ACRP DESIGN COMPETITION

SUSTAINABLE SOLAR CANOPIES

August 23 - December 23

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Executive Summary

In this proposal, a team of four Civil and Environmental Engineering undergraduate students at the Virginia Military Institute proposes a viable option for airports to implement solar energy into their infrastructure. The proposal is a design for placing solar panel canopies on the parking lots of airports. This is a feasible way to generate renewable energy without taking up any parking lot capacity, or placing solar panels in a location where they run the risk of reflecting light into a pilot's eyes. Another possibility is to incorporate electric vehicle charging stations into these solar panel canopies to help generate more revenue and offset construction costs. The ACRP challenge this report will address is the Airport Environmental Interactions Challenges H and I. These areas of focus include methods of reducing carbon emissions from ground equipment at airports, and helping airports plan for the expected growth in global electricity demands as the growth in electrical ground vehicle use continues. This study considers safety risk assessment, benefit-cost analysis, regulatory compliance, and sustainability as factors for the design.

To examine the implementation of the proposed design, Shenandoah Regional Airport (SHD) was selected as the case study airport. The close proximity of this airport to the team's college, Virginia Military Institute, allowed for in-person visits to the airport to communicate with SHD airport staff to discuss the aforementioned factors as they relate to the design and overall feasibility of the team's proposal.

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1. Problem Statement and Background

Airports contribute to 3.5% of global greenhouse gas emissions. (Sukumaran and Sudhakar, 2017). According to ACRP Synthesis 127, at most airports, landside vehicles are the second largest source of scope 3 emissions. Scope 3 emissions are indirect emissions sources from resources that the airport does not own or control. ACRP Synthesis 127 further states that 45% of emissions from Portland International Airport in Oregon come from scope 3 emissions. With the looming menace of permanent atmospheric damage due to climate change on the horizon, airports must find ways to mitigate emissions.

A common solution proposed is electrifying airports' land vehicle fleets and encouraging patrons to do the same by accommodating electric vehicles with charging ports. This creates another problem. With a shift to electric vehicles, the airport must find a way to supply the power necessary to keep up with the demand this shift will impose on the airport. The airports must also supply this extra power in a way that further reduces greenhouse gas emissions. A common solution proposed for this is the conversion of an airport's power source to solar energy, however, issues can arise with engineers and the airport authority when determining where to place the solar panels. Depending on where they are placed, solar panels could reflect sunlight that could blind pilots (FAA 2021). This leaves few options for locations of potential solar arrays. Constructing raised solar arrays over airport parking lots is proposed as a solution to this issue and has been proven around the world. Cochin International Airport in Kochi, Kerala, India is a fully solar powered airport. One of their notable locations of solar panels is none other than above the airport parking lots. (Sukumaran et al., 2017). If airports and engineers take inspiration from Cochin International Airport, and put that inspiration into action, airports around the world will be able to operate with net zero carbon emissions.

The ACRP challenge this report will address is the Airport Environmental Interactions Challenge. The areas of focus within this challenge will be methods of reducing carbon emissions from ground equipment at airports, and helping airports plan for the expected growth in global electricity demands as the growth in electrical ground vehicle use continues.

2. Summary of Literature Review

This section discusses the findings in literature, which include two main topics: renewable energy and solar panels. This summary reviews multiple sources either from research on airports or from research on the general land that people use on a day-to-day basis.

2.1. Renewable Energy and Greenhouse Gas Reduction

The United Nations predicts that 70%-85% of the world's energy must come from a renewable source by 2050 to stop increasing global temperatures (National Academies of Sciences, Engineering, and Medicine, 2020). Equally as important as conversion to renewable energy is the mitigation of actions that cause carbon emissions. Landside vehicles are the second largest producers of scope 3 emissions at airports. Scope 3 emissions are emissions resulting from sources that the airport does not own or control. Landside vehicles make up about 17% of emissions at San Francisco International Airport, 20% at Austin International Airport, 30% at San Diego and Seattle’s airports and make up over 45% of emissions at the Portland International Airport in Oregon. (ACRP Synthesis 127, 2023). Though airports are not directly responsible for these emissions, there is still something that can be done about them. According to ACRP Synthesis 127, successful emission reduction strategies airports have successfully implemented include: Providing electric chargers to serve passengers and employees who use electric vehicles, charging all motorists a fee to enter the airport to drop off or pick up passengers, provide a regional express bus service for passengers and employees who might otherwise drive to the airport, promote carpooling, and offering incentives to operators of commercial ground transportation vehicles to discourage nonessential trips and promote use of electric vehicles and consolidated shuttles. The method the team will focus on is the implementation of electric vehicle chargers and using a renewable energy source to power them.

The integration of renewable energy and green technology reduces an airport’s carbon footprint and conserves more non-renewable resources for future generations. Airports with visible green initiatives foster positive community relationships, becoming community spaces that promote environmental education and awareness.

2.2. Solar Panels

Solar panels are becoming an increasingly popular energy source. The reason for this is because it's an extra source of energy that we can use without any environmental impact. If airports wish to decrease their carbon footprint, solar power is an excellent place to start, however, finding places to install solar panels can prove to be difficult. FAA rules prohibit the placement of structures too close to runways, as this could impede pilots taking off or landing. Another concern is sunlight reflecting off solar panels and into the eyes of pilots. Despite this, Cochin International Airport in India found a way around this. The airport is powered completely by solar energy. To do this, solar arrays were placed above parking lots, on the tops of buildings, and in nearby land acquired by the airport. Each of these locations were chosen so that the solar panels did not impede pilots in any way. (Sakurmaran et al., 2017). Other Airports can follow in these footsteps and place solar panels on hangar rooftops, parking lots, and unused land, providing a significant portion of the energy needed for operations. A study conducted on solar powered buildings concluded that a solar system was able to cover 61% of the yearly heating loads for a building, and the required electricity load was supported by almost 99% of the energy storage system. (Vijayan et al., 2023). From this research, it shows that solar panels are a reliable power source.

Solar panels can greatly reduce reliance on the grid and minimize electricity costs. This encourages the use of electric vehicles, which further contributes to the reduction of greenhouse gas emissions. This reduction in operating costs can be redirected towards airport upgrades, maintenance, or passenger amenities. Incorporating solar energy into airports not only makes practical sense but also sets a positive example for sustainable infrastructure development. By adopting solar energy, airports can reduce their carbon footprint, demonstrating environmental responsibility and aligning with global efforts to combat climate change.

2.3 Economic Feasibility

From the business perspective, which is oftentimes the one that keeps an airport running, renewable energy sources are often met with hesitation. New technologies bring new challenges, new infrastructure, and new maintenance. These hurdles are easily overcome when a cost benefit analysis is performed that shows the economic viability of these renewable energy technologies. For example, some of the benefits to airports include but are not limited to limited fuel requirement (exemption for biomass); on site power, which reduces power transportation costs in addition to giving the owners more control; easily complies with emotions regulations (both local and federal); broad public appeal while being an investment for the future. (Whiteman A. 2015). Many of the specific costs associated with renewable energy along with their implementation, operation, and maintenance have been studied and tables, charts, and other analytical tools are available to understand the economic and financial demand of these technologies through a case-by-case lens. ACRP Report 197: “Guidebook for Developing a

Comprehensive Renewable Resources Strategy" will be used as a guidebook for developing and implementing renewable energy in an economically lucrative fashion. Research done on the equipment itself and its net positive impact ethically and morally is overwhelming in its support, and the last hurdle that remains is the willingness to make the investment. The research suggests that using efficient, local, off grid power gives airports the control and versatility needed to remain financially incentivized, in addition to the cost breakdown of the technology showing a breakeven point rapidly shortening in length, which is only more incentive for airports to make this critical investment.

3. Team Problem Solving Approach

This section discusses the process of design and innovation the team went through, to include the brainstorming and formation of ideas, the prototypes and feedback, to the finalized designs with future impact and cost reports. This section entails the specifics of the sustainable solar canopies the group has designed.

3.1 Problem Formulation and Background Investigation

The team was tasked with tackling a problem from a list of "Shenandoah Regional Airport's (SHD) Identified Concerns and Potential Needs". The team was instructed to use the concerns of SHD as a foundation for the ACRP design competition proposal. Throughout the early stages of the design challenge the team debated and brainstormed to attempt to narrow the focus and direction into a single solvable problem, Figure 1 depicts the brainstorming. The team members would work together inside and outside of the classroom to communicate ideas and direction for the competition. The team would consistently meet inside the engineering building or work separately through phone calls to collaborate. Each member of the team comes from past experiences, has taken different courses, and has very different personalities which allows for diversity of thought when collaborating.

Initially, the team selected two of SHD's identified problems and prepared to give a presentation on potential solutions, and questions about the airport's concerns to Mr. Chris Cary, the Director of Airport Planning and Development at SHD. The team gathered in person to brainstorm a few of the previously mentioned concerns for the airport and determine which concerns would be plausible, enjoyable, and impactful to address. The team used a whiteboard and color-coded markers for deciding which ideas to pursue in the presentation. A few of the slides from the presentation are depicted in Figure 2 and showcase the early thought process the team was going through.

