as high flux light sources that bring many advantages to the table when it comes to implementation. Studies have been conducted that measure a single LED fixture at high intensity to be working properly at 100,000 hours (Sajadi 2008). Significant maintenance savings are realized when the time to replace a bulb rarely occurs because their useful life is so long, which leads to a reduction in man hours that are needed to replace the burnt out bulbs (Seymour 2007).

The average electrician would have to spend less time on those taxiways and runways that have LED lights installed, as compared to those areas that are still operating incandescent bulbs. Depending on the amount of electricians on staff, a savings could be realized, or at least an increase in productivity to allow more time to be focused on other electrical issues that the electrician is required to complete.

Cost Analysis

As with any major equipment replacement project, there will be difficulties dealing with the cost and implementation of LED light fixtures. However, the potential for capital saved on energy use and equipment replacement over time can yield a significant return on investment. According to the U.S. Department of Energy, today's white LED's cost more than $50 per thousand lumens, where a typical incandescent high-wattage bulb costs $1 per thousand lumens. However the life of an LED bulb, degraded to 70% output, can be upwards of four times the life of incandescent bulbs.

In March of 2007 the Federal Aviation Administration activated a prototype LED system at Prescott Municipal Airport (PRC), in Prescott, Arizona. The study identified the current power requirements for incandescent, conventional LED, and the prototype LED technology, as provided by OPTIMUS Corporation. Results yielded from the experiment support the idea that significantly less power usage can provide substantial capital savings without sacrificing performance. Table 2 shows the typical wattage use for Incandescent, LED, and prototype LED discussed in the Prescott Municipal Airport (PRC) case study.

Table 2: Technical Performance Test Results at Prescott Municipal Airport

Incandescent	**Step 1**	**Step 2**	**Step 3**
Current (Amps)	4.88	5.56	6.7
Voltage	4.36	5.18	6.83
Power (Watts)	21.27	28.8	45.76
LED (with 6.6 Amp Circuit)	**Step 1**	**Step 2**	**Step 3**
Current (Amps)	4.86	5.57	6.7
Voltage	3.11	3.24	2.98
Power (Watts)	15.15	18.05	19.97
Prototype LED (2.8 Amp Circuit)	**Step 1**	**Step 2**	**Step 3**
Current (Amps)	0.28	0.84	2.84
Voltage	1.25	1.6	2.2
Power (Watts)	0.35	1.34	6.25

Source: "LED Technology: Lighting the Way," *The Journal of Air Traffic Control*

Table 3 shows the comparison of annual energy costs for Incandescent, LED, and prototype LED at PRC. This verifies that LEDs are much more economical to operate when compared to incandescent bulbs, operating at almost half the cost. The prototype LED would cost PRC less than $1/17^{th}$ of what it previously cost to operate the airfield lights.

Table 3: Energy Cost Calculations at Prescott Municipal Airport

Incandescent 6.6A Series Circuit with 30/45W Transformer

Brightness Step #	Amps	Brightness Level	Percent Usage	Hours Usage*	Load VA @ Each Fixture	Total Quantity Fixtures	Total Annual kWh For Circuit	Annual kWh Regulator @ 80% Efficiency	kWh Unit Cost	Annual Energy Cost @ 80% Efficiency
1	4.8	10%	10%	438	21.27	300	2,795	3,494	$0.15	**$524**
2	5.5	30%	80%	3504	28.8	300	30,275	37,843	$0.15	**$5,676**
3	6.6	100%	10%	438	45.76	300	6,013	7,516	$0.15	**$1,127**

Total Annual Energy Cost $7,327

LED 6.6A Series Circuit with 30/45W Transformer*

Brightness Step #	Amps	Brightness Level	Percent Usage	Hours Usage*	Load VA @ Each Fixture	Total Quantity Fixtures	Total Annual kWh For Circuit	Annual kWh Regulator @ 80% Efficiency	kWh Unit Cost	Annual Energy Cost @ 80% Efficiency
1	4.8	10%	10%	438	15.15	300	1,991	2,488	$0.15	**$373**
2	5.5	30%	80%	3504	18.05	300	18,974	23,718	$0.15	**$3,558**
3	6.6	100%	10%	438	19.97	300	2,624	3,280	$0.15	**$315**

Total Annual Energy Cost $4,246

*When using 10/15 watt series circuit transformers, fixture VA loading and energy cost may be further reduced by as much as 25%.

