Harnessing Wind Energy with Recyclable Materials

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Team 03

Final Report/Project Proposal

Document

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1.0 Problem Statement

1.1 Introduction (brief outline of project description)

The "Harnessing Wind Energy with Recyclable Materials" (H-WERM) design project is a project initiated, and sponsored by Srinivas Kosaraju, a Mechanical Engineering professor at Northern Arizona University, located in Flagstaff, Arizona.

1.2 Background

The customer of the design project cannot be specifically identified as an organization or a corporation: the final project design is intended for citizens of third world countries who are in need of relatively small quantities of electrical energy. The energy is intended to be used to provide basic living "luxuries" such as lighting and the use of fan(s)

1.3 Needs Identification

Inhabitants of third world countries, whom do not have access to electrical grid network(s) of power production facilities, are in need of electricity.

1.4 Project Goal and Scope of Project

Goal Statement: To provide inexpensive electricity to third world country citizens who are in need.

Scope: The scope of the goal statement to provide an inexpensive, portable wind turbine system to harness wind energy. The wind turbine system will include both a wind turbine to generate electricity, and a means of storing the electricity generated.

1.5 Objectives

The project objectives are to design a wind turbine system that is portable, easy to assemble, able to withstand high wind speeds, and can extract enough energy to store and/or provide 0.5 kWh per day.

The above objectives were determined by considering the following items:

- Portable: In third world countries (especially in rural locations) there is limited access to vehicles, fuel, and manicured roads. As a result, the wind turbine system must be designed such that two to three individuals can transport the system over long distances with varying terrain.
- Easy to assemble: Inhabitants in third world countries may have limited access to tools, especially tools that require power for operation. Therefore, the wind

turbine system must have the ability to be easily assembled and disassembled, using basic tools, by a few individuals.

- Withstand high wind speeds: To ensure the structural integrity of the wind turbine system will be maintained during common storms found in third world countries, the turbine must be able to withstand high wind speeds.
- 0.5kWh of energy extraction/ storage per day: This objective was determined based upon the use of a 60W incandescent light bulb and a 40W fan, both running 5 hours per day.

The basis of measurement for the above objectives is shown in Table 1 below:

Table 1: Design Objectives and Measurement Bases

Objective	**Basis for Measurement**	**Units**
Portable	Total Weight	kg
Portable	Total volume when disassembled	m^3
Easy to assemble and disassemble	Time required to assemble and disassemble without power tools	min
Withstand high wind speeds	Stress on turbine at 50 mph	MPa
0.5 kWh of energy extraction/storage per day	Energy generation rate and storage capabilities	kWh
Low cost	Cost analysis of material used for design	$

1.6 Constraints

- The total budget must not exceed $50.
- The total weight must not exceed 100 lbs
- The system must generate and store at least 0.5 kWh per day.

1.7 Functional Diagram

The following diagram (see Figure 1 below) is the proposed circuit for the design. A battery connected in parallel with the appliances will enable the system to provide supplemental power to the load (appliances) when the power generated by the turbine is less than the load requirements. *Note that DC will be used to power/ run the wind turbine system.*

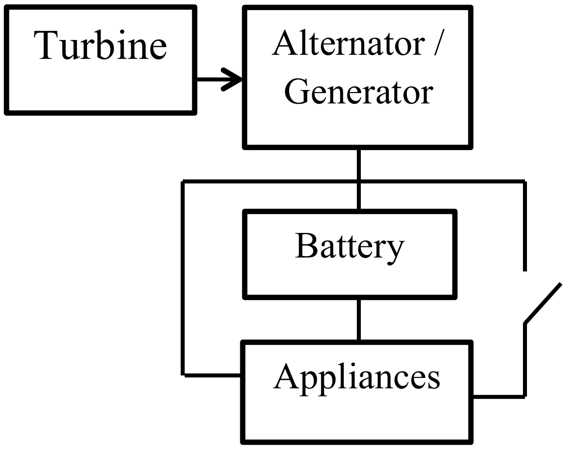

Figure 1: Functional Diagram

1.8 Design Criteria and Criteria Tree

The design team developed a list of design criteria based on the preliminary discussion with the H-WERM sponsor, the design objectives, and additional research performed in reference to the design problem statement. Table 2 contains the design objectives with the corresponding quantified objectives and criteria.