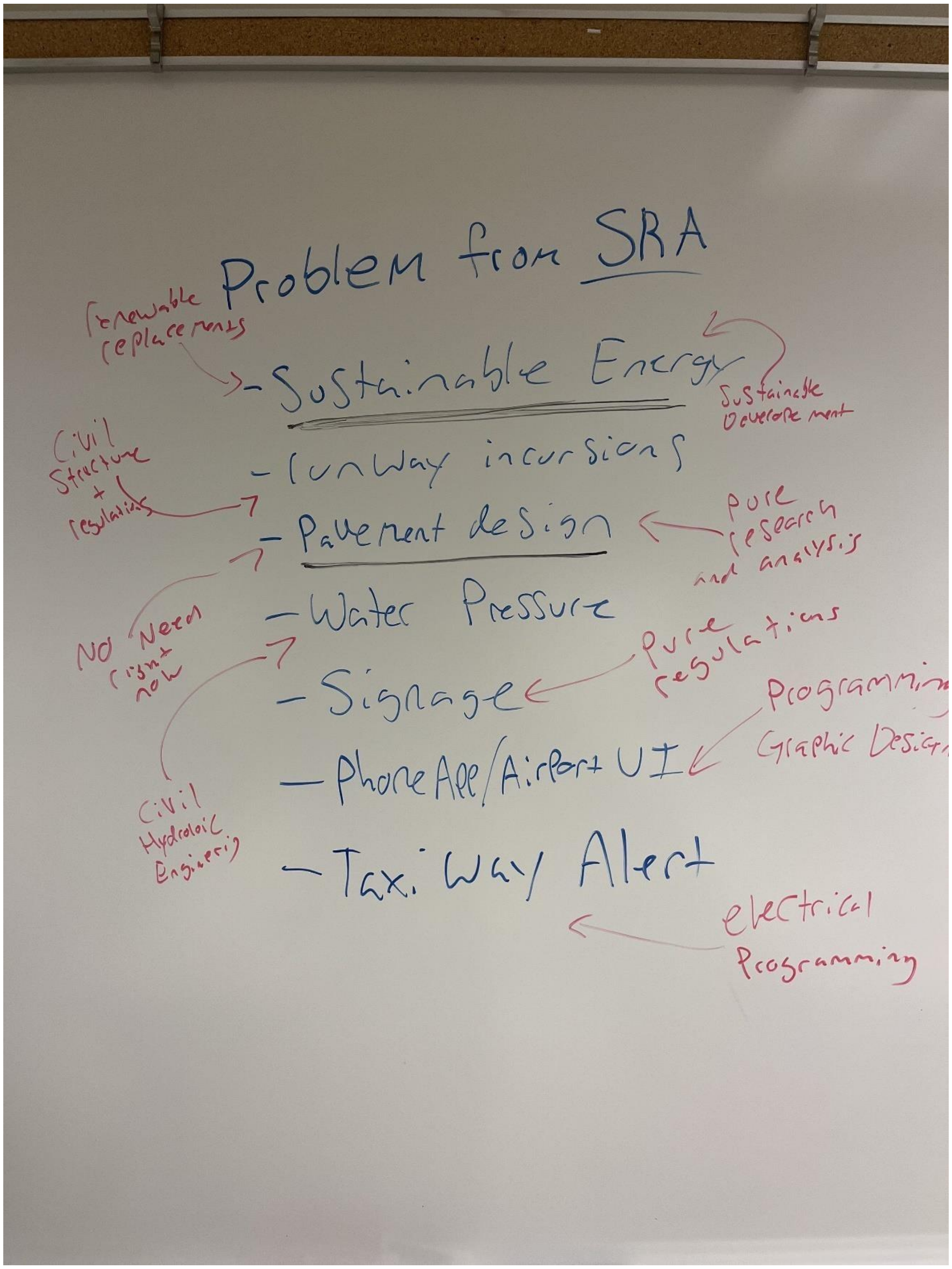
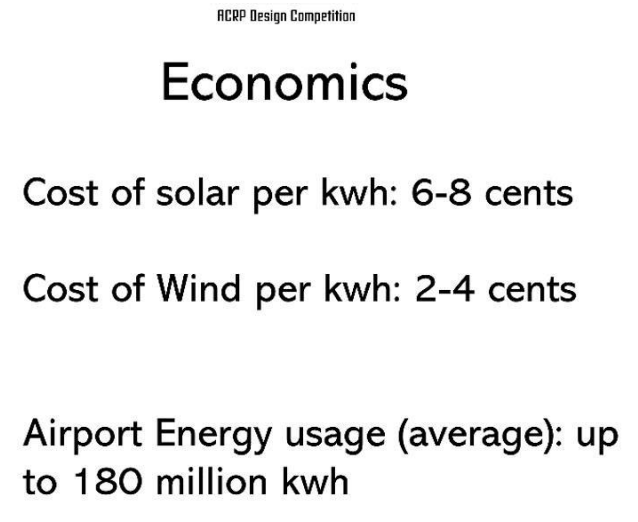


Figure 1: Initial brainstorming on selecting design idea from list of identified concerns.

The team did a short internal feasibility study on each of the concerns, of which not all are present in the brainstorm, to determine which would be problems that could be solved and what the team had the design knowledge and experience to take on.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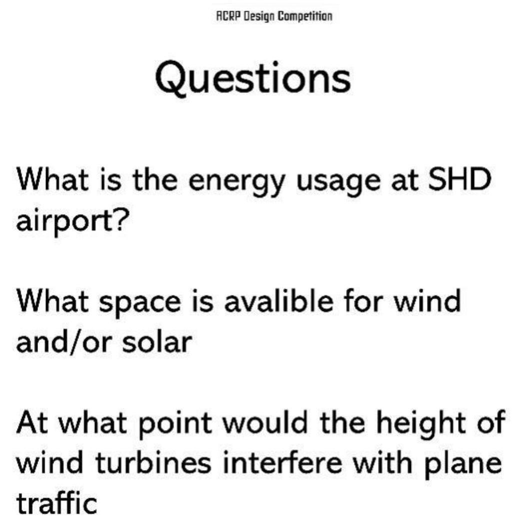
Economics

Cost of solar per kwh: 6-8 cents

Cost of Wind per kwh: 2-4 cents

Airport Energy usage (average): up to 180 million kwh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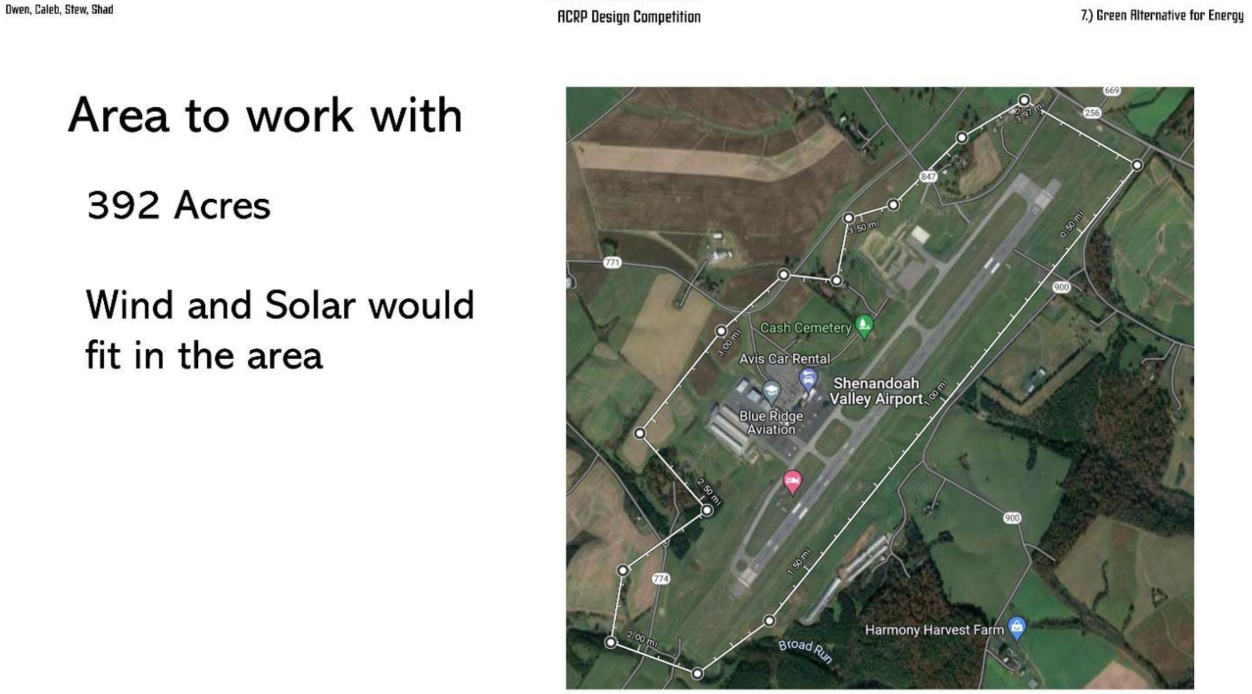
Questions

What is the energy usage at SHD airport?

What space is avalible for wind and/or solar

At what point would the height of wind turbines interfere with plane traffic


Owen, Caleb, Stew, Shad

ACRP Design Competition

7.) Green Alternative for Energy

Area to work with

392 Acres

Wind and Solar would fit in the area

Figure 2. Collection of Slides from Presentation to Shenandoah Regional Airport Regarding Sustainable and Renewable Energy Production

After being able to talk with Mr. Cary in-person at the airport, the team decided to go forward with the idea of pursuing renewable energy alternatives for the airport as this not only addressed a more present need, but was something the airport was already considering, along with being a project the group would reasonably be able to design effectively.

3.2 Refining the problem.

While the team had effectively focused on a clear overarching problem to be addressed, there were still a lot of decisions that had to be made with dictating the specific direction the team went forward with. The team had several lengthy discussions and spent days researching the leading innovations with renewable energy that could be applied to airport infrastructure. The team eventually decided to once again come together and physically brainstorm with a pro/con list of the three-leading sustainable, renewable, and alternative energy sources which is depicted below in Figure 3.