Prototype LED 2.8A Series Circuit with Interface Device

Brightness Step #	Amps	Brightness Level	Percent Usage	Hours Usage*	Load VA @ Each Fixture	Total Quantity Fixtures	Total Annual kWh For Circuit	Annual kWh Regulator @ 80% Efficiency	kWh Unit Cost	Annual Energy Cost @ 80% Efficiency
1	2.8	10%	10%	438	0.35	300	46	57	$0.15	**$9**
2	0.84	30%	80%	3504	1.34	300	1,409	1,761	$0.15	**$264**
3	28	100%	10%	438	6.25	300	821	1,027	$0.15	**$154**

Note: These calculations are based on a fixture to fixture comparison, operating 12 Hours a day for 365 days a year. Over the 12 hour period it is assumed that 10% is at step 1, 80% at step 2, and 10% at step 3.

Total Annual Energy Cost $427

Source: "LED Technology: Lighting the Way," *The Journal of Air Traffic Control*

Funding Component

Funding airport and airfield related projects revolve around a number of methods to obtain funding for the desired project. Among those different methods are Airport Revenue from concessions, lessees, and passenger facility charges (PFC's); local, state, or federally backed bonds and grant opportunities.

How is KCLE funded?

The Cleveland Airport System is an enterprise fund of the City of Cleveland, meaning that it is a self-sustaining operation. As such, all revenues earned by the airport must be spent solely for airport purposes. No local tax dollars are used to fund any projects or operations at the airport. The airport is funded by non-aviation related revenues (i.e., concessions and parking), aviation revenues (i.e., rents and landing fees), and federal grants. The airport has an annual operating budget of approximately $129 million (Airport Fact Sheet).

Airport Revenue

Airports generate revenue from concessions and leases that exist within the airport environment. Airport use or lease agreements define the financial and operational relationship between an airport and the airlines or vendors it serves. These can be in the form of legal contracts or leases for the airfield or terminal facilities. Some airports do not negotiate fees associated with use of the facility. Instead, rates are charged as set forth by local ordinances or resolutions. There are also subsidies available for funding resources through public and governmental agencies. These practices rely on the local government to balance operating costs. (Smith & Breen 2006)

Grants

Since the post-World War II era, the national government has provided grant programs from which owners of public-use airports could acquire funds for airport development and improvement. These funds are provided without responsibility for paying any money back to the government. However, airports must use the funds in accordance with the source's rules and regulations, as well as, maintain overall standards of operation. In addition to federal funding, many individual states offer grant programs for airport improvements. This funding is commonly found within state Departments of Transportations, funded from the general tax base, state user fees on transportation-related facilities, and fuel taxes (Wells, 2004).

The Airport Improvement Program (AIP) was established by the *Airport and Airway Improvement Act of 1982* and provides a single, national program for airport planning and development through funding from the Airport and Airway Trust Fund. The trust fund relied on under fees and taxes assessed on those who benefit from the services made possible by AIP grants. An airport must be part of the National Plan of Integrated Airport Systems (NPIAS) to be eligible for AIP funding. The sponsor must also meet several legal, financial, and miscellaneous requirements in order to ensure that the sponsor is capable of fulfilling the requirements stated in the grant obligations. AIP funds may only be used toward specific types of projects that directly contribute to the capital improvement of airport facilities. These projects may include the construction, improvement, or repair of an airport (Wells, 2004).