Table 2: Design Objectives, Quantified Objectives, and Criteria

Objective	**Quantified Objective**	**Criteria**
Low Cost	Maximum cost of $50.00	Cost
Recyclable	Available from local junkyards/stores	Recyclability Material availability
Energy Storage	0.5 kWh per day stored	Electrical storage capability
Easily assembled, disassembled, moved	Time limit of 1 hour for two people setting it up; weight limit of 100 pounds	Physical construction Materials Set-up
Able to withstand high wind speeds	No breaking/deformation under speeds up to 50 mph.	Materials Design strength

The above criteria are best grouped into five subcategories: cost, recyclability, before operation, during operation, and after operation. The cost and recyclability are in their own categories. The before operation subcategory includes moving and assembling the unit. The during operation subcategory includes the ability to store 0.5kWh per day and the ability to withstand high wind speeds. Finally, the after operation subcategory includes the disassembly of the unit. A compilation of the subcategories of criteria described above is illustrated in the criteria tree diagram shown in Figure 2.

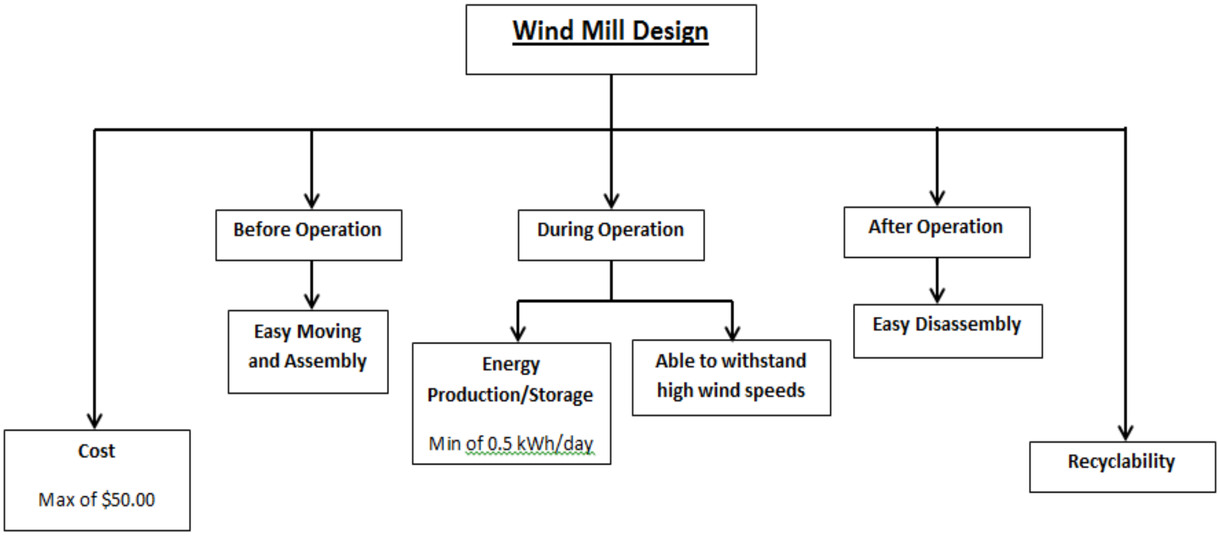

Figure 2: Criteria Tree Diagram

1.9 Quality Function Deployment / House of Quality

To relate the customer needs to the engineering requirements for the H-WERM project, Quality Function Deployment and House of Quality analyses was performed. The Quality Function Deployment Chart and House of Quality Diagram (see Figures 3 and 4 below, respectively) are visual tools that provide a cause and effect analysis of design requirements that directly correlate with either the customer requirements, and/or each other.

Specifically, the Qualify Function Deployment chart indicates the engineering design requirements that effect the customer requirements. The House of Quality diagram indicates the design requirements that affect each other. A positive sign on the House of Quality diagram indicates a positive relationship between design requirements, while a negative sign indicates an inverse relationship.

The conclusion of the following diagrams will be considered during the H-WERM design concept generation and selection process.

