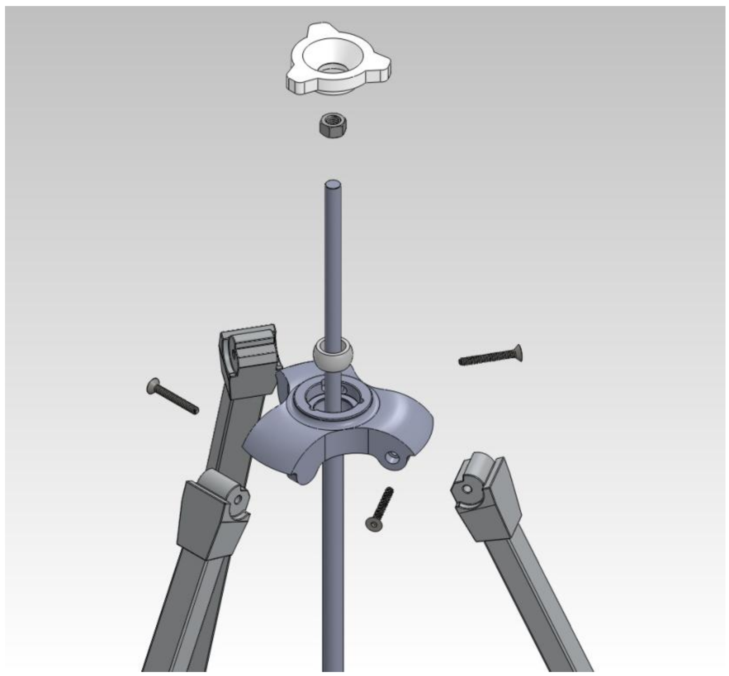
Obstruction Measurement Device

University of Rhode Island
FAA Design Report
April 24, 2011



Team 5

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Executive Summary

Current FAA regulations require updated measurements of runway obstructions at an airfield (i.e. tree lines, buildings, etc.) every two years via a standardized FAA 5010 Inspection. Currently, these obstructions must be measured using conventional surveying equipment and mathematical calculations, which is time consuming and can take up to a half day to inspect one airfield. The data on obstruction height and location must be available online for pilots to familiarize themselves with the conditions of airports at which they will land. With over fifty airports of varying size in Rhode Island, the Rhode Island Airport Corporation (RIAC) expressed the need for a device which could measure obstruction height accurately, in a repeatable, cost-effective fashion.

This report details the design process of a device to perform obstruction measurements using laser range finding and photo analyses. The output data of the device is the obstruction height, the distance to the obstruction, and the slope. The device will be used as a management tool to help RIAC employees carry out the FAA mandated 5010 inspection, ensuring safe operations at medium and small non-commercial airfields. The Obstruction Measurement device was designed with the support of the RIAC, which allowed admittance to numerous state airfields and provided several ideas including feedback on concurrent designs.

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Problem Statement and Background

The URI design team began the problem selection process by generating several concepts in all of the competition categories. These ideas were presented to RIAC, and current issues affecting airports in Rhode Island were discussed. Three areas were of particular interest to RIAC: Noise Level Monitoring, Burned-out Light Bulb Detection, and Obstruction Measurement. After in-depth deliberation and examination of factors such as feasibility, time constraints, and budget, the URI design team chose to pursue a design in the area of obstruction management.

Current FAA regulations require updated measurements of runway obstructions at an airfield (i.e. tree lines, buildings, etc.) every two years via a standardized FAA 5010 Inspection. Currently, these obstructions must be measured using conventional surveying equipment and mathematical calculations, which is time consuming and can take up to a half day to inspect one airfield. Additionally, a company named GCR uses Photoslope technology, taking photographs of obstructions from various positions along the end of the runway to determine if any obstructions penetrate the current mandated approach slopes. This service provides quantifiable data, which is useful in the event of a crash; however, it is only identifies obstructions which protrude through the minimum approach slope dictated by the FAA. It does not give exact measurements for height. Photoslope is also expensive, costing approximately $5000 per airfield. The data on obstruction height and location must be available for pilots to familiarize themselves with the conditions of airports at which they will land. With over fifty airports of varying size in Rhode Island, RIAC expressed the need for a device which could measure obstruction height accurately, in a repeatable, cost-effective fashion.

Summary of Literature Review

While designing the device for obstruction measurement, various literature sources were used throughout the design process. Most importantly, the FAA Regulations formed the backbone of the design specifications. In a joint decision, the design team and RIAC officials determined that the FAA regulations involving the 5010 inspection would be the main focal point of the project. Reviewing the 5010 inspection procedure resulted in the decision to implement a removable apparatus for use during routine runway safety inspections. In conjunction with the FAA regulations, the design team used a number of texts to aid in the design and analysis of the system.

To ensure the team was following proper engineering design procedure, the required textbook of the Capstone Design Course, "Engineering Design" (4th Ed.), was frequently referenced. The text, written by George E. Dieter and Linda C. Schmidt, proved to be a helpful tool that aided in the development of an effective design. The design team used the text to enhance specific aspects of the design, such as the problem definition, design specifications, cost analysis and several other design elements.

An essential part of any design is to insure reliability and proper functionality. With the help of an engineering analysis, the design team was able to measure their success of this key component. The analysis was used in accordance with the design process to assist the team in developing a safe, effective system. A number of engineering textbooks were referenced to aid the design team's analysis. Tony Gaddis' "Starting Out with Visual Basic 2010" was used to help evaluate software-debugging issues discovered during testing. In evaluating manufacturing costs and processes, "*Product Design for Manufacture and Assembly*" by Geoffrey Boothroyd and "Factory Physics" by Wallace Hoppwere consulted.

The process of engineering the bearing housing included referencing “Shigley’s Mechanical Engineering Design” (9th Ed.) by Richard Budynas and Keith Nisbett. The contents of this literature were used as follows: to ensure enough design to prevent static loading failure, fatigue failure resulting from variable loading, in the design of nonpermanent joints (i.e. threading, locking mechanisms), and lastly finite-element analysis. These design considerations allowed for streamlining the design process and resulted in a feasible bearing housing that will not fail during operating conditions.