State and local funding is offered either as supplemental funding to federal grants, or as primary funding for airport projects not eligible for funding through AIP. State grants are typically funded at some percentage of the total funds required, with the airport owner obligated to pay the remaining costs. In addition to individual state grant programs, some states have developed block grant programs. Under these programs, states apply for federal funding on behalf of their represented airports. The states then allocate the funds received from the federal government to the airports as they see fit. Block grant funding of airports at the state level tend to involve general aviation airports with large airports opting for categorical grants.

Municipal Bonds

A common way for municipalities to fund new projects and cover various expenditures is to issue debt securities, or municipal bonds, which are an alternative for raising capital aside from increasing taxes. The interest payments are free of federal taxes and usually state/local taxes as well. Municipal bonds are generally considered to be a safe form of investment for the simple reason that local governments are far less likely to go bankrupt than say a corporation. The two most commonly issued types of municipal bonds are General Obligation (GO) Bonds, and Revenue Bonds.

General Obligation Bonds are unsecured, credit-backed issuances that have maturities, or pay back dates of around ten years. Revenue Bonds are used for funding projects that will eventually create some kind of financial return, which will be used to pay back the debt issuance. The more likely candidate for funding a large project such as replacing current airport runway/taxiway lighting with LED's would probably be Revenue Bonds. The money saved from decreased electricity use and increased fixture life, as well as setting up airports for going green would be a great incentive for issuing Revenue Bonds. On the other side, investors would have an exciting cause by helping to fund a project that helps their airport become more efficient and environmentally friendly, whilst maintaining the utility of a safe investment in a municipal debt security.

FAA Requirements

According to the FAA's Advisory Circular 150/5345-46Ca, taxiway edge lights are omni-directional and blue in color, while runway edge lights are omni-directional white lights except for the last 2000 feet where the lights will be amber in order to warn the pilot that they are running out of runway.

The environmental requirements, in section 3.2 of the same AC, are as follows:

The light fixtures must achieve specified performance under the following environmental conditions:

a. Temperature
    1) Operating: exposure to any temperature from -40 °F to 131°F
    2) Storage/shipping: exposure to any temperature from -67 °F to 131 °F
b. Temperature shock: exposure of the hot light fixture to cold water spray
c. Salt fog: exposure to a corrosive salt atmosphere
d. Wind: exposure to wind velocities of 300 mph for all L-804, L-861, and L-862 fixtures, and 150 mph for all other elevated fixtures
e. Precipitation: exposure to rain, snow, ice, and standing water
f. Solar radiation: exposure to solar radiation

LED Light Colors

Light emitting diodes currently come in a variety of colors; although the only colors that this group is concerned with are amber, blue, and white.

Taxiway Lights

As far as the taxiways are concerned, LEDs would be an exceptional substitution. The taxiway edge lighting system defines the edge of taxiways. Blue incandescent optics transmit short wavelength radiation resulting in a very poor fixture efficiency. The photopic transmission of incandescent light sources is between 4% and 5%. On the other hand, the photopic transmission for LEDs is at least 82%, when matched with a blue glass optic (Fox 2). The colored LED must be matched with a like-colored cover in order to maintain optimal performance. A colored LED with a clear cover will not produce the same results. By switching from the traditional incandescent light source, a great amount of energy will be saved in addition to the increased color saturation.

Runway Lights

Runway edge lights are either white or amber, depending on the location on the runway. The benefits of amber LEDs would be similar to the benefits of blue LEDs; although, white LEDs have received a lot of criticism. The beginning form of white LED light was not as efficient as desired; but, over the years drastic improvements have been made (Sullivan 2007). Current technology produces white light through modified blue LEDs (Sullivan 2007). The procedure, developed by Nichia Corporation, gives the appearance of white, having better spectral characteristics to render the white color better. These LEDs would be covered with a clear lens. While white LEDs are not as beneficial as their blue counterpart, their lifetime expectancy is still +50,000 hours.