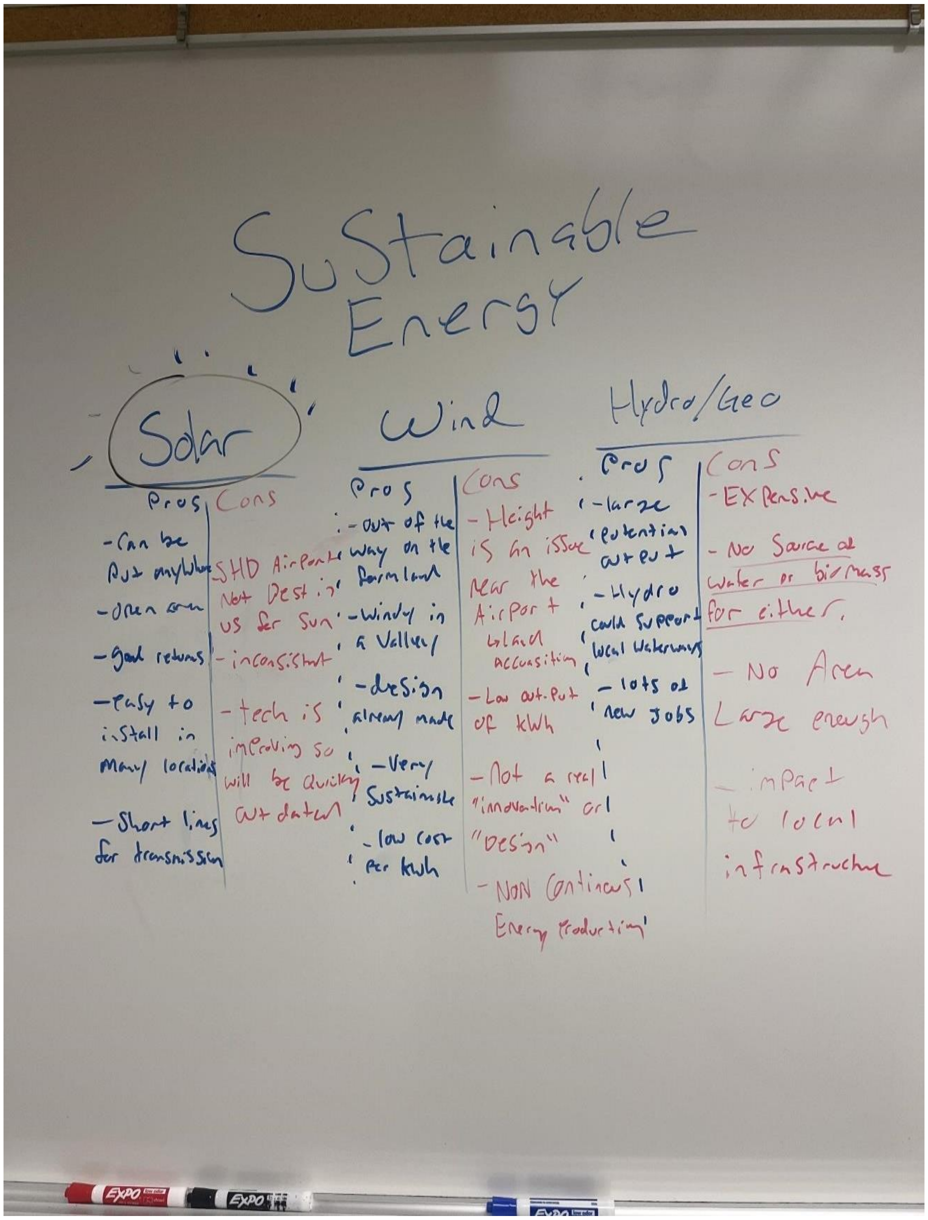


Figure 3: Brainstorming of Renewable Energy Sources for Airport Infrastructure

While this gave the team an initial direction to head towards, an analytical approach was needed to assess more definitively which option would be pursued for the final design. This brainstorming was helpful in letting the team eliminate the option of doing hydroelectric or geothermal from the possible options and instead focus on more nuanced variations of solar and wind energy.

3.3 Criteria Matrix

A Criteria Matrix was developed to further and more accurately assess the range of directions the team could go when creating a sustainable solution by objectively grading each option through a series of categories or criteria. The completed criteria matrix is depicted below in Table 1 and gives the platform for the comparison between the alternative energy routes.

3.3.1 Table Scale

All the design categories are ranked from 1-3. This equates to the design that receives a score of 1 to be the best design, or the one that does the best in that criterion, while the design that scores a 3 will be the worst design or most inefficient in the criteria.

3.3.2 Criteria Definitions

Each criterion was defined to enable objective and impartial consideration and scoring. The definitions are as follows:

A.) Safety in this case represents and refers to the potential of harm to civilians or infrastructure. Safety concerns present would consist of physical hazards to pedestrians, cars, and planes, glare or other obstructions.

B.) Feasibility represents how likely and plausible it is that this could be brought into reality. What permits, considerations, and technical struggles, face design and construction. How much of an issue is material procurement and constructability.

C.) Energy loss or efficiency represents the amount of energy generated that is lost purely to transmission or other factors, the longer the transmission lines, the more exposed to the elements they are, the loss from lack of storage, etc. are considered.

D.) Maintenance refers to the frequency, cost, and effort required to maintain the system. What is the consistent maintenance schedule, what possible problems will need to be addressed and their likelihood, what is impacted by the maintenance.

E.) Construction Time refers to the time needed from the start of the labor to the punch list and project completion. Construction time also necessitates what is impacted by the construction and what elements of the airport need to be shut down during construction and the following losses from that.

F.) Construction cost is the cost of the project. Including the solar panels, the steel, the labor, the permits, the land acquisition, and reinforcement or structural elements necessary, essentially the cost for each option if it were “put to bid.”

G.) Energy Generation simply refers to the expected energy produced by the systems. What option offsets the most kWh from the current electrical demand of the airport and can consistently supply the most kWh to the facilities during the whole year.

3.3.3 Completed Assessment Table

Design Criteria	**Solar Canopy**	**Hanger Roof Panels**	**Small Wind Turbine**
A.) Safety	1	2	3
B.) Feasibility	2	1	3
C.) Energy loss (efficiency)	1.5	1.5	3
D.) Maintenance	2	1	3
E.) Construction Time	1	2	3
F.) Construction Cost	1	2	3
G.) Energy Generation	2	1	3
Totals	10.5	10.5	21

Table 1: Design Criteria Matrix Assessment Table

4. Technical Aspects of Design Development

4.1 Technical design comparison

Using the prescribed design criteria, the team worked on further evaluating the technical aspects of the alternative designs. The two options the team considered for solar applications, that of a solar canopy for the parking lot or using the existing hangers for solar, were more closely and directly compared with each other. When creating the solution for this design project the team did not want to design in a vacuum and was also given the additional class requirement of working with SHD, therefore for this report, the design will be tailored specifically for the regional application, however, it is important to note that the concepts and ideas are still applicable anywhere and the following specific design merely represents a hypothetical application of the design. The team used a map of the area supplied via Google Maps and detailed in Figure 4 to draw out where the suitable area for solar panels would be in addition to calculating the specific area in square feet that the solar panels will be placed.

Figure 4: Color Coded Map Depicting the Suitable Areas for Photovoltaic Cells

4.2 Design Brainstorming

Before working in AutoCAD, the team continued the whiteboard brainstorming approach by hypothesizing and drawing out possible designs, shapes, angles, and other features to visualize many of the routes the team could take. Figure 5 depicts the design with notes that was being considered. This design concept is based on successful applications of similar solar canopy projects.

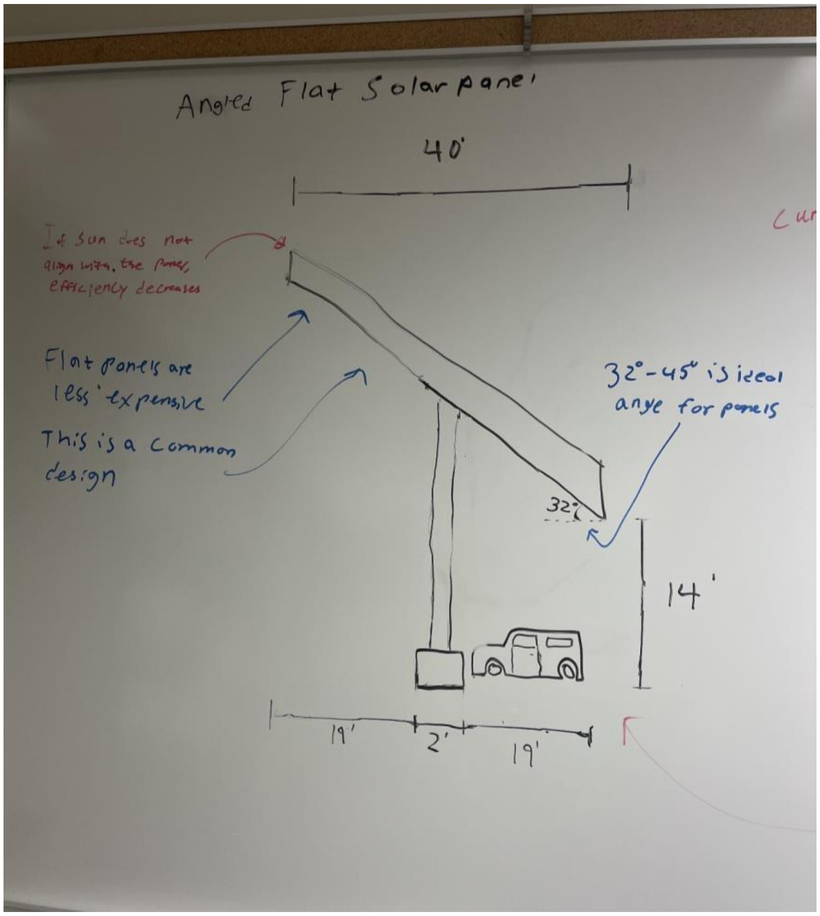
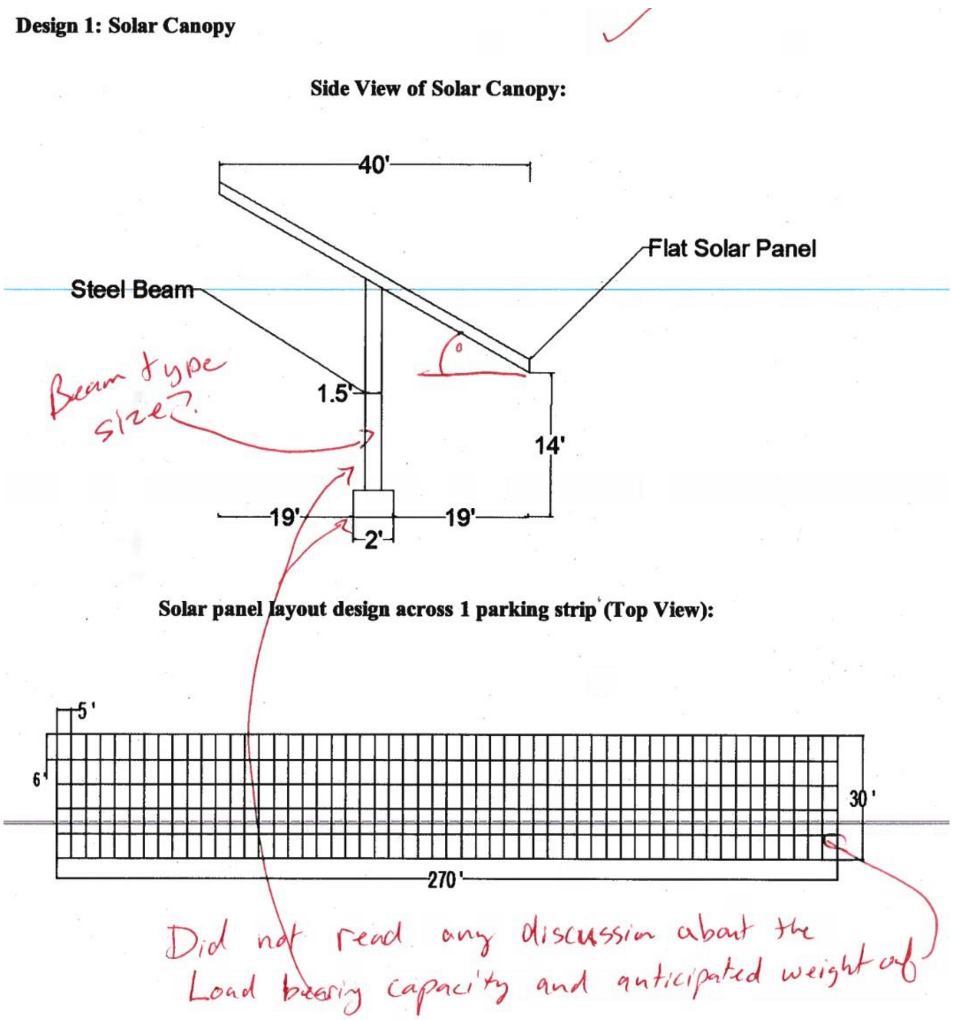


Figure 5. Initial Brainstorming of Solar Canopy Design with Angled Flat Panels

4.3 Initial design attempt with feedback

Using the matrices, maps, brainstorming, and data the team had originally collected, they prepared a sample design report that would be presented to the industry experts for further feedback and analysis. Before the initial design report was sent to the experts, it was shared with the faculty advisor for initial feedback. The report was scrutinized, and further specifications and clarifications were deemed necessary before the report was to be sent off. A few pages of the report are sampled below in Figure 6 and Figure 7 which show feedback given to initial designs while Figure 8 contains feedback given from the writeup. This gave the group enough feedback to further refine the design and presentation before passing it along again.