		Engineering Requirements					
		Weight	Energy efficient	Cost	Size	Strength	Surface Area
Customer Requirements	Ease of Mobility	**X**			**X**		
	Produces 0.5 kWh		**X**				**X**
	Durability	**X**				**X**	
	Ease of Assembly				**X**		
	Recycled Material		**X**				**X**
	Low Cost	**X**		**X**			
	Units	lb	W	$	ft^2	psi	in^2
		Engineering Targets					

Figure 3: Quality Function Deployment Chart

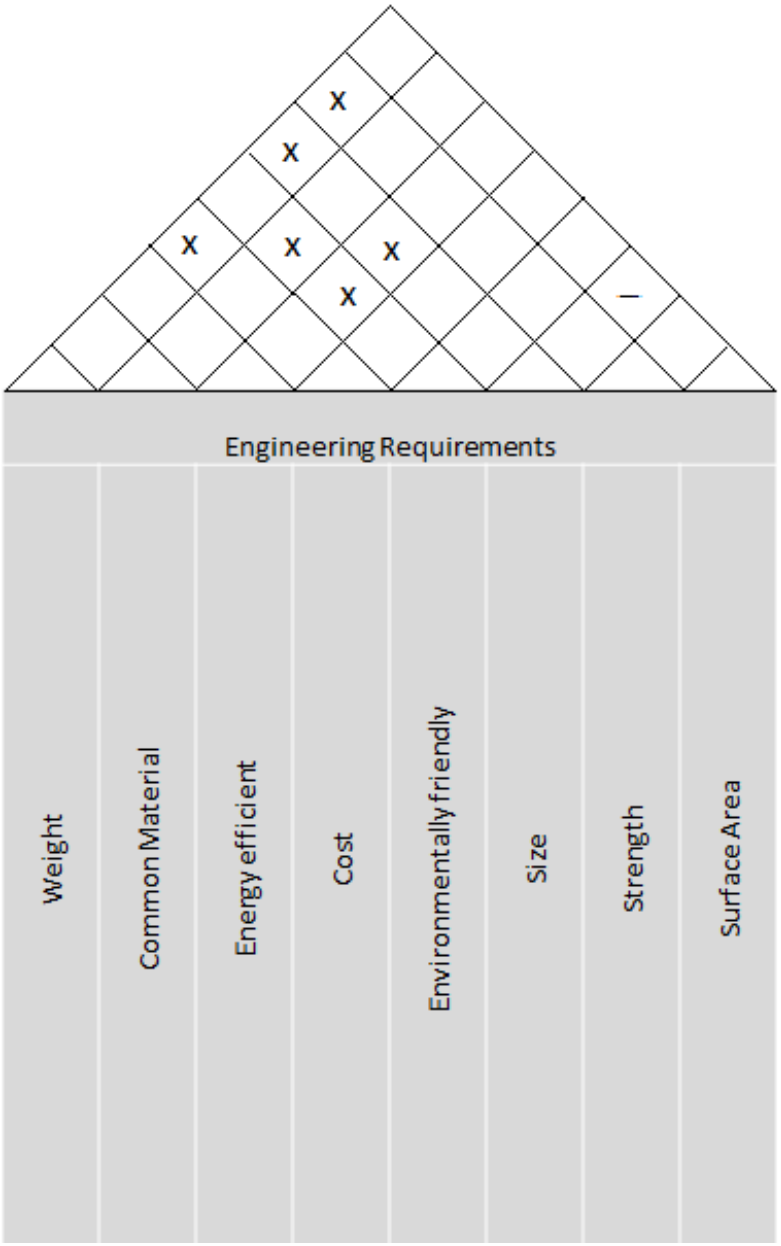

Figure 4: House of Quality Diagram

2 Concept Generation

When designing a turbine to be used in a third world country, many factors were considered in order to find the most cost and power effective solutions. A few of the design concepts the H-WERM team considered are described below.

The first concept considered is a horizontal turbine with PVC blades cut to form a helix shape prop, as shown in Figure 5, below. The primary advantage of this design is that the blades are made of recyclable materials that are easily obtained, lightweight, and fairly simple to assemble. However, since the wind direction significantly affects the operations of horizontal turbines, this design may not generate enough power, or may require additional components and assembly to allow the turbine to turn into the wind as the wind direction changes. Having inexpensive materials reduces cost, but the mechanical aspect of building this design may prove too complicated for a simple solution.

Figure 5: PVC Turbine Blades[1]

Other concepts researched were the Darrieus or “eggbeater” turbine, shown in Figure 6, and wind belt methods, shown in Figure 7. These wind energy devices have an intuitive design and are used to generate electricity in multiple countries. Although these types of devices have proved worthy in more advanced countries, the limited availability of specialized tools in third world countries makes implementing technology such as this difficult.