Changes to Allow Implementation

LED lights are compatible with the existing airport lighting and can be connected to the same loop, through the same isolating transformer (Urbaing 2007). The existing circuitry may be overrated for the associated loads of LED lighting, by having an excess capacity. Table 4 demonstrates a comparison between components required for a standard lighting system vs. the LED lighting system. Through the redesign of circuit components, power sources, cables, transformers, generators, etc. will be smaller and less expensive as compared to traditional (existing) components (LED Tech: Lighting the Way).

Table 4: Prototype LED Taxiway Lighting System Components-Standard vs. LED

Incandescent Lighting System (Current FAA Standards)	**LED Lighting System (Prototype)**
Incandescent Elevated Taxiway Edge Light	LED Elevated Taxiway Edge Light
6.6 Amp Constant Current Regulator	2.8 Amp Constant Current Regulator
30/45 Watt Series Circuit Transformer	10 Watt Series Circuit Interface
Cable Conductor Size #8	Cable Conductor Size #12 or #14
2-Inch Cable Conduit	1-Inch Cable Conduit
The following is a comparison of the estimated size of the primary power distribution gear used between an incandescent (142kW) airfield lighting design and a comparable LED (26kW) airfield lighting design	
300kW Generator	60kW Generator
400 Amp Transformer Switch	125 Amp Transformer Switch
400 Amp MCB Main Panel	100 Amp MCB Main Panel
400 Amp MCB Emergency Panel	100 Amp MCB Emergency Panel

Source: Seymour, Michael. "LED Technology: Lighting the Way." The Journal of Air Traffic Control *(2007): 43-49. 10 Nov 2007 <www.atca.org>*

LED Fixture Design

The airport has the option of using an adaptor in order to use the existing fixture, or install a new LED-compatible fixture. This group has created a modified design for a new LED fixture that performs on par with incandescent fixtures, and still meets all criteria set by the FAA.

Similar to the existing fixtures, the LED fixtures will have a cover over the bulbs. The properties of borosilicate glass make it ideal for airfield lighting, especially when coupled with LEDs. The durability of borosilicate glass allows it to be impact resistant, having the slowest rate of degradation (Fox 2007). Having a high conductivity, borosilicate glass runs the risk of thermal shock when coupled with incandescent lights. The conductivity will be used to our advantage when coupled with LEDs. It is a common misconception that LEDs do not produce heat; however, LEDs do produce heat within the device. This heat may be utilized to prevent any frozen accumulation on the fixture in cold climates (Whitaker 2007).

The light fixture will contain multiple LEDs, evenly spaced, as shown in Figure 4. The proper amount of LEDs should be used to provide the desired lumen output, specific to each application. The glass cover should be almost flush with the lights to provide maximum conductivity; along with steeply sloped sides to further enhance the prevention of any unwanted accumulations (Ripp 2008). This type of design is currently being used in other outdoor applications, including LED billboard signs. According to the Director of Lamar Digital, Mr. Bill Ripp, the company has not yet experienced any build-up of snow or ice on their billboards which are run 24 hours a day, 365 days a year. During summer months when the temperature increases, the intensity of the bulbs may be decreased if necessary to prevent overheating.

Along with this fixture design, the user could opt for an anti-icing coating to further reinforce the prevention of snow and ice accumulation; although, reapplication of the coating may be both necessary and costly.