Problem Solving Approach to the Design Challenge

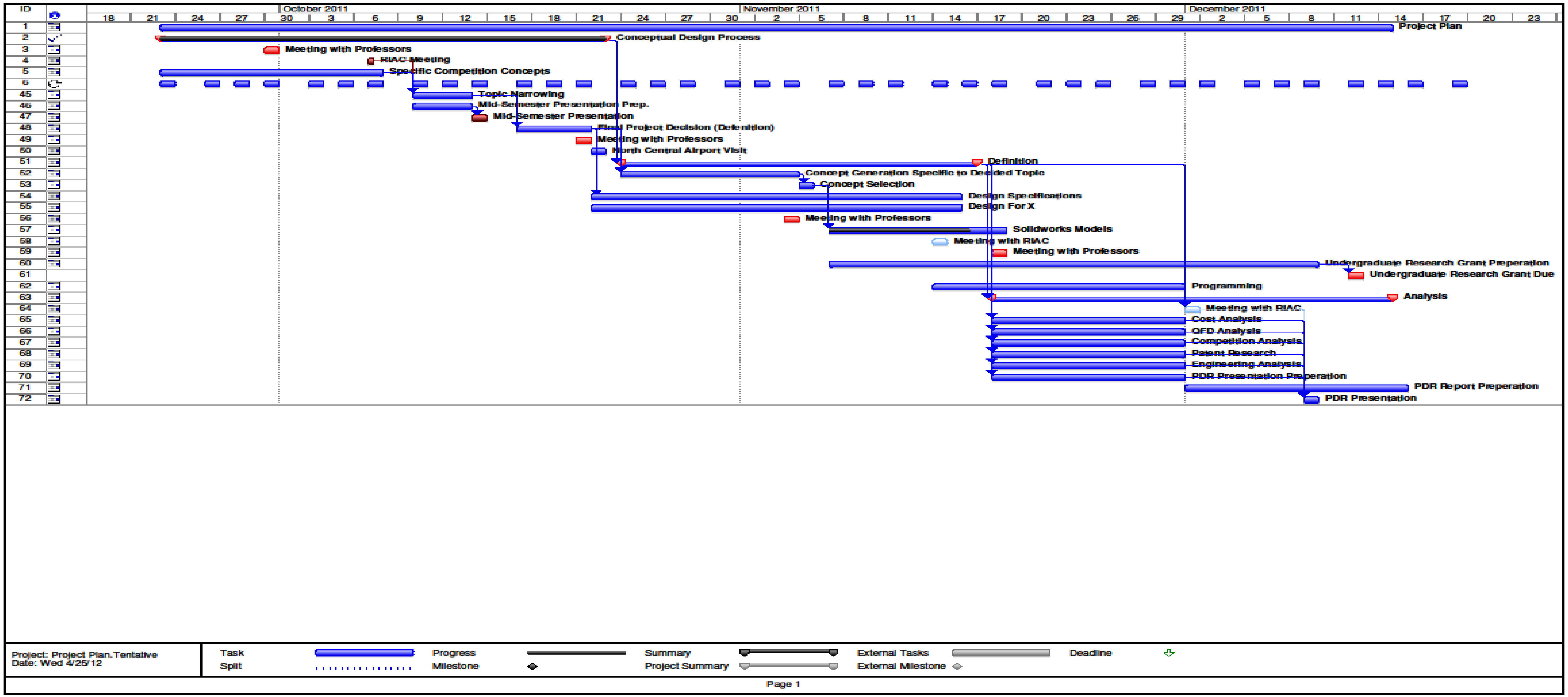


Figure 1: Fall Semester Gantt Chart

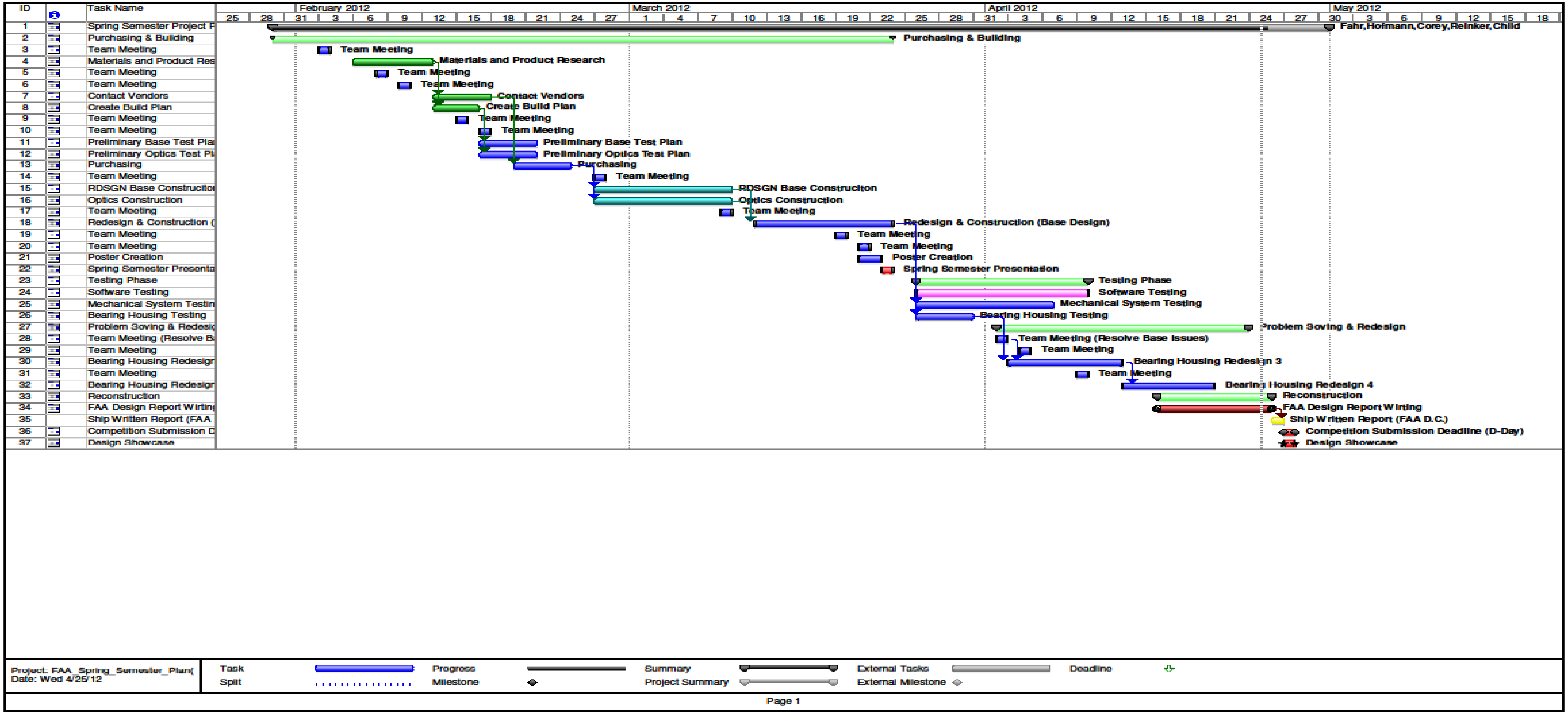


Figure 2: Spring Semester Gantt Chart

This year's University of Rhode Island FAA Design Team consists of three mechanical engineering and two industrial engineering students. The mechanical engineers, Brandon Corey, Andre Hofmann, and Payam Fahr, are all part of the International Engineering Program earning degrees in Mechanical Engineering and German. The industrial engineers of the team, Nicholas Child and Jeffrey Reinker bring valuable skill sets and experience outside of academic training. This was important as this project will be utilizing not only mechanical design and industrial processes, but also software development.

Throughout the year, the team followed a scheduled project plan which had an organized regimen laid out by a Gantt chart. This tool is used to organize, schedule, and create deadlines for all the design work and related administrative work of the project, including deadlines for grant proposals, schedules of weekly team meetings, and meetings with sponsors and professors. The preliminary Gantt chart for this project (Figure 1) detailed several main milestones of the design process; conceptual design, final project decision and definition, problem definition, and engineering analysis. These milestones consist of several smaller tasks and deadlines, and related tasks are illustrated with arrows connecting them. Within the conceptual design segment of the Gantt chart, a meeting with RIAC was set to discuss the concepts approved by the professors and further narrow the designs being considered.

After meeting with RIAC and the professors, the team narrowed down the number of possible projects to just three. The first was a noise pollution measurement device which would be used to monitor the decibel level of air traffic in residential areas. This would be used to verify and settle disputes among homeowners who file repeated complaints. The second project was a signal indication system for when lamps are burned out on important signs. This would be useful for maintenance persons who would be able to spot this indicator to alert appropriate persons to change bulbs ensuring safe night time operations. Finally there was the obstruction measurement device which would be used as a management tool to streamline the FAA 5010 Inspections. The budget restriction set by RIAC for the noise pollution measurement device, $300, was prohibitive as many higher end microphones cost much more, and aren't weather-resistant. It was felt that the signal indication system was not a challenging enough problem to test the engineering education of the team. The obstruction measurement device offered an interesting challenge that would bridge mechanical and industrial engineering design processes in conjunction with some software development.

After a project was selected in the first half of the fall semester, the next stage was to develop a design definition and to discuss the need for extra funding. Here, the team met again with the professors and prepared an application for the Undergraduate Research Grant. During this time, the team also generated several concepts, determining that a camera system was to be used in a photo analysis system. The camera would have to be stable and level to allow for accurate measurements. Drawing from the idea of camera stabilization found in the photo industry, a camera stabilization boom was then adapted into a pendulum concept which would utilize existing tripod equipment available from past FAA Design Groups at the university.

Two concepts were generated for the self-level base. One design would utilize a spherical bearing as the main pivot, the other would use two independently rotating wishbone shaped frames, resembling a universal joint. Due to the complexities of manufacturing and the number of moving parts, and the complexity of figuring out a locking mechanism, the wishbone design was eliminated. The idea of a simple pendulum structure was favored; therefore, the team focused its energy on producing designs utilizing the spherical bearing for its pivot. The final segment of the first semester was the analysis period where the final design concept was reviewed. In this section the team prepared Solid Works drawings, developed a Quality Function Deployment (QFD) assessment, prepared a cost analysis, researched competition, and performed engineering analysis.