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[1] http://www.mdpub.com/Wind_Turbine/images/blades1.jpg

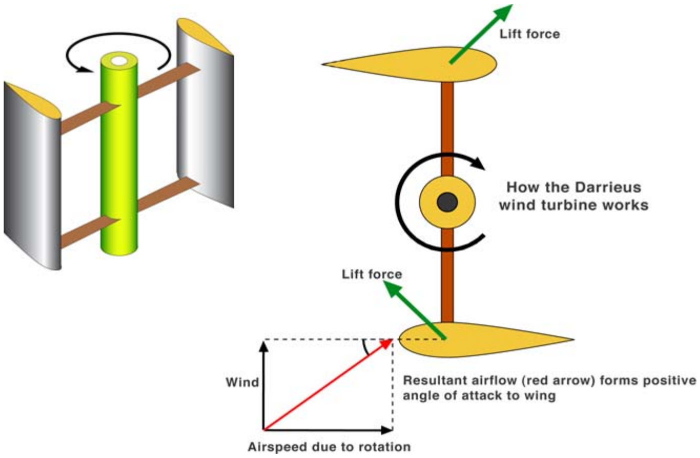

Figure 6: Darrieus Turbine 2

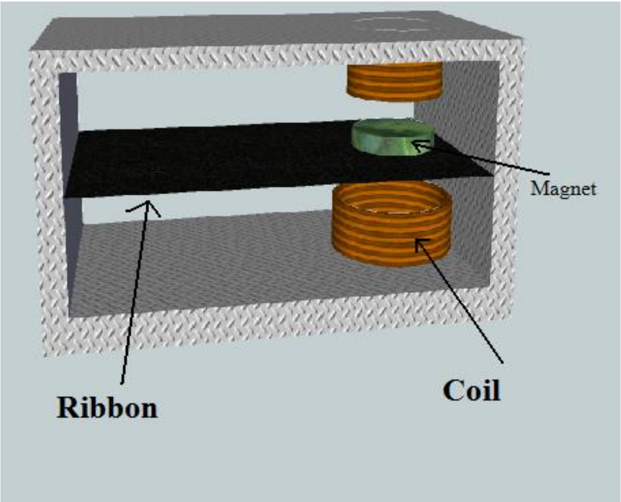

Figure 7: Wind Belt

Another concept considered involves making a wind turbine out of a bicycle wheel, as shown in Figure 8. By wrapping sheet metal, foil, plastic, or another material around the spokes of a bicycle wheel in the orientation shown in Figure 8, one can very nearly replicate the blades of a wind turbine.

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[2] http://2.bp.blogspot.com/-CxJjuGSbuiY/UAAO0MW5LBI/AAAAAAAAArU/62GzAOCH8aY/s1600/Darrieus.jpg

Figure 8: Bicycle Wheel Turbine [3]

A final concept considered consists of a 55-gallon oil drum and a stand, as shown in Figure 9. As with the PVC turbine blades, this design utilizes recycled materials, namely oil drums, which are readily available in many countries. In addition, transporting the materials required for this design to rural areas will be simple, because an oil drum may be easily rolled across a flat surface. While cutting a steel drum in half may require advanced tools, the overall design will require little assembly. Since this design features a vertical axis, this wind turbine can generate power regardless of the wind direction. In addition, the drum has a large surface area, which helps it catch more of the wind, yielding a higher rate of revolutions per minute, and thus more power generated.

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[3] http://3.cf.shn.m3cdn.net/wp-content/uploads/2012/03/3500bike-wheel-turbine.png.400x300_q85_crop-smart.jpg

Figure 9: 55 Gallon Drum Turbine

A generation device, as well as an electrical storage device, is necessary to harness and store the wind energy collected by the turbine. Based on research and available materials, the most readily available devices used for power generation are car alternators, motorcycle stators, and bicycle dynamos. Based on research, motorcycle stators and car alternators are the most cost effective and readily available storage devices that can be obtained in third world countries. However, the higher rpms required limits the usefulness of these devices for this application. Therefore, bicycle dynamos are the primary choice for this design.

3 Concept Selection

Based on the previous steps of the design process, several criteria were identified as being the most important focuses of the design. These main criteria were further grouped into three categories to represent the overall goals of the project. The criteria are listed in Table 3.