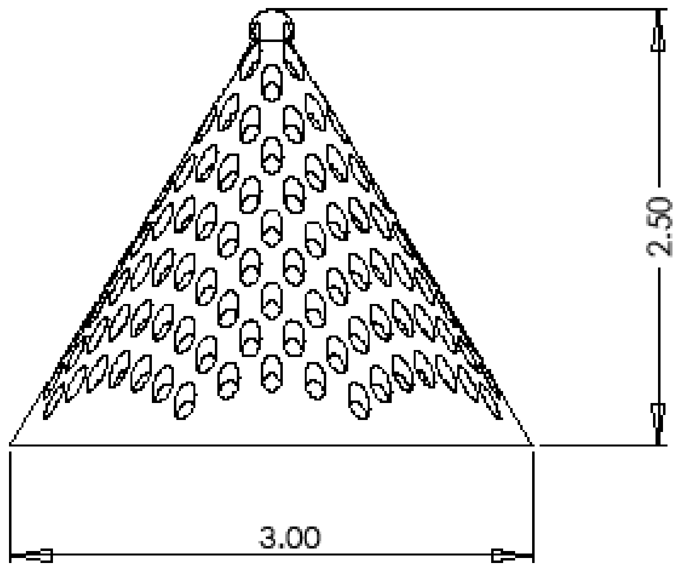

Figure 4: Prototype LED Fixture Design

Interactions with Industry Professionals

After choosing the scope of this proposal during a series of initial discussions with Dr. I. Richmond Nettey, faculty advisor, Dr. Nettey contacted Mr. Dana Ryan, Chief of Planning for the Cleveland Airport System, to provide practitioner assistance. A meeting was held with Mr. Ryan to discuss impacts that the project might have in the future enhancement of airports. It was explained that KCLE had recently begun a runway extension project and considered using LEDs. The technology is still new to airports, and it was ultimately decided that LEDs were not yet effective for KCLE, even with all of the benefits that may be experienced. Mr. Ryan expressed his primary concern being that the LEDs were not able to prevent snow or ice accumulation; and, with the addition of a heater the benefits of the LEDs may be outweighed by the added expense to run the heater. The goal of this group was to create a fixture design that would be suitable for cold weather regions, especially KCLE.

Consulting was also done with Mr. Bill Ripp, Director of Lamar Digital. Lamar billboards currently utilize LED technology. In order to best determine how to implement LEDs on an airfield, the group consulted outside sources to determine how and where LEDs are currently being used in other outdoor applications. Through email correspondence, Mr. Ripp explained that their billboards have not experienced any accumulation of ice or snow, even in colder states such as Montana and Wyoming.

Meeting Airport Needs through LEDs

The team's problem solving approach to the design challenge revolves around the need for improvement of current lighting systems to withstand extreme meteorological environments in airports nationally. LED lights offer a worthy alternative to airport lighting options by their low maintenance cost and energy savings. The challenge in incorporating LED technology into airports today is the variable weather conditions located across the country at various airports. Currently, incandescent lights generate enough heat in snowy conditions to aid in the removal of accumulation. LEDs lack the filament that produces the excess heat capable of doing such, therefore a design enhancement needed to be considered. With the high life expectancy, low maintenance, and energy saving capabilities, the LED bulb deserves to be tested in different conditions for possible future use.

The LED bulb was researched and compared to the FAA standards and goals to assess the solutions that LED technology encompasses. The team then broke down the respective improvement to include a safety risk assessment including; prototype airports and the success rate of LED's implemented at them, intensity and necessities to improve the intensity in all weather conditions. The technical aspects of the design challenge addressed the differences of lights and the advantages and disadvantages of each. Lighting components of the system were analyzed including the fixtures, bulbs, circuitry, voltage requirements and transformers that would need to be implemented at an airport.

The maintenance costs associated with implementation and upkeep are examined in an averaging of electrical company costs associated with energy consumption and electrician's costs as compared to staff positions. Funding for airport improvement programs are viewed from three different prospective. Airport Revenue, bonds and grants are all considered in the funding discussion.

The impacts of LED technology can be seen on a yearly cost benefit analysis and emphasis on going green in today's global society. Not only do LED's benefit the airport, but the pilots and air traffic controllers also get to bask in the new lighting systems. LED's would provide a more efficient lighting system that lasted through harsh environmental conditions to aid in the safety of transient aircraft and passengers.