The original tripod housing was modeled in SolidWorks and modified to incorporate a spherical cavity. A polymer spherical bearing from Igus was utilized and a rod was selected for the pendulum. The inner diameter of the spherical bearing was too large so reducers were created to allow the rod to fit into the bearing. The next step was to find a way to secure the bearing in the housing to keep it from pivoting when the camera is attached.

Initially the cap was to be threaded and would tighten down onto the spherical bearing. The team designed the base using High Density Polyethylene (HDPE) but due to manufacturing limitations at the university, the parts were made using ABS plastic with a rapid prototyping process. Since the threads were too complex for the rapid prototyping machine to make, and the diameter and thread sizes were proprietary, a redesign was made. The cap now had three protrusions and grooves were cut into the housing. A simple quick lock mechanism was established allowing for easy assembly as well as fastening.

Because the camera was to be oriented in the same direction for every use, the spherical bearing had to be constrained in the Z-axis. A vertical groove was cut into the side of the bearing and a pin was inserted into the housing at the center line concentric to the bearings center. This allows the bearing to pivot in all directions and restricts rotation.

With a prototype assembled, the addition of a split collar at the end of the pendulum rod added the weight required to achieve self-leveling. The upper portion of the pendulum rod was drilled and tapped, allowing the mounting of a base plate to which a camera quick release feature was utilized. During testing, the torque applied to the cap was enough to break one of the supports holding the tripod legs in place. This prompted a redesign, using a thicker portion of material and some bracing in the form of fillets for the leg attachment points. The team was not satisfied with the leveling properties of the bearing and it appeared to be binding at times. Inconsistencies were noted and it was calculated that for best performance, the ratio of the rod to the diameter of the spherical bearing was an important variable. To gain better self-leveling performance, the team ordered a smaller bearing from Igus and redesigned the housing to accommodate. Further tests reveal improved self-leveling capabilities as well as an increased spherical bearing locking capabilities.

Safety Risk Assessment

The FAA dictates a strict culture of safety, which requires that all inherent risks have been considered, described, and outlined within numerous regulations and procedures. In order to practice caution and safety, a Safety Management System (SMS) has been implemented at numerous airports to ensure the safety of the populace, pilots, and airport personnel. Documents such as the "FAA Safety Management System Manual" and the "Introduction to Safety Management Systems for Airport Operators" provide an outline for maintaining safe operations when installing a new system. Furthermore, the Federal Aviation Regulation Part 77.25 outlines approach slopes.

The obstruction measurement system designed by the team is utilized by personnel to streamline approach slope inspections and will abide by FAA regulations. During the design of the system, the hazards were identified and assessed in accordance to the five phases of Safety Risk and Management (SRM). Risks such as improper usage resulting in collision and mishandling were considered by the team. This resulted in a strong, lightweight system that if left unattended and were to be struck by an approaching airplane, would mitigate damage to the aircraft and runway. Nylon bolts were utilized to shear upon impact and a tether will tie the base plate and tripod together, discouraging further damage in the event of collision. The two and a half foot system, standing 200' from the end of the runway, will not penetrate specific FAA approach slopes therefore mitigating the risk of collision on the chance of improper use. The system has an overall specific design to abide by FAA regulations minimizing risk, maximizing safety, allowing this system and operation to be classified as a medium-low risk hazard.

In order to provide and maintain a safe environment a proper SMS is required. Specifically this system must include education and training of airport personnel to utilize the system properly and safely to conduct approach slope measurements. Education on reporting then safely removing the largest obstacle must be outlined within an SMS. A safe environment will be achieved through the above mentioned utilization of the system.

Technical Aspects of the Design

A proposed system will be introduced as a management tool capable of reducing the amount of time it takes to perform the FAA's **5010 Inspection.** Consistency and repeatability are important as catalogued information is used to forecast revenue needed for airport maintenance. The obstruction measurement device will consist of 5 parts: a webcam, a laser range finder, computer with database, self-leveling tripod assembly and base. Design specifications were developed in conjunction with the customer, Rhode Island Airport Corporation (hereafter RIAC), to ensure the best possible product. Figure 3 lists the customers' requirements and the respective design specifications.

RIAC Requirements	Design Specifications
1. A cost effective system	1. The total system shall not exceed 3,000 dollars per unit
2. Reliable and Accurate system	2a. The system will provide accurate data up to 3,280' (1000 m) from end of runway with accuracy of ±1' (±30 cm) horizontal distance and ± 0.25° vertical distance
	2b. The system will provide a clear image of surrounding obstructions
	2c. The self-leveling capabilities will be within ± 0.5°
	2d. The system will allow for 100% repeatability
3. Safe for Airport Personnel	3a. The system will not exceed 20 lbs carrying weight
	3b. The laser range finder will not emit laser radiation deemed harmful or unsafe by the FAA
	3c. The system will incorporate an intuitive Graphical User Interface
	3d. The system will fail within the nylon bolts when the force exceeds 16,000 lbs
4. Adverse environmental Conditions	4a. The system will function properly in weather conditions from -4°F to +140°F (-20°C to +60°C); limited to icing and extreme heat.
	4b. The system will withstand corrosion and the elements for up to 15 years.
5. Stress-free maintenance	5. The system will be maintainable in a manner that requires only visual checking on a yearly basis
6. Process run-time	6. The system will measure runway obstructions within less than 30 minutes per runway.

Figure 3: Design Specifications

Self Leveling Tripod

The self-leveling tripod base acts as the support structure for the camera and laser range finder capable of leveling on any terrain or slope. This structure consists of 9 parts: a quick release, a ½" rod, a 3/8 nut, an Igus® WEI-10 spherical bearing, a bearing housing, a bearing cap, a counter weight, three tripod legs, and three bolts. It has been designed from an inexpensive minimalistic standpoint utilizing the force of gravity to attain level rather than relying on the principals of conservation of angular momentum used in motor and other gyro applications. This prototype consists of components that meet all FAA regulations as it will not be permanently fixed to the airfield. The bearing is constrained in the Z-axis using a pin that is inserted into the housing concentric to the bearings center point. A longitudinal groove is machined into the bearing, and with the pin in place, allowing rotation and pivoting in all direction except the axis on which the pendulum is fixed. When the bearing cap is released, the bearing will be free to pivot and self-level. Once the cap is tightened, the cap will exert a pressure on the bearing causing it to bind and be secured in place. This is important as the pendulum should not move from level position once the camera is attached.