Table 3: Overall Categories of Design Criteria

Portability	Cost	Operation
Weight	Purchased materials	Power produced
Number of parts	Found materials	Material strength
Dimensions		Directionality

These criteria were identified from the project need statement. Since the design must be easily moved, assembled, and disassembled, the team considered the weight of the system, the number of parts, and the size of both the individual pieces and the fully assembled design. The problem statement did not address the issue of cost, but after further meeting with the client, a limitation of fifty dollars per unit was imposed. The directionality of the system (how the design will operate under different directions of wind) must allow for 0.5 kilowatt-hours of energy to be produced, and the strength of the materials used must allow for operation under high wind speeds.

After the design criteria were identified, weights were assigned to each criterion, based on overall importance to the project. The weights of each design criteria are listed in Table 4.

Table 4: Weighted Criteria

Criteria	**Weight**
Portability	**0.3**
Weight	0.15
Dimensions	0.075
Number of parts	0.075
Cost	**0.2**
Purchased/found	0.2
Operation	**0.5**
Power produced	0.3
Directionality	0.1
Material strength	0.1

These weights were assigned based on what aspects of the project the team felt were most important. Operation received the largest weight of 0.5, because the main goal of a power system is producing power. For this same reason, the sub-criteria of power produced was given a higher weighting of 0.3, and the directionality and material strength criteria each received a rating of 0.1. Portability followed operation in weight, because it contained more criteria factors than the cost, so 0.3 was assigned to portability overall, and 0.2 to cost.

After the criteria were weighted, the team developed a decision matrix to determine which design provided the best solution to the problem statement. Each design was given a rating of 1-5 (1 being the worst and 5 being the best) for each of the criteria and the weighted amounts were summed. The decision matrix is shown in Table 5, below.

Table 5: Decision matrix for various designs

Criteria	**Criteria Weight**	**55 Gallon Steel Drum**	**Horizontal PVC Turbine**	**Vertical Turbine**	**Rubber Wind Belt**	**Horizontal Bike Wheel Turbine**
Portability						
Weight	0.15	3	4	4	5	5
Dimensions	0.075	3	4	2	5	4
Number of parts	0.075	5	2	2	3	2
Cost						
Purchased/found	0.2	4	4	3	4	4
Operation						
Directionality	0.1	5	2	5	1	4
Power produced	0.3	5	5	4	1	5
Material strength	0.1	4	5	5	4	5
		4.25	**4.05**	**3.7**	**2.94**	**4.4**

The two designs with the highest scores from the decision matrix were the 55-gallon steel drum and the bike wheel turbine. These were the designs that the team focused on moving forward in the design process. Various ways to refine and improve these designs were considered throughout the design process.

4 Engineering Analysis

The following sections describe the engineering analysis performed on each the turbine blade design and the turbine weather vane for a horizontal bike wheel turbine design.

4.1 Turbine Blade Design

The following equation calculates the power from a wind turbine, and can be rearranged to find the required swept area for a certain desired output of power:

$$P = \frac{1}{2} C_p \rho A V^3 \rightarrow A = \frac{2P}{C_p \rho V^3}$$

With this equation for the required swept area, and the following values in Table 6, the swept area required for the project's specific wind turbine requirements is calculated as:

$$A = 1.83\ m^2 = 19.730\ ft^2.$$

Table 6: Assumptions/Givens for Swept Area Equation

Symbol	Variable	Quantity
P	Power produced (15W DC CFL Bulb + 40W DC Fan)	55 Watts* (for 5 hours each day)
C_P	Coefficient of performance	0.4 (average value for horizontal axis)
ρ	Density of air	1.2 $\frac{kg}{m^3}$ (average)
A	Swept area of turbine blades	$(A)\ m^2$
V	Average wind speed	5 $\frac{m}{s}$ (estimated average)