Design 1: Solar Canopy

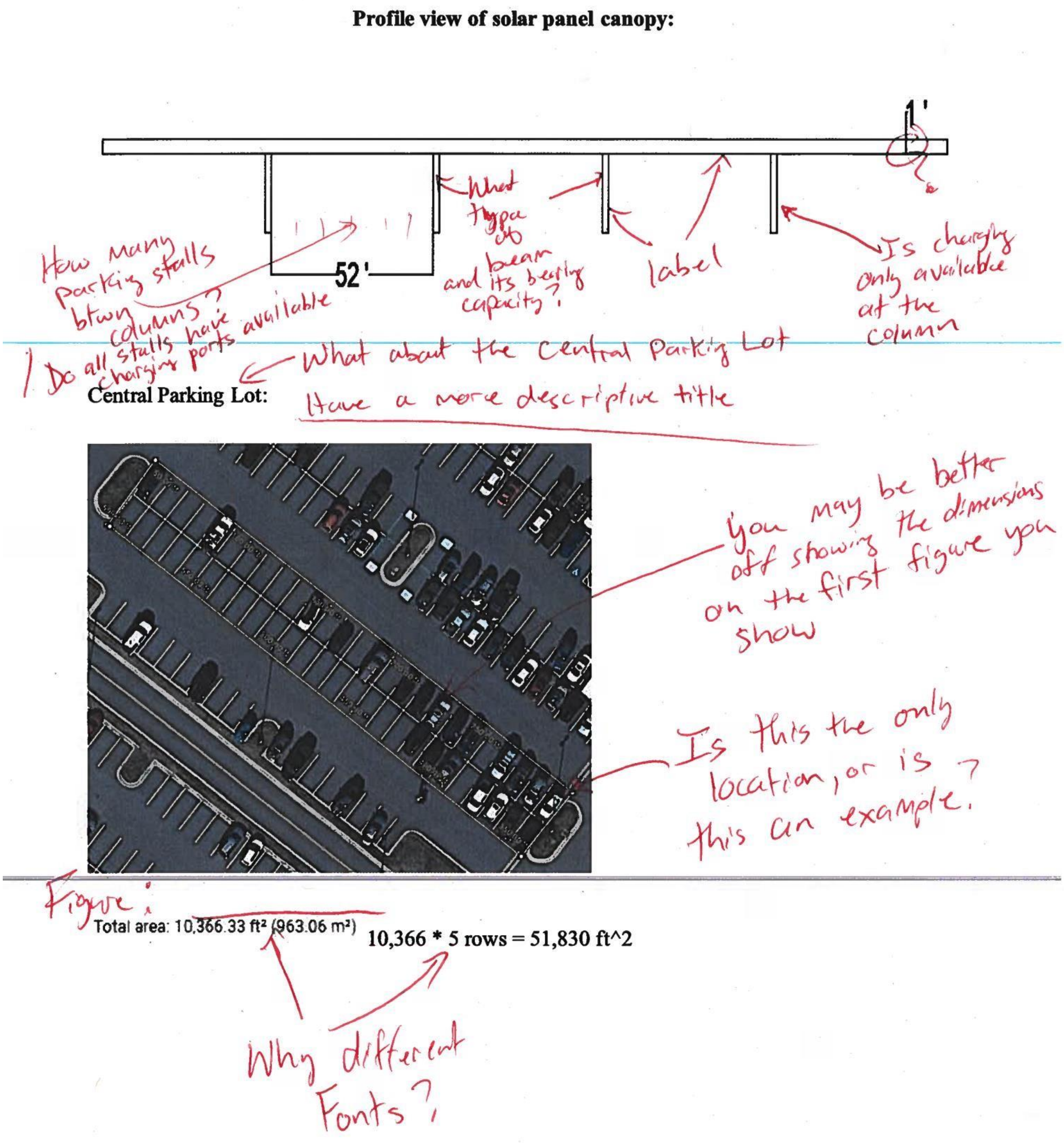
Side View of Solar Canopy:

Beam type size?

Solar panel layout design across 1 parking strip (Top View):

Did not read any discussion about the Load bearing capacity and anticipated weight of

Figure 6. Page Depicting AutoCAD Design of Solar Canopy with Faculty Advisor Markup.



Profile view of solar panel canopy:

1'

52'

What type of beam and its bearing capacity?

label

Is charging only available at the column

How many parking stalls btwn columns?

Do all stalls have available charging ports

What about the Central Parking Lot

Central Parking Lot:

Have a more descriptive title

You may be better off showing the dimensions on the first figure you show

Is this the only location, or is this an example?

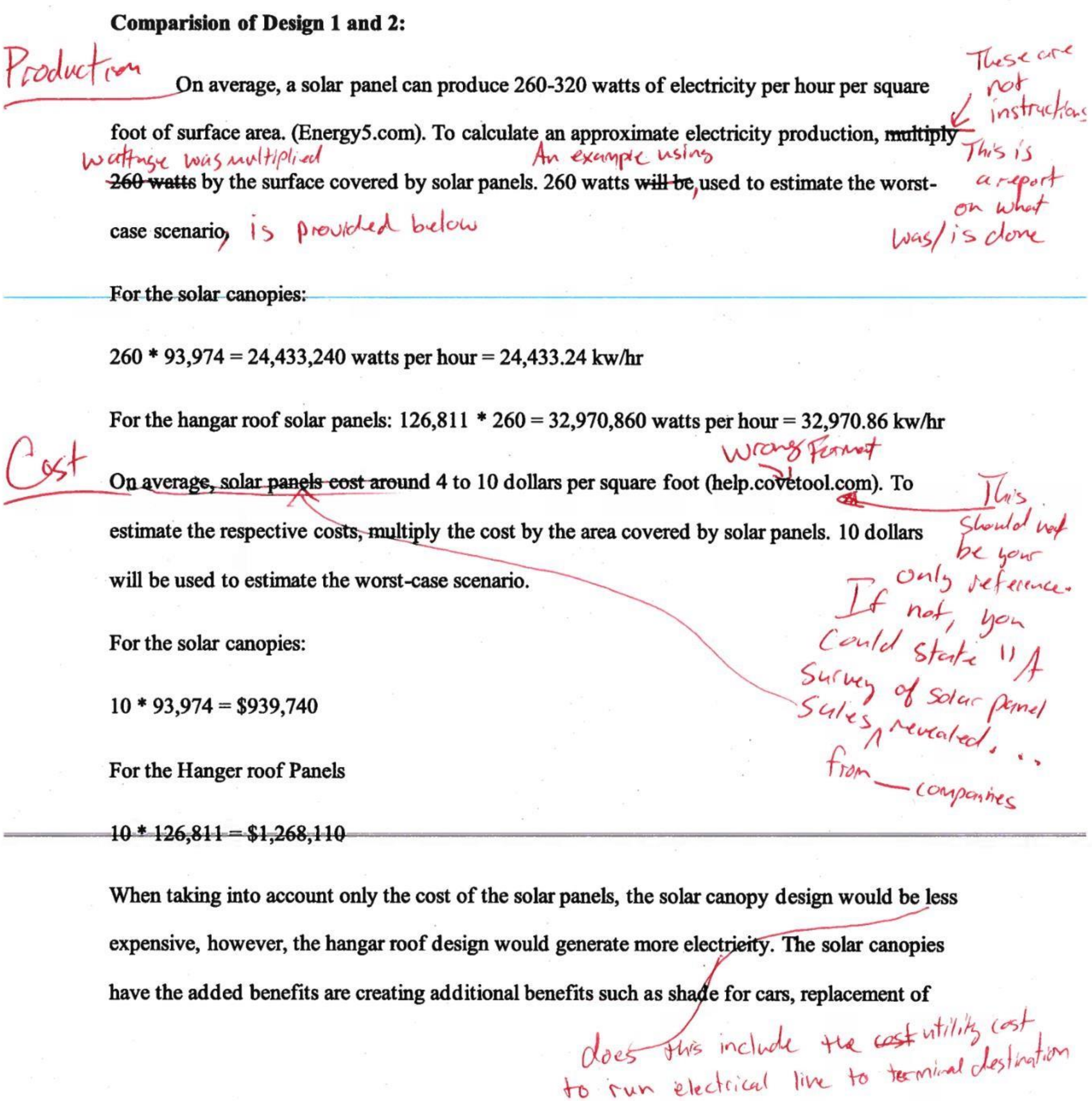
Figure:

Total area: 10,366.33 ft² (963.06 m²)

10,366 * 5 rows = 51,830 ft^2

Why different Fonts?

Figure 7. Additional Page of Initial Design Report with Faculty Advisor Markup.