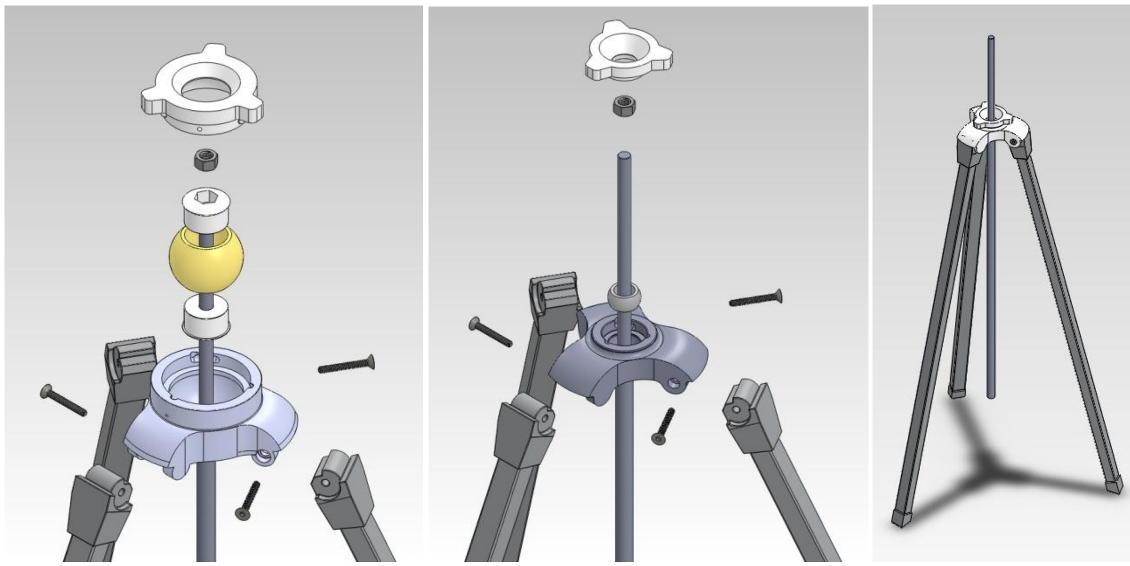
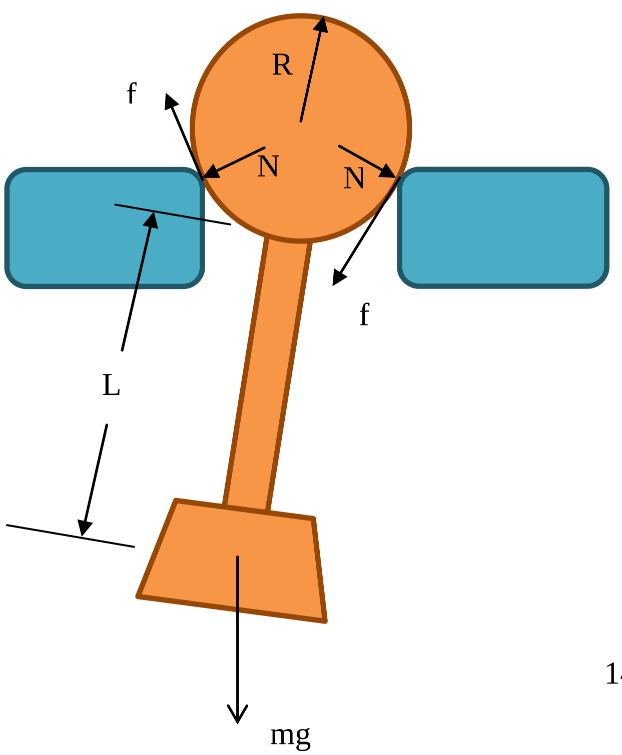


Figure 4: CAD Images of the Self-Leveling Base

<u>Engineering Analyses of the Self-Leveling Base</u>

The analysis of the binding conditions below was made to ensure that the weight would in fact swing into a level condition and to examine material selection for the spherical bearing.



f	force due to friction
mg	weight of centering mass
N	Normal Force
R	Radius of Spherical Bearing
L	Length of the rod from the sphere surface to the mass

The figure above represents the self-leveling device, assuming the spherical bearing sits in the collar and touches only at two points and that the mass is concentrated at the bottom of the rod. The first assumption is viable, as the collar will not be completely concentric with the sphere, and therefore will contact the sphere at a limited number of points. The second assumption is also viable, because the mass of the rod and sphere are extremely small in comparison to the weight at the bottom.

The system was analyzed by summing the moments of all the forces around the center of the spherical bearing. These are the two frictional forces and the force due to the weight of the mass. The summation of the moments is as follows:

$$2(fR) = mg(tan\theta)(L + R)$$

where theta is the angle at which the rod is positioned. Given that the normal forces each equal half of the weight of the system and that the friction force is given by the product of the normal force and the coefficient of friction, μ, the equation can be modified as follows:

$$2\left(\mu\frac{mg}{2}\right)R = mg(tan\theta)(L + R)$$

Rearranging for μ yields the following expression:

$$\mu = mg(tan\theta)(L + R)/(mgR)$$

Therefore, the system will bind under the following condition:

$$\mu > tan\theta\left(\frac{L}{R} + 1\right)$$

This relationship provides several useful pieces of information on the design of the self-leveling system. First, the mass does not affect the performance of system; therefore, the mass should only be heavy enough to counteract the moment due to the weight of the camera mount and camera on top of the bearing. Second, the system is most effective when the length of the rod, L, is maximized, and the radius of the sphere, R, is minimized. Lastly, this expression shows that as the mass swings towards the center and the angle, θ, decreases, a point will be reached where the mass no longer produces a moment large enough to overcome the moments due to friction. In other words, the coefficient of friction, μ, is directly related to the minimum angle and essentially the accuracy of the system at leveling. By minimizing the coefficient of friction, the system is optimized.

Aluminum Base

The 6061 aluminum base utilized in this design has been “recycled” from the FAA Design Competition 2009 design. During the rare case of an accident with an aircraft the base will ensure failure at the ¼” nylon bolts ensuring minimum destruction. To ensure repeatability, design specification 2d, the base will mate with an in-ground landmark located 200ft from the end of each runway. Using two stakes on the base it will mate with two holes in the marker ensuring 100% repeatability.

Camera

A Logitech webcam has been selected to be used to take images of controlling and other potential obstructions. The resolution was deemed acceptable for preliminary tests providing a clear picture of all runway surroundings, but the final product would be available with a higher resolution webcam of up to 10 Megapixels meeting design specification 2b requirements. The current webcam is equipped with a hole tapped with a standard ¼-20 thread found on many contemporary camera bodies. This is important for the use of a quick release system.

Quick Release Mount

While consistency is very important and will affect the measurements taken, the unbalanced weight of the camera was taken into consideration. A base is installed on the top of the pendulum rod by drilling a small hole and threading the rod to accept a screw. Once the pendulum levels, the camera is fastened into place using the quick-release system commonly found on tripods marketed for photography. This quick release has only one orientation and is tight fitting, eliminating measurement deviation due to loose tolerances in parts. The 'shoe' that latches into the quick-release base is equipped with a screw utilizing the standard ¼-20 thread used in camera mounting.

Laser Range Finder (LRF)

The laser rangefinder is a key component to the obstruction measurement device allowing personnel to attain height and distance measurements to the control obstruction and any object deemed important. This particular Tru Pulse 200 Laser Rangefinder extensively met all the requirements necessitated by the engineering design problem. The Tru Pulse 200 is accurate to within ± 1ft at a distance of 3280ft complying with design specification 2a. Furthermore, this particular model is fitted with a standard ¼-20 thread allowing personnel to fit the device onto the self leveling tripod once the picture has been taken.

Design Iteration

In order to conduct a thorough design process the self leveling tripod underwent four design reviews and iterations after testing on each was completed. This ensured that the self leveling tripod functioned to the best of design specification 2c.

The complexity of our initial design lead to a bearing housing that was too intricate to machine by CNC. Therefore, the bearing housing had to be rapid prototyped using ABS plastic. Although the plastic is rigid the prototyping process produces a delicate device. Hence the first model created required bulkier flanges where the tripod legs connect along with further fillets for strength. See figure. Furthermore, this first design lacked a proper locking mechanism.

The second refinement of the design included thicker flanges for durability along with fillets in key areas. This iteration was purely used for testing applications.

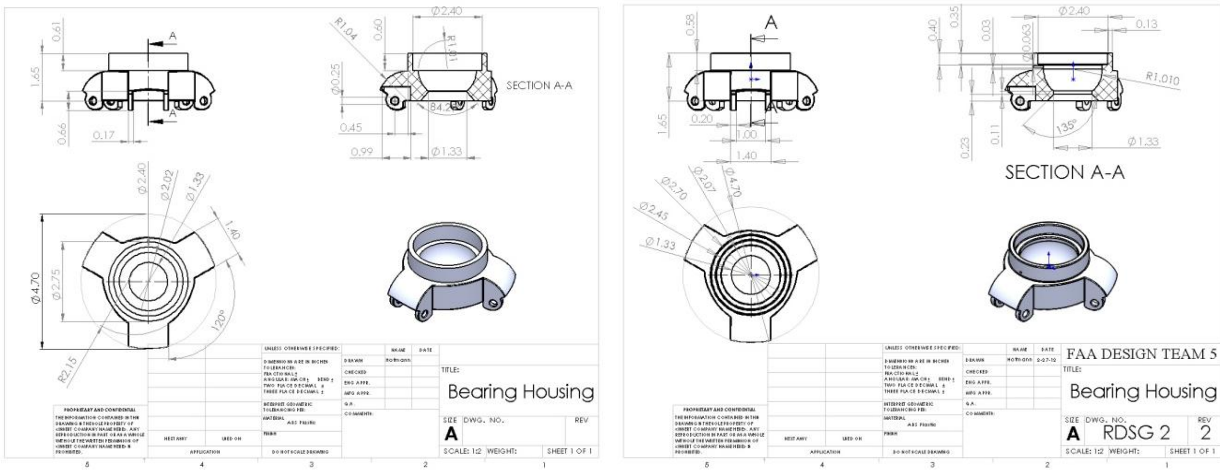


Figure 5: Bearing Housing 1st and 2nd Iterations

The third iteration included a locking mechanism by implementing three machined grooves into the Bearing Housing. The clam like cap was manufactured with three protrusions that would nest within the machined grooves and once tightened, would apply a pressure against the bearing, binding it in place.