Appendix A – Contact Information

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Appendix B- Description of Kent State University and the Aeronautics Program

Established in 1910 as Kent Normal School by a statutory act of the State of Ohio, Kent State University has evolved into the second largest state university system in Ohio, the "birthplace of aviation," as well as the oldest and largest state university in Northeast Ohio with over 35,000 graduate and undergraduate students at Kent campus, the home of the Aeronautics Program, and seven regional campuses around Northeast Ohio. The internationally known events of May 4, 1970, which involved the tragic loss of four students during a period of national unrest, have also influenced institutional purpose and contributed towards the evolution of Kent State University into a well known leading university in the United States and the entire world. In transcending these events, Kent State University has become renowned for the broad range and distinction of its academic programs, innovative research, collaborative partnerships, and broad-based policies on faculty work.

Kent State University ranks among the top 90 public universities in the United States, according to the Carnegie Foundation for the Advancement of Teaching. This Carnegie ranking places Kent State University in an elite group among the 3,900-odd colleges and universities in the United States. Kent State University's institutional purpose is fulfilled, in part, through providing numerous associate degree programs in various technical and business fields at the seven regional campuses, some 271 academic programs of undergraduate study, 214 academic programs at the master's level, and 59 areas of doctoral study in the Colleges of Architecture and Environmental Design; the Arts, Arts and Sciences; Business Administration; Communication and Information; Education; Nursing; and Technology, the academic home of the Aeronautics Program. In addition to the preceding colleges, which are administered and headed by academic deans who report to the University Provost, Kent State University has the College of Research and Graduate Studies, College of Continuing Studies, the Honors College, as well as diverse centers, institutes, and research bureaus in specific areas, such as the world-renowned Glenn H. Brown Liquid Crystal Institute.

With Kent State Airport dating back to 1917, aviation education at Kent State University has evolved into a nationally renowned and accredited degree program with six areas of academic concentration (AOC) in Aeronautical Studies, Aeronautical Systems Engineering Technology, Aviation Maintenance Related Technology, Air Traffic Control, Aviation Management, and Flight Technology. Flight training is provided with Kent State University's fleet of 25 single- and twin-engine airplanes under 14 CFR Part 141 at Kent State Airport, which is located 2.5 miles from Kent campus.

On 16th February 2006, the Aeronautics Program became the first and only aviation program at a university to become accredited by the Aviation Accreditation Board International (AABI) in Ohio, the birthplace of aviation. At present, the Aeronautics Program's four original AOC's in Aeronautical Studies, Aeronautical Systems Engineering technology, Aviation Management, and Flight Technology hold full accreditation by AABI through February 2011. In fall 2007, the FAA authorized Ohio's only Air Traffic–Collegiate Training Initiative (AT-CTI) program at Kent State University.

Appendix C- Description of Non-University Partners

The implementation of LED airfield light fixtures was intended to be applicable for all airports, in both cold and warm weather regions. This proposal was developed with the intention of possible initial implementation at Cleveland-Hopkins International Airport as a test bed or proof of concept, with the help of Mr. Dana Ryan, Chief of Planning.

As Chief of Planning at Cleveland Hopkins International Airport, Mr. Ryan has responsibility for the development and oversight of airport projects. Cleveland Hopkins International had recently planned for a runway extension, and considered using LED lights. With Mr. Ryan’s input, this student group created a modified design that may be sufficient in meeting the challenges of future runway and taxiway projects.

The input from Mr. Bill Ripp, Director of Lamar Digital, was essential to the creation of the LED fixture design. While LEDs are relatively new to aviation, they have been used for years in many indoor and outdoor applications in other industries. Through e-mail correspondence, Mr. Ripp explained the basic design of a LAMAR outdoor billboard sign, which has remained clear of any frozen accumulation, even in states such as Wyoming and Montana. Through brainstorming, this group developed a design that should hold up well during the worst of nature’s elements.

Appendix E – Evaluation of Educational Experience

Student Evaluations

Lannie Marsh: The knowledge gained while working on this project is invaluable. Our group collectively chose to work on the topic of LED lighting for airfields, before realizing that this was a subject covered during last year's proposal. Upon further inspection, we felt that there were many options to implementing the LEDs, and that our group may discover an innovative concept that would be invaluable to airport operators. LEDs are used in more applications than realized, and the benefits of implementation are exceptional.