Comparision of Design 1 and 2:

Production

On average, a solar panel can produce 260-320 watts of electricity per hour per square foot of surface area. (Energy5.com). To calculate an approximate electricity production, ~~multiply~~ ~~260 watts~~ wattage was multiplied by the surface covered by solar panels. An example using 260 watts ~~will be~~, used to estimate the worst-case scenario, is provided below

These are not instructions This is a report on what was/is done

For the solar canopies:

260 * 93,974 = 24,433,240 watts per hour = 24,433.24 kw/hr

For the hangar roof solar panels: 126,811 * 260 = 32,970,860 watts per hour = 32,970.86 kw/hr

Cost

On average, solar panels cost around 4 to 10 dollars per square foot (help.covetool.com). To estimate the respective costs, multiply the cost by the area covered by solar panels. 10 dollars will be used to estimate the worst-case scenario.

Wrong Format

This should not be your only reference. If not, you could state "A survey of solar panel sales from — companies revealed. . .

For the solar canopies:

10 * 93,974 = $939,740

For the Hanger roof Panels

10 * 126,811 = $1,268,110

When taking into account only the cost of the solar panels, the solar canopy design would be less expensive, however, the hangar roof design would generate more electrieity. The solar canopies have the added benefits are creating additional benefits such as shade for cars, replacement of

does this include the ~~cost~~ utility cost to run electrical line to terminal destination

Figure 8. Sample of Initial Design Report Writeup with Faculty Advisor Markup.

4.4 Revised Designs

Using this feedback, the team reworked the designs to provide a more detailed and professional analysis. The team also implemented an additional sustainability element for construction with the use of wood, dimensional lumber, and timber, as the main construction material to further minimize the planetary and environmental impact of the designs. The use of wood is sufficient for outdoor use with treated white oak.

4.4.1 Design 1: Solar Canopy

The following design depicts the team’s model and assessment with full dimensions and load analysis of the parking lot solar canopy. Figures 9 through 12 depict each aspect or view of the design. The design represents a workable and functional prototype while ultimately still leaving room for the team to refine and specify smaller details for full-fledged implementation.

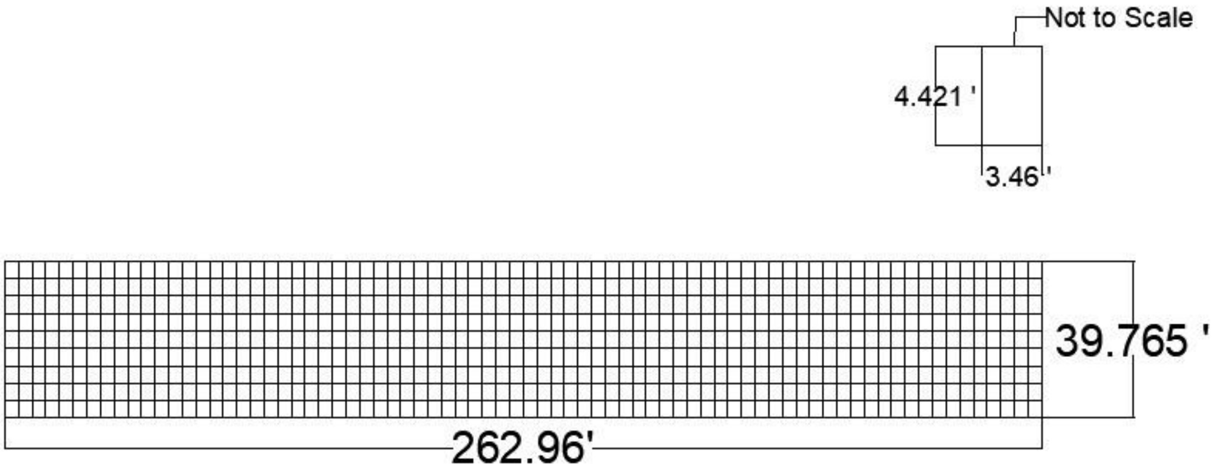


Figure 9. AutoCAD Top View of Large Solar Canopy and Individual Panel Dimensions

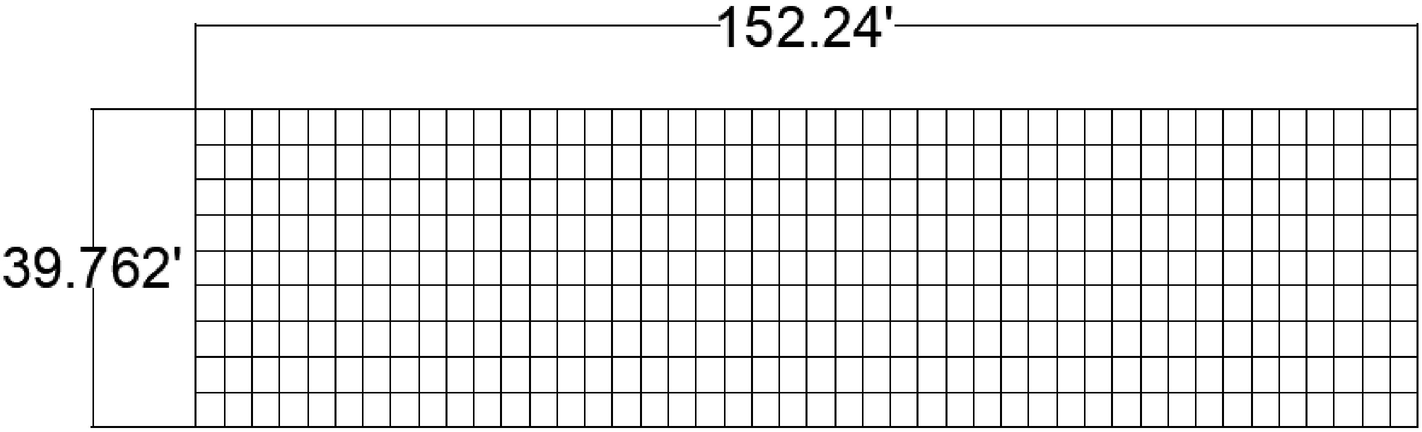


Figure 10. AutoCAD Top View of Small Solar Canopy and Individual Panel Dimensions

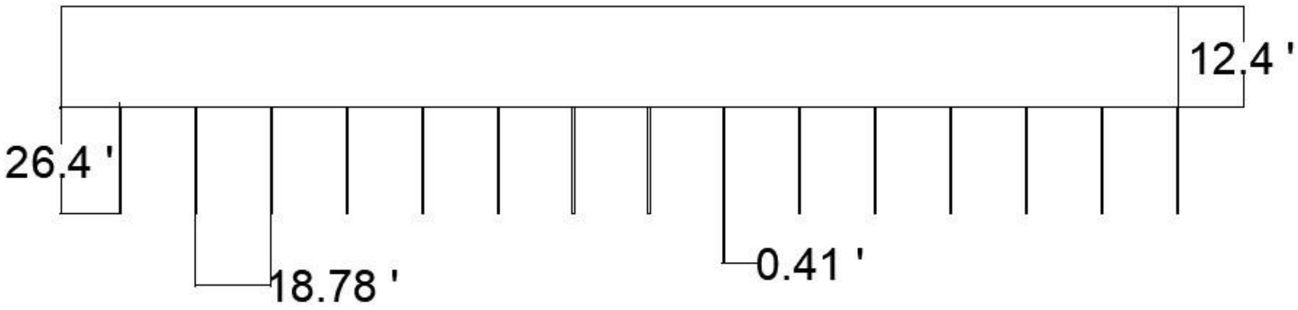


Figure 11. AutoCAD Front View of Solar Canopy

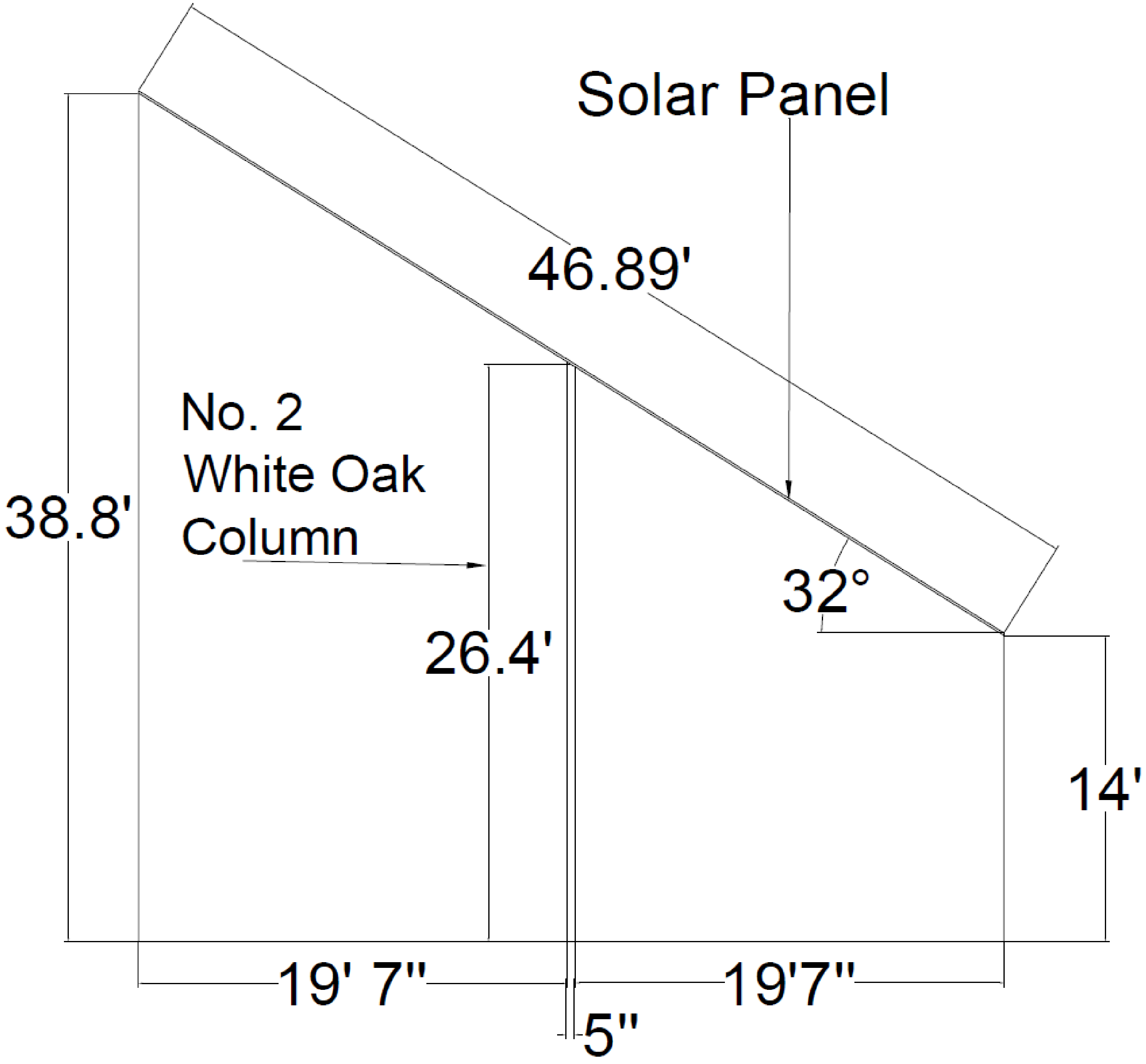


Figure 12. AutoCAD Side View of Solar canopy

The AutoCAD figures depict the dimensions for the solar canopies to be placed in the parking lot. There are varying lengths of parking lot rows, and both received their own designs.