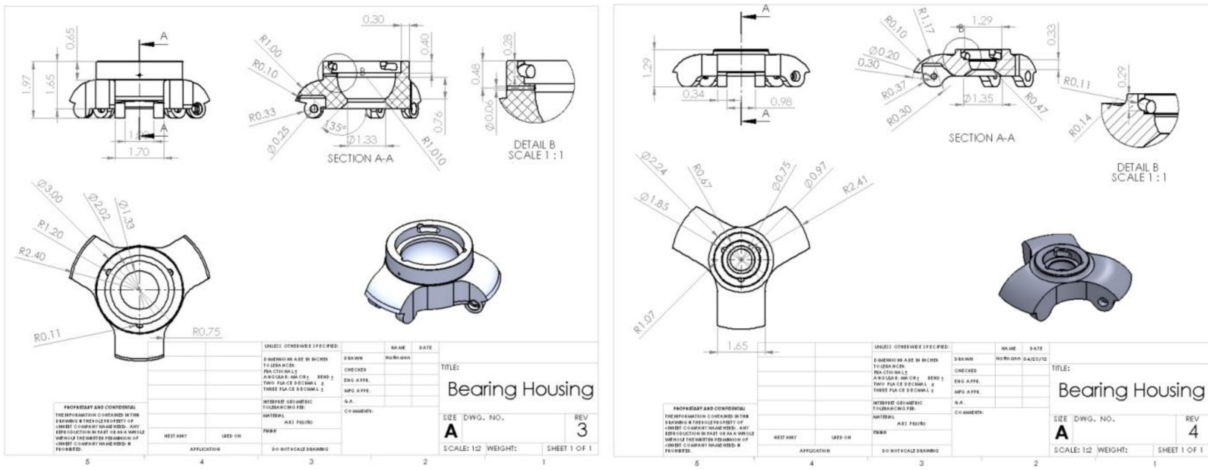


Figure 6: Bearing Housing 3rd and 4th Iterations

The final iteration overhauled the entire bearing housing making it smaller, lighter, and sleeker. Self-leveling issues presented themselves while using the larger bearing; it did not rotate as freely and level as accurately as was needed. Through analysis of the system (see Engineering Analyses of the Self-Leveling Base, p. 14), it was determined that a higher ratio of the rod length to the bearing radius allowed for greater leveling capabilities. This fourth bearing housing excelled at leveling meeting design specification 2c, and the cap far surpassed its predecessors in binding the bearing. The flanges were further strengthened with tighter tolerances offering a snug fit when the legs are mounted.

Software

Several key factors were considered when evaluating criteria for the initial software design. First, simplicity was the primary concern, as this eliminates much of the user error that can be attributed to a complex interface. Next, fail-safe functionality was important to be built into the program. This ensures proper data acquisition, so the program may successfully interpret the data input by the user and provide an accurate analysis of the information. Finally, the environment of the user was considered. Due to limited screen size of a laptop, the view from the webcam must be as large as possible to easily identify obstructions and map the surrounding tree line.

Figure 7: Home screen of the Airfield Safety Technologies software.

The main form that greets the user when the software is launched can be seen in Figure 7. It allows the user to choose between the Airfield Library and Data Wizard program functions, in addition to exiting the program.

The Airfield Library, as seen in Figure 8, is a simple database system that gives the user the necessary tools to keep up to date information for each airfield they are operating. The airfield, runway, and position inputs are used to identify the specific location the tripod and camera system will be placed on for obstruction analysis. The latitude, longitude, and angle correction inputs allow the Data Wizard to calculate GPS coordinates of any potential obstruction. Finally, the slope input takes into account the current approach slope of the runway. This data is stored in the program database and is easily retrievable for editing in the future.

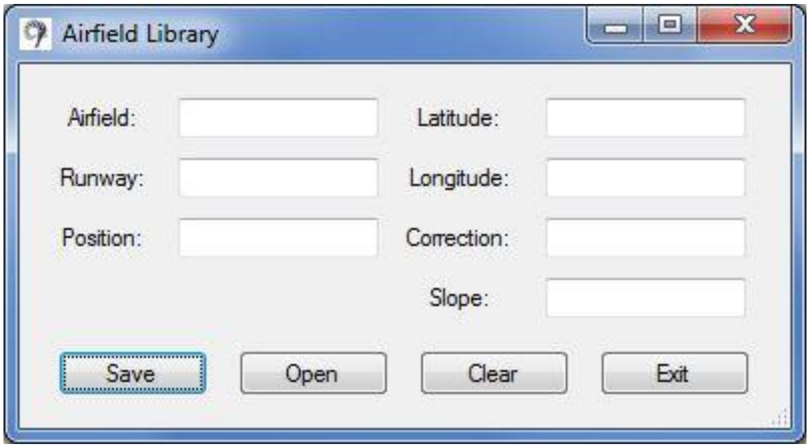


Figure 8: Airfield Library database interface.

The Data Wizard, the key component of the software, is used to capture images and record data points to identify potential obstructions, as well as track tree line growth. First, the user imports the relevant location information created in the Airfield Library with the ‘Import Data’ button. Next, data points are taken by clicking on the data point button, clicking on the top of the object in the picture generated by the webcam, and using the laser range finder to record the height of the object and distance to the object. This process is repeatable for up to five data points for each position, or 15 total data points for the 3 positions taken at each end of a runway. The ‘Insert Lines’ button allows the user to insert two lines onto the webcam display: a red line representing the controlling obstruction based on the data points chosen, and a blue line representing the current reported approach slope of the runway. An example of this is seen in Figure 9. If the red line is at or above the blue line, a warning message appears alerting the user of the obstruction danger. Then the user may get the GPS coordinates of each object chosen as a data point by clicking the ‘GPS Data’ button. Finally, the ‘Save’ button allows the user to save their work by creating a JPEG image and exporting the data to an excel file.