*Replaced 60W incandescent bulb with 15W CFL DC bulb

To satisfy the swept area requirement above, the diameter required is:

$$D = \sqrt{\frac{4A}{\pi}} = 1.528\ m = 5.013\ feet$$

The length of one turbine blade is equal to the radius of the swept area. Therefore, the required length of one airfoil blade is:

$$R = \frac{D}{2} = 0.7638\, m = 2.507\, feet \approx 30\, inches$$

4.2 Weather Vane Design

Horizontal axis wind turbines generate electricity most efficiently when the turbine is facing directly into the wind. Since the wind direction varies, most turbines are designed to rotate based on the wind direction. For small-scale turbines, weather vanes are commonly used to rotate the turbine into the wind. As a general guideline, the area of the weather vane must be at least 5% of the swept area of the wind turbine. The swept area of the final design is 1.833 m^2, therefore the area of the weather vane must be at least 0.92 m^2 or 142 in^2. The length of the tail should be approximately 60% of the rotor diameter. The rotor diameter of our final design is 1.53 m, therefore a tail length of 0.92 m or 36 in is required. The weather vane can be seen in Figures 10 and 12.

5 Final Design

After performing the engineering analysis on the horizontal axis bike wheel turbine design, the area requirements proved to be too large to use solely a bike for the turbine face. Consequently, the team abandoned using a bike wheel, and instead decided to use a horizontal turbine with PVC blades cut to form a helix shape prop, as shown in Figure 10, below.

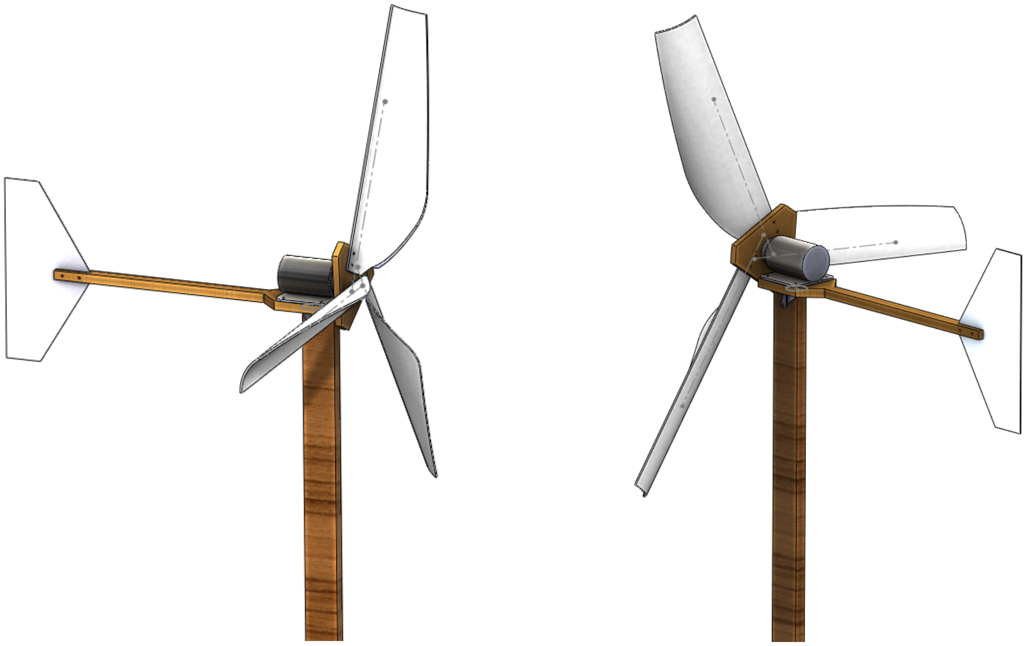


Figure 10: Final Windmill Design

The following sections describe the major hardware parts of the final wind turbine design, electrical component specifications, and the final design cost analysis. Detailed part drawings are included in Appendix 1, on page 30.

5.1 Major Hardware Components

Turbine Blades:

The wind turbine blades will be constructed by cutting, heating, and molding pieces of PVC pipe into an airfoil-type shape, as shown in Figure 11, below. This material was chosen because of the availability, lightweight properties, and strength. A standard nominal pipe size of 8.625” diameter with a thickness of 0.332” and length of 30” will be used.

Figure 11: Turbine Blade Shape

Generator →Turbine Blade Interfacing:

The interfacing between the generator and the turbin blades requires several parts to complete the assembly. First, three turbine blades (of equal radial spacing) will be fastened to a wooden block with lag bolts to create the turbine face. To translate the rotational motion of the turbine face to the generator shaft, a PVC device will be used.