4.4.1.1 Design 1 Calculations Brainstorming

The group, in the process of redesigning their structures, performed calculations to assess and understand the total amount of photovoltaic panels available for the space along with the weight and generation of the panels. The group then revised and recalculated the load capacity and forces for the members with feedback from a professor, which can be seen in Figure 13. The group then used the updated numbers to finalize the report and design sizes for the beams and spacing.

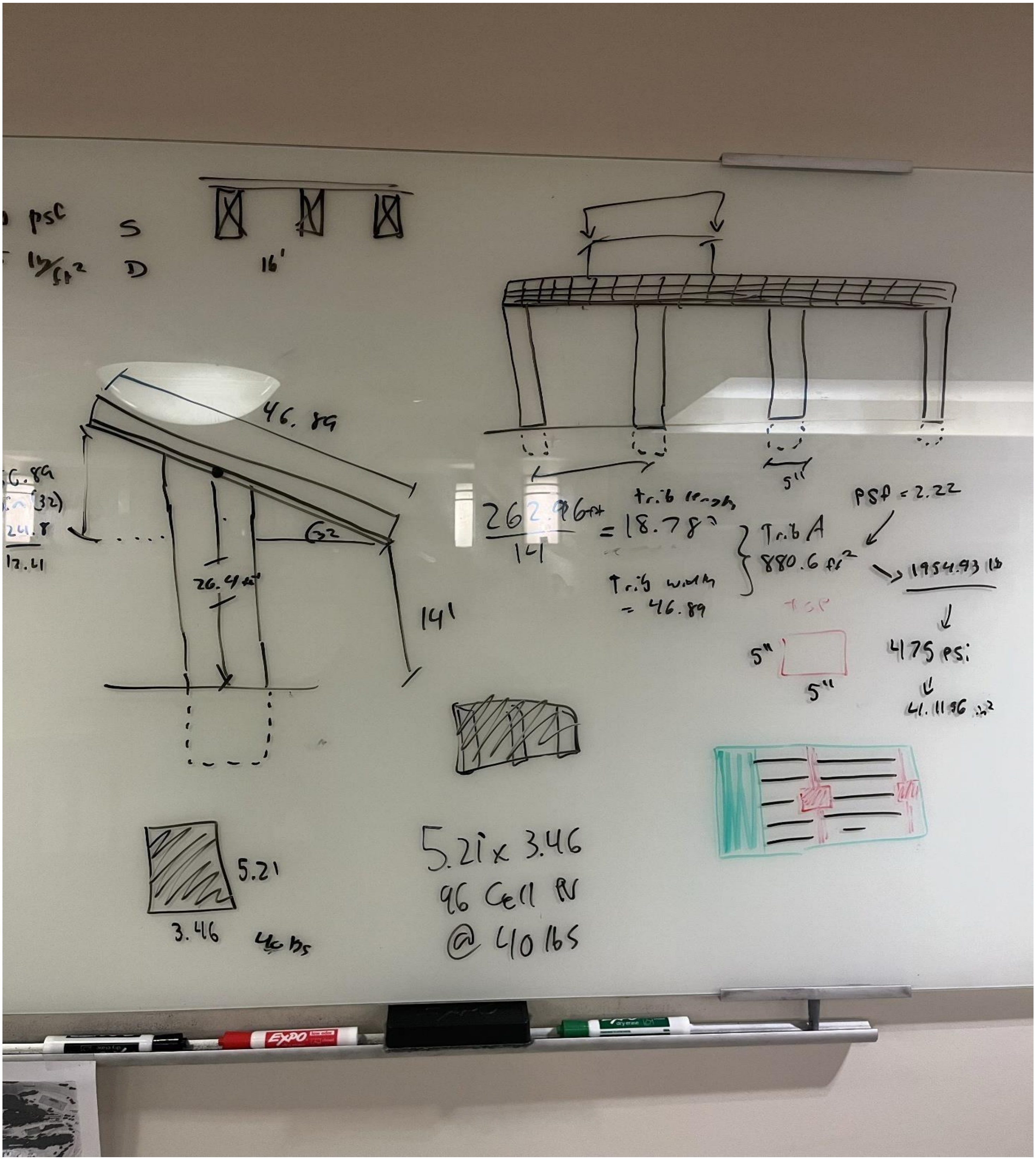


Figure 13. Panel Load Design Calculations

4.4.1.2 Design 1 Writeup and calculations

Through speaking with our professor, the team found that the weight of a 5.21’ by 3.46’ solar panel is 40 lbs, the area of the panels is 18.025 feet, the load in pounds per square foot (psf) is determined by 40/18.025’ which comes out to slightly under 2.22 psf. The tributary length of solar canopy is 18.78’, which represents the center-on-center distance between the panels, while the tributary width is 46.89’ therefore multiplying the two produces a tributary area of 880.6 feet squared. Multiplying the psf by the tributary area, we find that each of the columns on either structure must support 1954.93, or nearly 2000lbs. Using the structural properties of No.2 White Oak columns found in the NDS Supplement, the compression force for the wood must be less than 475 psi. The 2000-pound load was divided by the strength of the wood to determine a minimum area needed of 4.2 inches squared. Due to constructability constraints the team sized up to a 5” by 5” post as that is the smallest readily available post and far exceeds any additional environmental loads by increasing the area of the wood used for support by nearly 5 times the minimum requirement.

The width of the canopies is 9 panels long with each panel being 5.21’ wide proving a width of 46.89’. Because the panels are installed at an angle, the width when viewed from above, and the actual horizontal area shaded, is 39.765’. The longer and shorter canopies are 76 and 44 panels long respectively, which comes out to 262.96 and 152.24 feet in length for the canopies. The respective lengths of the parking spans are 260’ and 150’ therefore the canopies will provide a slight overhang. The true area of one row of the smaller canopies is 7,138.53 square feet. The small canopies will cover the 5 smaller rows of parking, for a total of 35,692.67 square feet for the smaller canopies. The area of one row of the large canopies is 12,330.19 square feet. The larger canopies cover the 6 longer rows of parking, for a total area of 73,981.17 square feet. The total area of solar panels needed for this design will be 109,673.79 square feet.

On average, a solar panel can produce 260-320 watts of electricity per hour per square foot of surface area. (Energy5, 2023). 260 watts will be used to estimate the worst-case scenario. To calculate an approximate electricity production, 260 watts was multiplied by the area of solar panels. 260 watts multiplied by 109,673.79 square feet results in 28,515.19 kilowatts per hour (kw/h) of energy produced. On average, solar panels cost around 4 to 10 dollars per square foot (Chopson, 2023). To estimate the respective costs, this is multiplied by the area of the solar panels. 10 dollars will be used to estimate the worst-case scenario. 10 dollars multiplied by 109,673.79 square feet results in an approximate cost of $1,096,737.9.

4.4.2 Design 2 Writeup

Using Google Maps, the approximate area of the roofs of the hangars at the airport were measured. Each individual building's area was calculated. The total area of all the roofs combined was 126,811 square feet. Assuming that this is the required square feet of solar panels that will be used, multiplying 260 watts by this will result in an approximate power production of 32,970.86 kw/h. To calculate the approximate cost, the same process as the solar canopies will be used. Ten dollars multiplied by 126,811 square feet results in an approximate cost of $1,268,110.

4.4.3 Comparison of Design 1 and 2

When considering only the cost of the solar panels, the solar canopy design would be less expensive, however, the hangar roof design would generate more electricity. The solar canopies have the added benefits of the potential to implement electric vehicle charging stations and offering shade to cars and pedestrians. Both the solar canopy and using the hangar roofs provide excellent options to incorporate renewable energy into the airport. Therefore, it is the recommendation of the team that further research be conducted by the airport to determine if either option would have a negative impact on airport services. For the sake of this proposal, the team decided to choose the solar canopy design, as it is not known if the roofs of the hangars are able to support the added load of the solar panels.

4.5 Stakeholder Feedback

The team met and deliberated with many experts with a diverse range of background experiences and areas of expertise. The team initially received feedback from Chris Cary, Project Manager of the Shenandoah Regional Airport. Mr. Cary informed the group about a potential issue regarding using timber for the system due to environmental exposure and warping. The team addressed this by choosing a species of wood, such as White Oak, which is naturally resistant to the elements. He also noted that timber is not strong against lateral impacts, such as those from a car, as this is in a parking lot. The team addressed this by considering the implementation of concrete footers for the timber posts. Mr. Cary was interested in the team's original proposals which included alternatives that took advantage of hanger roofs or wind power, however he ultimately agreed on the groups decision to pursue solar canopies due to the difficulties presented with the other options. The last note that Mr. Cary had for the team was to think about the implementation of an electric vehicle charging system into the posts of the canopies to serve the parking lot. This idea is something the team would love to see but is not necessarily what the team is designing for, therefore it will be included in section 4.6 Future Modifications.

The next expert the group talked with was Billy Kelly who had worked on the planning and design for the Shenandoah Regional Airport for the last couple decades, in addition to being a judge for the ACRP competition. Through various phone conversations and email exchanges

Mr. Kelly relayed the sentiments brought up by Mr. Cary regarding the choice to choose solar canopies coming with additional advantages such as shade for pedestrians, along with potential electric vehicle infrastructure. Mr. Kelly mentioned aspects of the construction that the team had not considered such as needing to tie into the co-op, potentially relocating power lines, or using FAA Green funds along with the BALE program to fund the initiative. Another big component regarding constructability was to ensure a good return on investment. Finally, Mr. Kelly commented that regarding the installation of the solar canopies, the decision of liability and maintenance responsibilities would be a task that airports would seldom choose to take on. The team eagerly took this advice, along with the advice from Mr. Cary, and the continued advice from the team's advisor, Dr. Idewu into consideration.