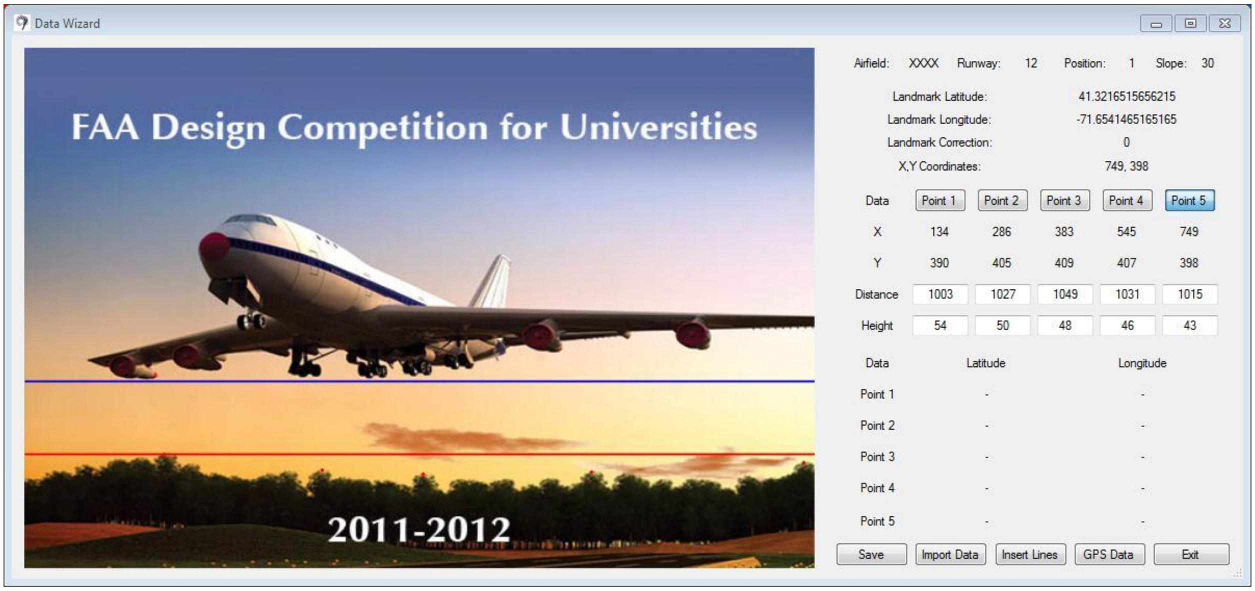


Figure 9: Data Wizard complete with selected data points, distance and height measurements, controlling obstruction line, and current approach slop line.

User Guide

The following describes the procedure for using the obstruction measurement device and software. The self leveling system function is as robust as the tripod it was designed around; under normal use, the system will be able to provide consistent and accurate results. A standard measurement is taken as follows:

1. Place the legs of the tripod on the landmarks to ensure precise measurements during each use.

2. In order for the self leveling base to operate properly, the locking clamp must be loosened to allow movement of the bearing.

3. Once the bearing has leveled, tighten the clamp. This will eliminate movement during the attachment of the camera to the top of the tripod via the quick release.

4. Attach the provided USB cable from the webcam to the computer and proceed to take the picture utilizing the software when prompted.

Upon completion of step 4, a picture of the runway can be loaded in the program.

Using the AST Software

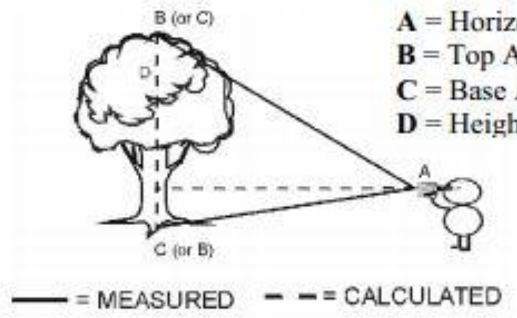
1. Open the Airfield Safety Technologies software.
2. If the desired airfield data exists and is up to date, proceed to Step 6. If it does not exist or is outdated, continue to Step 3.
3. Click the ‘Airfield Library’ button on the main window located on the lower left of the window.
4. The Airfield Library window will open. If new data needs to be added, complete all fields and press the ‘Save’ button. The file is automatically named based on the information the user enters into the textboxes (named as “Airfield_Runway_Position”). To edit existing data,

click the ‘Open’ button and select the file to modify. Edit the data and press the ‘Save” button to update the file.

5. Click the ‘Exit’ button to return back to the main window.
6. Click the ‘Data Wizard’ button on the main window located on the lower middle of the window. The Data Wizard window will open.
7. Click the ‘Import Data’ button and select the proper file for the airfield, runway, and position for the current location of the camera and self-leveling base. The data for the Airfield, Runway, Position, Slope, Landmark Latitude, Landmark Longitude, and Landmark Correction will appear. If any information is incorrect, click the ‘Exit’ button and return to Step 3.
8. To start adding data points, click the ‘Point 1’ button to toggle the point selection for the first data point. Click the top of an object you wish to make your first data point in the display of the webcam view (i.e. the top of a tree) and a red dot will appear on the point you selected. The X and Y data for the selected point (based on pixels) will appear in the column under the ‘Point 1’ button. If the first selection was incorrect, click another point and the red dot will move to your new selection. Once satisfied with the placement of the red dot, click the ‘Point 1’ button again and proceed to Step 9.
9. Input data from the laser range finder for the object in Point 1’s Distance and Height textboxes. Measurement modes can be cycled through by pressing the up and down areas on the face of the Laser Rangefinder. Instructions on the use of the Laser Rangefinder are as follows:

Height Routine

Height Measurements involve a simple routine that prompts you to take 3 shots to the target: HD, INC base (or top), and INC top (or base). The TruPulse uses these results to calculate the height of the target. Figure #17 shows the three shots required for the height routine.



A = Horizontal Distance
B = Top Angle
C = Base Angle
D = Height

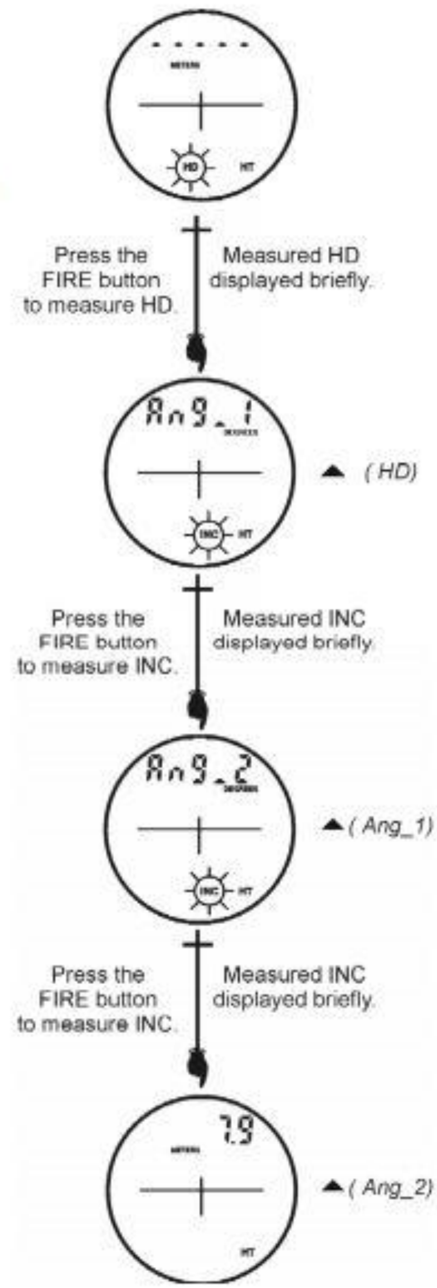
Figure #17

1. Select your target and look through the eyepiece, using the crosshair to aim to your target. The HT indicator displays steady and the HD indicator flashes; prompting you to measure the Horizontal Distance to the "face" of the target.

2. Press-and-hold FIRE. The LASER status indicator is displayed while the laser is active. The laser will remain active for a maximum of 10 seconds while acquiring data about the target. The measured horizontal distance appears briefly in the Main Display and then Ang_1 and the INC indicator flashes; prompting you to measure the inclination to base (or top) of the target.

3. Press-and-hold FIRE and aim to the base (or top) of the target. The measured inclination appears in the Main Display and is updated as long as us you continue to hold FIRE. The measured inclination is "locked" when you release FIRE. The measured inclination appears briefly in the Main Display and then Ang_2 appears and the INC indicator flashes; prompting you to measure the inclination to the top (or base) of the target.

4. Press-and-hold FIRE and aim to the top (or base) of the target. The measured inclination appears in the Main Display and is updated as long as you continue to hold FIRE. The measured inclination is "locked" when you release FIRE. The measured inclination appears briefly in the Main Display and then the calculated Height is displayed. The measurement flashes one time and then displays steady until you press any button or the unit powers OFF.



10. Repeat Steps 8 and 9 to complete all five data points.
11. Select the 'Insert Lines' button to insert two lines onto the webcam display: a red line representing the controlling obstruction based on the data points chosen in Steps 8 and 9, and a blue line representing the current reported approach slope of the runway. If the red line is at or above the blue line, a warning appears alerting the user of the obstruction danger.
12. Next, click the 'GPS Data' button to get the GPS coordinates of each of the objects (data points) selected.
13. Finally, click the 'Save' button to save your work. Two files are created: a JPEG image file and an excel file. The files are automatically named based on the information the user imported and the date it is created (named as "Airfield_Runway_Position_Date"). These files may be used in other programs for presentations, further analysis, or other applications.
14. Click to 'Exit' button to return to the main window.
15. Click to 'Exit' button to close the program.