Working with a group on this project proved difficult at times, as each person had different times of availability, separate limitations, and each had a different idea on how to proceed with this project. Our hypothesis came months after the project was started. We formulated and reformulated our hypothesis to ensure that it fit with the goal of our design, which is to increase efficiency through reduced energy consumption using LEDs.

It was very rewarding to undertake this project and have the opportunity to make contacts with industry experts. My knowledge regarding airfield lighting and light emitting diodes was very limited. Without the contacts made with industry experts, this project would have been very difficult to complete. New technology is introduced on a daily basis, without talking to those more knowledgeable about our topic, our project would not have been as complete.

The information that I learned while working on this project will help me prosper in the future. As I am completing my last year of school, I must begin preparing to enter the workforce. Having had the opportunity to work in a team on a project of this magnitude, I believe that it will make the transition to entering the industry much smoother.

Michelle Lanning: My experience with this project has impacted my researching techniques and overall knowledge of LED lighting systems. By working in a team oriented environment with professional expertise and advice through our contacts, everyone had an opportunity to do individual and group research. This experience has allowed me to expand into more in depth researching techniques and improve my communication skills in a team environment. Our professional contacts were extremely helpful, by giving us detailed information about our test airport, Cleveland Hopkins International Airport, that proved useful in all research aspects. I encountered some difficulty when trying to research the electrician wages as compared to a national average across the United States. The government websites provided the most detailed information regarding this topic by consensus information that they had collected in previous years. This experience has also allowed me to be a part of a fantastic research group, and submit an end product to the FAA for review and analysis.

Ryan Cole: Overall the experience gained by working on this project was very positive. It showed that a team that can work together through the difficulties associated with projects like these can produce favorable results in their work.

Nicole Sellers: The FAA Airport Design Competition has provided a meaningful learning experience for me. It has provided me with an invaluable experience in teamwork and learning about regulations in regards to aviation. By working in teams, I have learned that although every group member may not agree on something, there is always compromise. The first challenge we had was to find a topic for airport improvement. But we came to a decision and progressed from there. Our team decided to take a divide and conquer approach to finishing this competition. We came up with an outline and then divided the aspects of our submission according to our strengths.

Participation by industry members was vital in our project. In fact, our first step was to meet with an industry professional to receive ideas on how to improve airport lighting and what is currently being used. By meeting with industry professionals and researching sources including the FAA and industry standards on lighting, I have learned about airport lighting and a better form of lighting but, also about the importance of teamwork. Thank you for putting this opportunity out for university students.

Faculty Advisor Evaluation – **Dr. I. Richmond Nettey**

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

The FAA Airport Design Competition program provides an invaluable opportunity for Aeronautics students in the Airport Management class to gain invaluable experience in task-oriented teamwork that addresses critical issues and projects in airport operations and management, safety, and environmental issues.

Learning to work effectively on task oriented teams that deal with these critical issues will prepare students to surmount challenges that are likely to be faced by future operators and managers of airports and the National Airspace System. In this respect, the FAA Airport Design Competition program makes an invaluable contribution to aviation.

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

The learning experience was appropriate to the course level and the context in which the competition was undertaken. This holds true for students who recognize the import and scope of such a national competition.

3. What challenges did the students face and overcome?

The most critical challenges faced by students involved dedicating ample time to the project and working with a collective focus to produce a first rate proposal they will be proud of throughout their professional lives.

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

It will be a continued privilege to use this Competition as an educational vehicle in future sessions of the Airport Management class so long as there are aviation students who are willing to do the required work. Continued use of this Competition is justified by the continued need to provide aspiring aviation professionals with practical opportunities to acquire critical skills associated with team oriented work and projects.

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

(1) Increase the prizes to $5,000, $3,000 and $2,000 with consolation prizes of $1,000.
(2) Make provision to have all serious candidates present at the presentation ceremony.