4.6 Future Modifications

The initial solar panel canopy prototype serves as a proof-of-concept to demonstrate that solar power could be a viable source of sustainable energy for the Shenandoah Regional Airport (SHD). Being this is a prototype, there are several flaws that would need to be addressed before arriving at a final product. Firstly, the selection of wood columns to support the solar panel was done for sustainability purposes. The manufacturing of steel and aluminum leaves a massive carbon footprint. Despite this, steel or aluminum columns still may be the better option. Wood columns left uncovered could cause them to warp under extended exposure to the elements. Considering Rockbridge County is known for a hot summer season and an even colder winter season, wood columns would be subject to extreme fluctuations of temperature, and therefore, would be susceptible to permanent warping. Wood also does not resist lateral impacts as well as steel or aluminum. If a vehicle strikes one of the columns supporting the solar panel, a steel or aluminum column would be more likely to withstand the impact. Using a steel or aluminum structure would also provide greater support while using fewer overall materials. In other words, less columns would need to be constructed to support the solar panels. SHD should also consider installing electric vehicle charging stations within the solar canopies. This would be an additional revenue generator that could help offset construction costs, while also allowing SHD to attract electric vehicle drivers. With these modifications, the use of solar canopies in an airports parking lot is a viable option for airports to implement solar energy.

5. Safety Risk Assessment

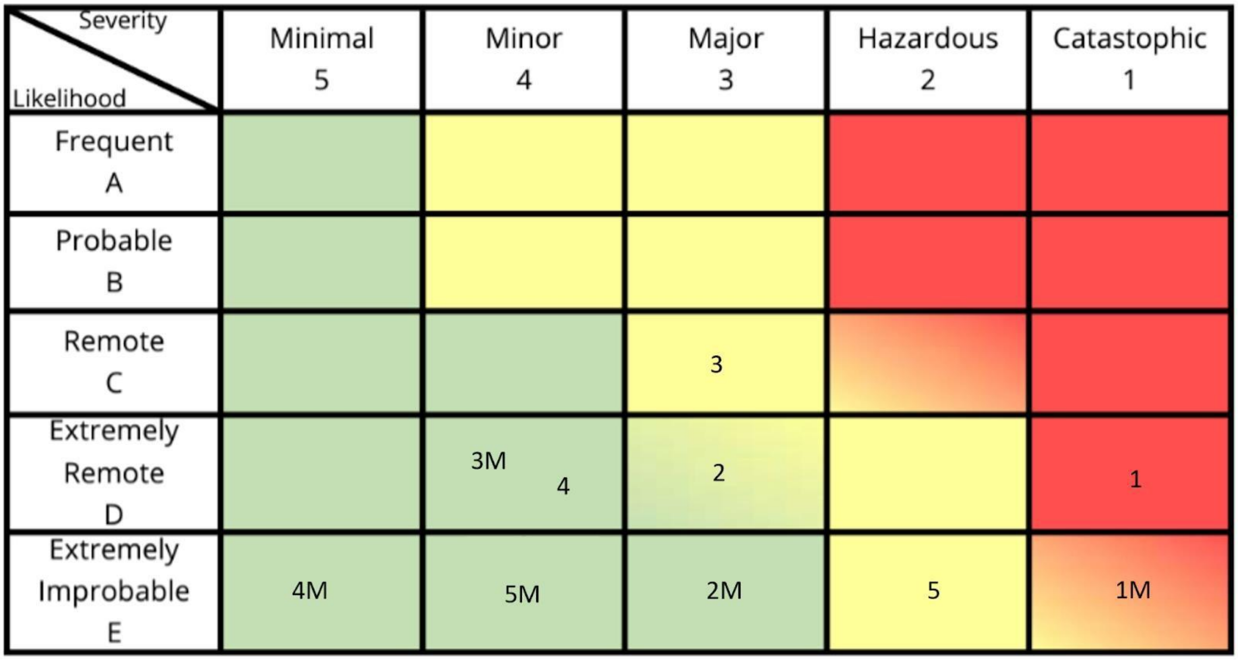
Regardless of the application, location, and installation of solar panels, there exists some inherent risk. For use in an environment such as airport operations, where the risk cases are considerably high, there must exist all necessary precautions to ensure that safety standards and guidelines are met. To effectively prepare designs that meet these standards and criteria the team conducted a risk assessment to ensure that all possible applications and adaptations of the designs maintained an environment where there were no unacceptable risks or outcomes for civilians, staff, or equipment. This assessment has given the team the needed perspective and knowledge to ensure that any inherent risks are properly mitigated.

While there always exists a multitude of potential risks, some are larger than others. When implementing any new technology or construction, it is the responsibility of the engineer to ensure those risks have been properly mitigated. The FAA outlines a five-step process for “Developing and Implementing Safety Risk Management” Which involves describing the system, identifying the hazards, analyzing the risk, assessing the risk, and finally mitigating the risks. (Federal Aviation Administration, 2023). This process was completed by the team through initial brainstorming, discussion, and research, where the team identified the points of contention and risk to avoid, followed by analyzing the proposed system and design to identify the present risks. And finally with in-depth analysis and further research into the necessary mitigation efforts. In addition to the FAA, the Airport Traffic Organization has noted on the subject that, “if a safety issue or hazard is identified through an audit or assessment, [it is important] to document the hazard and identify mitigations” (Safety Management System Manual 2022).

The team has followed suit and has properly identified the risks and considerations that may contribute to a hazardous environment along with planning thorough mitigation efforts to limit the identified risks to acceptable levels. The FAA’s AC 150/5200-37 serves as a guideline for developing risk assessments. The team specifically used the FAA Office of Airports’ Risk Matrix to identify and assess the concerns. When preparing this matrix, the team analyzed the five most pertinent and impactful risks to develop into the matrix along with their respective mitigation efforts, which can be shown in Figure 14. The matrix is subdivided into three risk categories which are as follows:

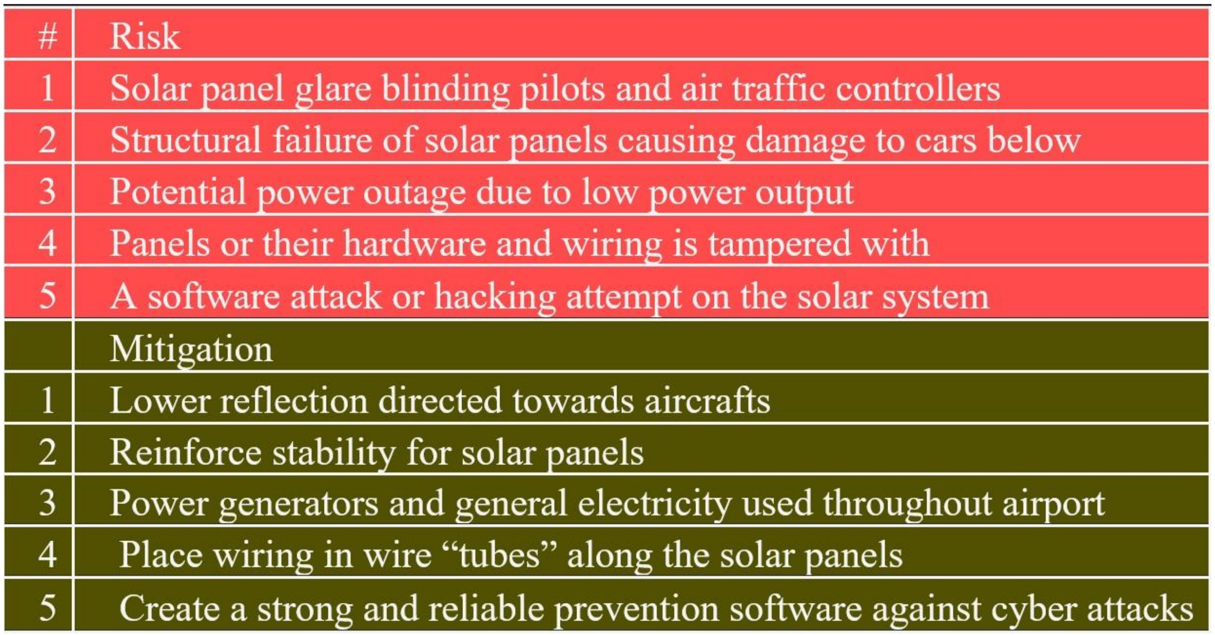
1. Dangerous Risk: Risk in which the potential exists for and is expected to include injuries, fatalities, and or the loss of life; the destruction beyond repair of aircraft, runways, airport infrastructure, and or specific equipment at intervals not consistent with the scale of damage. Individual risk items that fall into this subcategory are deemed too hazardous and likely to be worth implementation and necessitate mitigation efforts prior to implementation.
2. Manageable Risk: Risk in which the potential hazards and damages are controlled to the extent where the implementation of a design creates more value than the expected cost of failure. Failure in this case results in limited injury, repairable damage, and situations where repair does not shut down operations completely. Risks in this subcategory oftentimes require more continual supervision, maintenance, and assessment, to ensure that they do not necessitate a move to the ‘Dangerous Risk’ category.

3. Acceptable Risk: Risk in which the benefits to implementation far exceed the potential hazards, which are generally consistent of minor inconveniences for pedestrians and staff, small delays, inexpensive repairs, and other minor problems. These risks do not require constant maintenance and only necessitate periodic assessment. All risks should be mitigated by efforts in the attempt to bring them into this subcategory.



Severity / Likelihood	Minimal 5	Minor 4	Major 3	Hazardous 2	Catastophic 1
Frequent A	🟩	🟨	🟨	🟥	🟥
Probable B	🟩	🟨	🟨	🟥	🟥
Remote C	🟩	🟩	🟨 3	🟧	🟥
Extremely Remote D	🟩	🟩 3M 4	🟩 2	🟨	🟥 1
Extremely Improbable E	🟩 4M	🟩 5M	🟩 2M	🟨 5	🟧 1M

🟥 Dangerous Risk
🟨 Manageable Risk
🟩 Acceptable Risk



#	Risk
1	Solar panel glare blinding pilots and air traffic controllers
2	Structural failure of solar panels causing damage to cars below
3	Potential power outage due to low power output
4	Panels or their hardware and wiring is tampered with
5	A software attack or hacking attempt on the solar system
	Mitigation
1	Lower reflection directed towards aircrafts
2	Reinforce stability for solar panels
3	Power generators and general electricity used throughout airport
4	Place wiring in wire “tubes” along the solar panels
5	Create a strong and reliable prevention software against cyber attacks

Figure 14. Risk Analysis Matrix

Each potential risk falls within the manageable or acceptable categories, with the notable exception of Risk 1: Solar Glare. This is due to the worst-case outcome being catastrophic, despite the unlikelihood of the event. To further justify the teams design, despite this risk, it is important to note that the FAA mandates that airport solar projects do not create a hazardous glare that could blind pilots and air traffic controllers as this creates a catastrophic risk of planes crashing, However, this issue is easily resolved by following in the footsteps of the Cochin International Airport and placing solar panels above the parking lot. All an airport must do to make this happen in the United States is to submit a Notice of Proposed Construction or Alteration Form 7460-1, that includes a statement confirming the added solar panels will not visually impede any pilots or air traffic controller towers. (FAA 2021).