Interactions with Industry Experts

The URI design team received aid and guidance from two members of the Rhode Island Airport Corporation: Vice President of Operations and Management, Alan Andrade and Inspector James Warcup. At the beginning of the project RIAC helped the URI design team to identify a project which would be of significance to airports in Rhode Island and a feasible challenge for the design team. Several ideas were discussed with RIAC and the benefits and potential problem areas of each were discussed. This lead the URI design teams selection of obstruction measurement as the project of choice.

After selecting the obstruction measurement device as the area of interest, RIAC was instrumental in providing information on the 5010 inspection process. Inspector James Warcup was especially helpful in detailing the current inspection methods and their shortcomings. This helped the URI design team develop a device to address these issues and streamline the process. RIAC also provided information on the range of scenarios encountered during a 5010 inspection, which translated into a set of design parameters including the effective range needed by the device. Additionally, RIAC was able to provide access to an active airfield in so that the URI design team could examine the working environment and positioning of the device.

Projected Impacts

FAA regulations mandate measurements of runway obstructions be taken at airfields (i.e. tree lines, buildings, etc.) every two years via a standardized FAA 5010 Inspection. Currently, these obstructions are measured using conventional surveying equipment and mathematical calculations, which are time consuming and generally take several hours to complete. Additionally, a company named GCR uses Photoslope technology, which uses photographs taken along the end of the runway to determine if any obstructions are higher than permitted by the FAA. This service provides quantifiable data, which is useful in the event of a crash; however, it only identifies obstructions which protrude through the minimum approach slope. It does not give exact measurements for height. It is also expensive, costing approximately $5,000 per airfield. That is the price without considering the cost of actually removing anything that might serve as an obstacle for an airplane, which can be in the tens of thousands of dollars.

The data on obstruction height and location must be available in order to ensure safe arrivals and departures within an airport. Thus, airfields monitor the critical obstructions in their vicinity by way of the previously mentioned 5010 Inspection. This order assigns responsibility, and provides guidance for assuring compliance with the provisions of the Airport Safety Data Program. The FAA has the legal requirement under the Federal Aviation Act of 1958, Section 311, “to collect, maintain, and disseminate accurate, complete, and timely airport data for the safe and efficient movement of people and goods through air transportation.” This is the ultimate goal in airport management and planning challenges, and the purpose of URI’s design team’s invention. However, the proposed design surpasses other methods of obstruction measurement in that it will help airports to further optimize the use of existing airport resources, and plan for future obstruction removal needs.

The URI team's design incorporates some basic software in combination with a webcam and a laser range finder to provide accurate measurements of obstructions threatening an airfield. The software also allows the user to record and save the data collected during the inspection. This can provide information on the growth trends of shrubbery and trees in the area while monitoring future threats. If the goal of the FAA is to vigilantly record airport data then this obstruction measurement device sets a new standard. Not to mention it is the simplest of all existing practices, and the cheapest. Airports have spent huge amounts of money removing obstructions, but this product makes it possible to pinpoint the critical obstacle. This would greatly reduce the possibility and occurrence of large scale removals, potentially saving airports tens of thousands of dollars.

Potential Buyers and Market Demand

According to the 2011-2015 National Plan of Integrated Airport Systems there are over 5,000 airports open to the public in the United States. All of them must direct an FAA 5010 inspection study every 2 years; local obstructions are examined to determine the legitimacy and safety of practiced approach and take off angles. This ultimately helps an Airline determine fault in the event of an accident. Correcting an obstruction problem can be extremely expensive, so identifying the controlling obstruction (the tallest) is essential. The economic difference between having to cut one tree down versus ten trees is huge, and the product developed by URI's design team can help customers realize these benefits.

The obstruction measurement device is being developed exclusively for RIAC at this time, but there is potential for a market across the nation. It could potentially be of interest to airport governing bodies across the state. Since there are very few designs improving on current obstruction measurements, there is potential for units to be used at every airfield. One unit will most likely satisfy the needs of a small state like Rhode Island, but in larger states, two or three units may be necessary, so a projected demand of 100 units can be assumed. In addition to units sold, this product stands to earn residual income through annual licenses for its software.

Implementation

The device would first need to gain approval by the FAA. However, the Photoslope process, which is the closest competition for URI's design, has gone through the process of gaining approval from the FAA, and it is now an acceptable tool to aid in the 5010 inspection. Therefore it is quite realistic that the URI team's product could go through the same process. Other steps for implementation would consist of setting a landmark for the device so that the measurements for each 5010 inspection are taken at exactly the same location. This would require airports to hire a land surveyor to map out the location in order to activate the global positioning functions of the design software.

Mass Production

The obstruction measurement device requires more part integration than actual part fabrication. Predicted demand of 100 units is very low, thus manufacturing our own parts would be very expensive. Instead, savings in mass production would come primarily from discounts incurred by ordering in bulk because the URI team intends to order most of the parts ready for assembly. Contracts would have to be set up and negotiated with various suppliers of the necessary materials and equipment. Slight milling operations would have to take place on the Igus bearing and the anodized Aluminum rod, so one lathe and one mill would be required in the factory. However, that is the extent of necessary machinery. With the expected life of the device being ten years production would most likely occur once and then consist of regular maintenance. After considering all of this, it is clear that a machine shop type production facility is best suited for this design. This type of factory is relatively unaffected by a low volume of inventory moving through it.

The sensitivity of the camera and laser would be a concern in a machine shop factory environment though. If any aspect of the design is damaged during assembly, especially the camera or laser, the product must be thrown out. This is a huge waste of resources and funds, so it must be avoided at all costs. Therefore, a factory for the URI team's obstruction measurement device would resemble a jumbled, job shop, type flow; operations would be performed by skilled workers rather than an automated system. Still, researches on the URI team found that the cost of materials to produce 100 units be roughly $121,000 with a production cost around $2,100. This brings the cost per unit in mass production to $1,231 approximately. Note that the projected costs of a single prototype did not include manufacturing costs and the price per unit was $1,390.73. Even after including manufacturing costs for mass production it is still cheaper per unit than the prototype by almost $160. That means the savings would be significant if this operation was ever run on a mass scale, simply from discounts received through ordering in bulk.

One specific investigation conducted by the researchers at URI was to look at the economic benefits die casting could have for the parts currently made from ABS plastic. For example, the base the camera will rest on will cost around $45 to produce in the machine shop. If the same part was produced via die casting the cost is reduced to about $0.30 per part. That includes material cost and the cost of running the machine. However, creating a mold can cost upwards of $3,000 depending on the number of cavities which makes this method only appropriate for large scale production. If the URI team's design is approved by the FAA and a long, profitable future can be expected for their obstruction measurement device then purchasing a die would certainly be cost effective.

It is difficult to determine the exact return on this product for potential buyers. The URI design team expects to sell their obstruction measurement device for somewhere between $2,000 and $3,000; once value can be assigned to the incorporated software. Keeping in mind that the only other product capable of obstruction measurement costs airports $5000 per use; a single expense of $2000 to $3000 is quite attractive. Assuming that an airport used only the URI team's design for obstruction measurement, savings could be seen immediately or ten years down the road.

Financial Analysis

The proposed design consists of six major components: the self-leveling base, laser rangefinder, webcam, camera quick release, and a laptop computer. The TruPulse Laser Rangefinder was purchased from TruPulse Technologies for $699.00. The camera quick release and webcam itself were purchased from various vendors online for a combined price of $66.00. The laptop computer was donated by the URI Engineering Department, but it was determined that it would have cost the team roughly $500.00. The self-leveling base was assembled by the URI design team using a number of components from McMaster-Carr; its subassembly can be seen in Figure 10.