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Appendix G- Airports utilizing Light Emitting Diodes (LEDs)

The following is a list of airports around the world that are currently using, or have tested LEDs for airfield lighting:

Auckland Int'l, New Zealand[3]
Baghdad International Airport, Iraq[2]
Bagram AB, US AF, Afghanistan[1]
Balad AB, Iraq[2]
Bankok Int'l, Thailand[3]
Beale AFB, CA[1]
Beaufort Marine Corps AB, SC
Brussels Int'l, Belgium
Bryan Airfield, US Army, AK
Calgary Int'l Airport, Canada[3]
Cartagena Airport, Columbia
Carupano Airport, Venezuela
Chicago O'Hare Int'l, IL[1]
Delhi Int'l, India[3]
Dubai Int'l, UAE[3]
Dublin Int'l, Ireland[3]
Dubrovnik Int'l, Croatia[3]
Edmonton Int'l, Canada[3]
Eglin AFB, FL[1]
Ellington Air Field, TX
Ellsworth AFB, SD[1]
Elmendorf AFB, AK[1]
Ganci AFB, Kyrgyzstan[1]
Gatwick Int'l, UK[3]
Grand Bahamas Int'l, Bahamas[3]
Grantley Adams Int'l, Barbados[3]
Halifax Int'l, Nova Scotia[3]
Harrisburg Int'l[3]
Hickam AFB, HI[1]
Homestead ARB, FL
Honolulu Int'l, HI
John F. Kennedy Int'l[3]
Kabul Int'l, Afghanistan[3]
Kandahar AFB, Afghanistan[2]
Keesler AFB, MS[1]
Kingsley Air Field, OR
Kirkuk AFB, Iraq[2]
La Guardia Int'l[3]
Langley AFB, VA[1]
Las Americas Int'l, Dominican Republic[3]
Linden Pindling Int'l[1]
Logan Int'l, MA
London Int'l, Ontario
Los Angeles Int'l, CA[3]
Louisville Int'l, KY
MacDill AFB, FL[1]
Manchester Int'l, UK
McGhee Tyson, TN
McGuire AFB, NJ[1]
McEntire Air Field, SC
Memphis Int'l, TN
Miami Int'l[3]
Milan Int'l, Italy[3]
Minot AFB, ND[1]
Moody AFB, GA[1]
Murtala Muhammed Int'l, Nigeria[3]
Nassau Int'l, Bahamas
Naval Air Station North Island, CA
Nellis AFB, NV[1]
New Castle Int'l, VA
Oakland Int'l, CA
Old Bridge, NJ
Ottawa Int'l, Ontario[3]
Perth Int'l, Australia[3]
Phoenix Int'l, AZ
Piarco Int'l, Trinidad & Tobago[3]
Pohnpei Port Authority, Pohnpei State[3]
Prescott Municipal, AZ
Prince George, BC
Quito Int'l, Ecuador[3]
Ramstein AFB, Germany[1]
Richmond Air Field, SC
RAF High Wycombe, UK
Salt Lake City, Int'l[3]
Scott AFB, IL[1]
SeaTac Int'l[3]
Seymour-Johnson AFB, NC[1]
Singapore change Int'l, Singapore[3]
Smith Reynolds Airport, NC
Southampton, UK
Spokane Int'l, WA
Stockholm-Arlanda Int'l, Sweden[3]
St. Paul Int'l, NM
Sustainer AB, Iraq[2]

SW Florida Int'l, FL
Sydney Int'l, Australia[3]
Tallil AFB, Iraq[1]
Toronto Int'l, Ontario[3]
Travis AFB, CA[1]
Truckee Tahoe, CA[1]
Vancouver Int'l, British Columbia[3]
Victoria Int'l, British Columbia
Warner Robins AFB, GA[1]
Washington Dulles Int'l, DC[3]
Whiteman AFB, MO[1]
Yellowknife Int'l, NWT
Zurich Int'l, Switzerland[3]
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