6. Projected Impacts of the Team's Design and Findings

6.1 Cost benefit analysis

To understand the feasibility of this proposal, the team performed calculations to determine the potential cost of constructability. For the solar panels, the area of one row of the large canopies is 12,330.19 square feet. The larger canopies cover the 6 longer rows of parking, for a total area of 73,981.17 square feet. The small canopies will cover the 5 smaller rows of parking, for a total of 35,692.67 square feet. The total area of solar panels needed for this design will be 109,673.79 square feet. On average, a solar panel can produce 8-10 watts of electricity per hour per square foot of surface area. (KMB Design Group 2014). 10 watts will be used to estimate. To calculate an approximate electricity production, 10 watts was multiplied by the area of solar panels. 10 watts multiplied by 109,673.79 square feet results in 1,095.19 kilowatts per hour (kw/h) of energy produced per hour.

On average, solar panels cost around 4 to 10 dollars per square foot (Chopson, 2023). To estimate the respective costs, the cost is multiplied by the area of the solar panels. 10 dollars will be used to estimate the worst-case scenario. Ten dollars multiplied by 109,673.79 square feet results in an approximate cost of $1,096,737.9. In addition to calculating the cost of the panels by square foot, it is also common to estimate costs by wattage. The average cost to install solar panels per watt is between $0.90 and $1.50 per watt (Forbes), the team will be using $1.50 to continue the worst-case scenario planning. At $1.50 a watt, with a 1,095 kW system, the expected costs are to be $1,645,095. While a more realistic estimate, especially for a larger jab with state and federal funds, would put costs closer to $1.00 per watt, nearly equaling the two estimates, the team understands the importance of what the bare minimum it would take to break even.

The team also considered the cost of other materials such as timber posts, footers, connections, and wiring. For the posts, the team used white oak timber which generally costs $10 per board foot. For the design the team used 26.4’ long posts that were 5” by 5” for an area of 25 square inches. These dimensions come out to an equivalent board feet of 54.69, which brings the cost per post to $546.88. The team designed for a total of 15 posts per section with 10 parking lot sections bringing the total number of posts to 150. When multiplied by the cost per post the team expects a total material cost of timber to be $820,860. The team also considered around $1000 for connection equipment and footers for each post based off work done for other timber framed projects for a total cost of $150,000 for the supporting equipment

The total summed costs of the project come to $1,250,000. (averaged) for the price of panels, $820,860 for the price of the posts, $150,000 for the costs of construction parts including everything but the panels and posts. This added up to just over $2,200,000 which is useful for labor calculations as labor can be estimated at 25% of the cost of parts for solar (Forbes). This gives the team an estimate of about $500,000 for labor. Giving the full project an estimated total cost of $2,700,000. While this is a lot of money, especially for a small airport, through feedback from experts, the team realizes that there are many state and federal programs such as FAA Green, which provide funding for these expenses. The airport would also save a tremendous amount of money over time with the now self-produced 1,095.19 kilowatts per hour (kw/h) of energy saving $0.124 per kWh as that is the average energy cost in Virginia. This comes to an hourly savings of $136. Assuming this hourly production is only during 12 hours of the day, The yearly savings using the lower estimate or worst-case scenario for all the numbers would be nearly $598,820. This is a pretty substantial amount of savings and based on the proposed cost, the project would pay for itself in around 4.5 years, although in actuality, where the numbers are not all worst case, that figure would be much less.

6.2 Future Impacts

Impacts to the Shenandoah Regional Airport (SHD) from the solar panel canopy prototype can vary from weather protection to electricity provided to the airport. A wind turbine alternative was also evaluated for future impacts. The solar panel canopy provides protection from the ever-changing weather in western Virginia. With all four seasons being prominent in the area, the canopy covers the parked cars from hot summers and cold winters. The angled solar panels allow the precipitation to slide off the canopy instead of creating puddles on top on the canopy, which in turn creates another problem with standing water around the electrical components of solar panel. With the solar panels providing electricity to the airport, this allows SHD to allocate the existing cost of electricity to other projects and needs around the airport. Labor rates play a significant role in determining the overall labor cost. Labor rates can vary widely depending on the region and the skill level of the workers involved. The canopy structure without solar equipment is about $500- $5,000 depending on the size and use of certain materials. The canopy including solar panels would range between $3,500- $9,000 including mounting equipment and wiring. When According to FAR 77 and expert feedback, the wind turbine impacts are not feasible for this airport. The reason FAR 77 makes this option unfeasible according to expert feedback, is that it would affect the surrounding air navigation for an aircraft. This can overall show that there is no reason to install the wind turbine since it is not economical.

Appendix A: Contact Information

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Appendix B: University Description

The Virginia Military Institute (VMI), located in Lexington Virginia, is the oldest state supported military college in the United States. Since its founding in 1839, VMI has produced men and women of strong moral values who work in both military and civilian environments after graduation. There are roughly 1,600 Cadets attending VMI that study one of 14 academic majors. 50% of Cadets earn degrees in STEM fields. (Science, technology, engineering, or mathematics).

VMI has a rich history of producing some of the United States' best military leaders. 7 VMI alumni have received the U.S. military's greatest honor, the Medal of Honor. 266 have achieved the rank of General or Flag Officer in the U.S. military. VMI's ultimate goal is to produce citizen soldiers, and as such, not all VMI Cadets are required to serve in the military. Roughly 40% of all cadets enter the civilian workforce after graduation.

VMI participates in 16 NCAA Division 1 sports as part of the Southern Conference. VMI also offers a variety of club sports, clubs, student organizations, and other extracurricular activities for Cadets to participate in. VMI's commitment to instill honor, integrity, discipline, and good morals into each of its graduates makes VMI a respected institution around the world.

Appendix C: List of Industry Experts

Mr. Chris Cary - Mr. Cary serves as the Shenandoah Vally Regional Airports Director of Airport Planning and Development.

Mr. Bill Kelly, CM – Mr. Kelly has worked in the airport industry for his entire career. Working as the Airport Manager at New Kent Airport in Virginia for 13 years from 2001 to 2014. Since 2014, Mr. Kelley has worked for Delta Airport Consultants, where he is currently an Airport Consultant and the Special Services, Planning, and UAS Program Manager. He also served from 2011 to 2013 as President of the Virginia Airport Operators Council.

Appendix E: Evaluation of Educational Experience

Students

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

There are several reasons that the ACRP design challenge was a meaningful learning experience for the team. The ability for the team to find a local airport and determine a challenge area based on an overlap in the airport's specific needs and the team members' areas of interest made for a captivating project that kept the team motivated throughout the process. The industry professionals interacted with by the team offered valuable insight into the life of an engineer and will remain excellent resources throughout our civil engineering careers.

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

Being a group of Military school Cadets, time was a scarce resource. Initially, the team struggled with finding times in which all the team members could meet. As the project went on, the team developed an effective work delegation strategy, so that even if the team was not able to meet on a particular day, each team member knew exactly what task they were expected to work on. Our design went through several changes as well. The team would work diligently on ideas we expected to work out perfectly, only for Dr. Idewu and our industry expert contacts to point out flaws in our designs. This caused the team to spend several hours correcting calculation errors alone on several occasions. Although the team's design is still not perfect, this feedback was greatly appreciated, and assisted the team in creating what we see as a feasible option for the Shenandoah Regional Airport to implement clean energy into their power systems.

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

The team’s first step was reading over a list of specific problems the Shenandoah Regional Airport (SHD) wished to address. After finding an overlap in the airports needs and the team’s interests, the team conducted preliminary research into sustainable energy options as our focus, and held a video call with Mr. Chris Cary, the Director of Airport Planning and Development at SHD, and pitched our initial ideas to him. From there, we decided to focus on solar power. Later on, Mr. Cary gave us an in-person tour of SHD, where we were able to ask questions and better understand the feasibility of our ideas. After the visit to SHD, the team took into consideration which of our ideas addressed the ACRP competition challenges and decided that the solar panel parking canopy was the best choice. We determined this based off sustainability, safety implications and cost-benefit analysis.

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

Contacting the industry experts was perhaps the most enlightening and helpful aspect of this project. Our experts offered sound advice, for both our future careers and for our project. The expert's insight revealed issues in our design and ideas that we could not have realized on our own and gave us alternatives and solutions to each problem they addressed. The team feels that from interacting with these industry experts, our engineering judgement skills have vastly improved.

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

This project gave the team a greater understanding and appreciation for the work and cooperation between industry experts to create meaningful change at airports. The team came to realize that having what we believe is a good idea is simply not good enough. All the industry experts the team contacted emphasized the fact that airport stakeholders will not be interested in proposals that do not have the potential to make back the money that an airport would need to spend, or at least have some other significant benefit that would be worth the cost. This required our team to carefully consider the economic aspects of our design, which is not something that is often discussed in our previous design courses.

Faculty

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

Through this project, students learned the value of receiving feedback. Their proposed design-solution improved with each iteration of their report. Between each iteration students received feedback about their design from industry consultants, “clients”, and faculty.

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

Yes. The course in which this design competition was incorporated was a transportation engineering elective course. As a subdiscipline of civil engineering, the focus area of transportation engineering in undergraduate education is primarily focused on highway road design. As this is the case in most civil engineering programs throughout the country, coverage of the other modes of transportation are not adequately addressed due to limited offerings and truncated schedules. Incorporating design challenges that are airport specific create opportunities to explore other critical modes of transportation.

3. What challenges did the students face and overcome?

The students (at our undergraduate level) were challenged by the technical details inherent in every design. They had to overcome solely relying on what was learned in previous introductory-level courses and engage with other subject matter experts in the field to create and present an appropriate/viable solution to the problem they were addressing.

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

Yes. I believe most of our students learn best by doing. Furthermore, conditioning students to learn how to “find” answers that are not already written in a textbook is a skill that they can take with them and develop further in the workplace.

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

I am a bit biased here, but I would suggest adding more challenges that require civil engineering components (soil analysis, water resources, etc.)

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