Component	Price	Component	Price
Anodized Al Rod	$13.97	Igus Bearing	$3.00

ABS Plastic	$72.15	Steel Weights	$7.00
Tripod	$18.95	Screws (x3), Nut (x1)	$10.45

Figure 10: Breakdown of the Self-Leveling Base Component Costs

A Software-as-a-Service (SaaS) delivery model will be developed where the software and its associated data will be centrally hosted. Unlike traditional software conventionally sold as a perpetual license with optional ongoing support fees, SaaS will allow pricing for the software based on the number of users, or "seats," a customer requires. Our SaaS system will be based on a multi-tenant architecture with support for scalability through horizontal scaling. This will generate passive income which can be used for customer support services, in addition to funding for further product development and expansion of the business. An annual licensing fee of $500 per seat will be billed to the customer. Therefore, total cost incurred at the initial purchase of the obstruction measurement device can be seen in Figure 11.

Self-Leveling Base	TruPulse 200 Laser Rangefinder	Logitech Webcam	Camera Quick Release	Laptop Computer	Software Cost	Total Cost
$125.52	$699.00	$30.00	$36.21	$500.00	$500.00	$1890.73

Figure 11: Breakdown of Costs for Entire System

An additional cost to consider is the price of having the land surveyed at the point where the obstruction measuring device will sit during 5010 inspections. We anticipate a cost of no more than $475.00 based on current averages for similar procedures.

Cost-Benefit Analysis

Correcting an obstruction problem can be extremely expensive, so identifying the controlling obstruction is essential. The economic difference between having to cut one tree down versus ten trees is huge, and the product developed by URI's design team can help customers realize these benefits. The cost-benefit analysis cannot be quantitative until the rise of an obstruction occurs because the nature of obstruction removal is as of now unpredictable. The expenses to correct an obstruction issue can vary depending on the obstacle itself. If this product helps an airport limit their tree removal to just one instead of a dozen, or recognize that only a trimming is necessary, then the device has paid for itself. Potential buyers can easily recover their investment and begin to see savings, perhaps in a single utilization.

Cost is obviously the most important variable and the URI team has beaten the top competitor's price by thousands of dollars. However, do not undervalue the time, man-hours, and overall human effort that will be saved by using the proposed design as well.

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Appendix B

University of Rhode Island

The University of Rhode Island, founded in 1892, is Rhode Island's public, learner-centered research university, holding accreditation from the New England Association of Schools and Colleges (NEASC). It is the only public institution in the state offering undergraduate, graduate, and professional students the distinctive educational opportunities of a major research university. The main campus lies on 1,200 acres in Kingston, Rhode Island with three satellite campuses: Feinstein Providence Campus, Narragansett Bay Campus, and the W. Alton Jones Campus. As of this fall, there are 13,219 undergraduate students and 3,098 graduate students; of those students, 10,124are state residents and 6,193 are from out of state. There are over 80 majors offered at the university from seven degree granting colleges: Arts & Sciences, Human Science & Services, Environmental & Life Sciences, Business, Nursing, Pharmacy, and Engineering.

College of Engineering

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

Appendix C

Rhode Island Airport Corporation

The Rhode Island Airport Corporation (RIAC) was formed on December 9, 1992 as a semiautonomous subsidiary of the then Rhode Island Port Authority, now the Rhode Island Economic Development Corporation, to operate and maintain the state's airport system. The powers of the corporation are vested in its seven-member board of directors, six appointed by the governor, and one appointed by the mayor of the City of Warwick. RIAC is responsible for the design, construction, operation and maintenance of the six state-owned airports. RIAC also supervises all civil airports, landing areas, navigation facilities, aviation schools, and flying clubs. In addition to T. F. Green Airport, RIAC is responsible for five general aviation airports throughout the state: Block Island, Newport, North Central, Quonset and Westerly.

Appendix E-Evaluation of the Learning Experience

Student Assessment

The FAA Design Competition provided an extremely meaningful and unique learning experience. The scope of the project makes it very challenging in that a team must first decide what area they wish to compete in, followed by deciding which subcategory of those areas to focus on, and finally create a product that reflects those decisions. It is a true invention. Some of the other senior designs used for the class offered much information, even a prototype, and teams had to accomplish predetermined goals. The FAA Competition provides no direction, so projects within it are built from the ground up. The competition also served as a valuable tool for improving each team member's ability to work effectively in a group. The group aspect of the project also allowed the team to tackle problem solving issues as they arose throughout the design process.

There were numerous challenges facing the design team at URI while designing and constructing the obstruction measurement device. The first challenge to overcome was the team's lack of knowledge of airport operations and standards. This was handled through extensive research on the FAA website as well as through meetings with RIAC sponsors. The majority of the problems that we faced came in the designing process of the self-leveling base though. The first bearing that we used to pivot the hanging mass was too large and caused binding within the collar. So, we ordered a smaller bearing and adjusted the size of the collar to fit the new bearing. This allowed free motion of the mass so that it could self-level before being locked into position. The bearing rotation was a main consideration as well. Motion had to be free in the x and y directions, but we had to lock movement from occurring in the z-axis. This was accomplished by cutting a slit into the bearing and using a pin to lock the bearing in place, once it is set. Yet another consideration the team had to face was coding the software to use with the system. Collectively our coding experience made anyone within the group a novice at best. However, through diligence and extremely long hours at the computer a software program has been developed. Finally, the process of narrowing the possible designs that the team was focused on took much longer than anticipated. The result forced us to work as efficiently as possible for the remainder of the time, closely following our project plan. This was actually a negative that became a positive, because following that project plan timeline helped us to finish the design.

To develop our hypothesis, the team used resources at RIAC as well as the vaults of information located on the FAA and FAA Design Competition websites. The folks at RIAC spoke to us about some of the greatest dilemmas facing airports currently, and we used information from the FAA to realize, specifically, where to concentrate our efforts. It was clear that obstruction measurement was lacking in the technical acquisition of data. As a result, we decided that a partially automated system to collect obstruction data would serve as a successful solution.

Participation in the project by industry professionals was absolutely beneficial to the development of our proposed design, but RIAC's role primarily helped us to decide where to focus. They did offer some information on the current practices for obstruction measurement and some data on competing products. They also let us tour airfields which helped us to gain an understanding of the procedure. Despite their impact not being visible in our product, their aid came in the form of understanding the theory we would need to produce a new competitive product. Outside of RIAC, industry professionals were very helpful. We even obtained certain parts for the design from various manufactures (Igus) for free.

The knowledge and experience gained during this competition is unlike anything we have experienced in any of our classes. It is challenging and yes, difficult, but nothing worth doing is easy. None of the team members had been a part of the designing process from start to finish before. This is especially beneficial to the mechanical and industrial engineers that make up the URI team, as this could easily be what they end up doing after graduation. We also learned more than we ever expected to about the obstruction measurement criteria and techniques within an airfield. The FAA Design Competition is so open-ended that it requires participants to use all of their engineering knowledge and apply it to one common goal.   It was almost like a final exam for all four years that we have spent as undergraduates. The real world experience gained from that is enormous. Not to mention, the numerous reports and presentations that we had to do during the year. Overall, this experience will go on to serve team members as they choose to enter the work force or continue their studies.

Professor Assessment

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April 25, 2012

To: FAA Design Competition

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

The value of the educational experience for students participaing was excellent. In particular, interactions with our local Rhode Island Airpoirt Corporation (RIAC) was outstading and we received tremendous support from the engineering staff there. The students conducted a broad and comprehensive search through the problem soace outlined by the FAA design competition and identified a problem of signficance to RIAC that is also of significant interest nationally (and perhaps internationally).

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

The student team has done an excellent job in thoroughly exploiring their problem (chracterizing obstacles to runway approach). They have designed a practical and economical solution. They have prototyped their solution and have obtained reasonable results to pursue the creation of an engineered product. This is exactly the type of process and experience that we expect for our students on design projects. I am very pleased with the competition process, project solicitaion, and organization of the FAA design competition. I will definitely use this competition again in the future if it will be continued.

If you have any questions or need additional information, please contact me.

Sincerely,

Bahram Nassersharif

Bahram Nassersharif, Ph.D.
Distinguished University Professor

Appendix F-References

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