The PVC device contains two pieces of PVC pipe (fitted concentrically inside of one another other) and a PVC pipe cap (which fits concentrically around both the fitted pieces). The PVC cap will be screwed into the back side of the turbine face (wooden block), and then a set screw will be used to connect the cap to the PVC fitted pieces. The smaller of the concentric pieces will be cut such that the generator keway will slide into the newly created PVC hole. (See Figure 12, below). In addition to the set screw, epoxy will be used to reinforce the connection between each PVC piece.

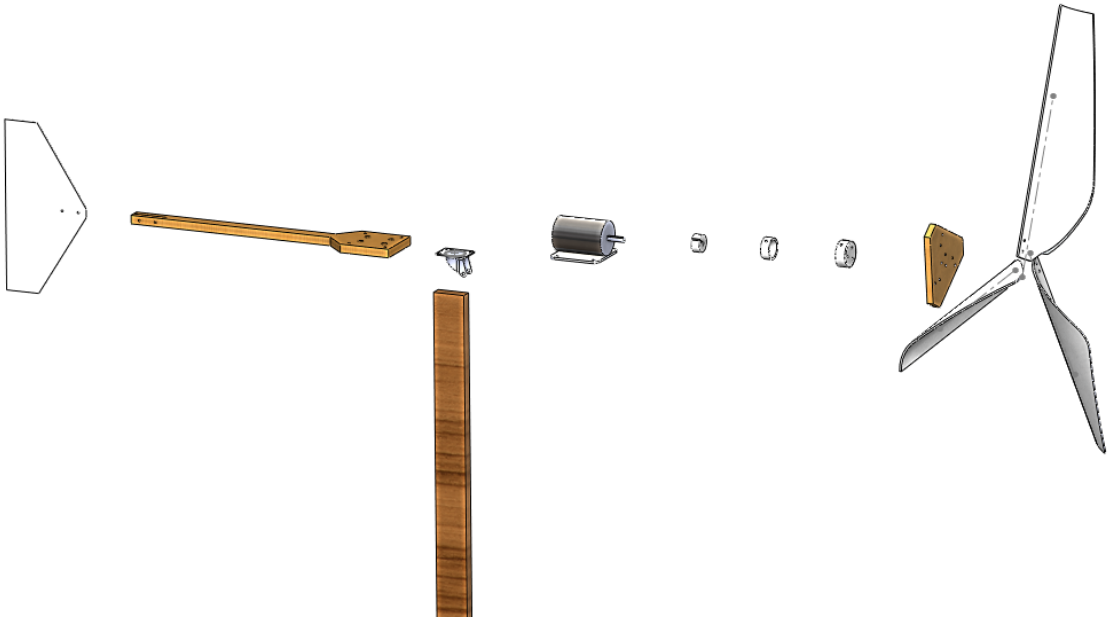


Figure 12: Final Windmill Design

Turbine Horizontal Pivot/Base Design:

In constructing a horizontal axis wind turbine, multiple aspects of rotation were considered. Because wind direction is characterized by varying along the horizontal plane, a weather vane will be installed to the back of the system in order to direct the turbine into the wind, as shown in Figure 12 above. Varying wind direction will require a pivot point, enabling the turbine to rotate. A caster wheel, as shown in Figure 13, will provide the necessary pivoting motion for the turbine.

Figure 13: Caster Wheel Assembly

The caster wheel and base pole assembly is shown in Figure 14. The wheel will be removed from the caster wheel assembly and replaced with a wooden 2x4 post, inserted between the brackets. A horizontal hole will be drilled through the wood, and the existing bolt will fasten the two brackets to the wooden post.

Figure 14: Bottom pivot assembly

Once the wooden post and caster wheel frame are assembled, a top plate containing the rear tail as well as the generator will be fastened to the top of the caster plate (refer to figure 14, above). The existing mount holes will be used to secure these two plates together. Set screws will be placed 90^{o} apart to prevent the turbine from over-rotation. Over rotation can cause multiple problems, such as tangled wires, ultimately destroying the entire system.

5.2 Electrical Components

The following table contains the specifications for the wind turbine electrical components.

Table 7: Electrical Components

Component Type	Description	Specifications
Appliance	Incandescent Light Bulb	60 W
	CFL Bulb	15 W, 12 V DC
	Fan	40 W, 12 V DC
Battery	Car Battery	12 V, 80Ah, 1 kWh
	Motorcycle Battery	12 V, 6 Ah, 72 Wh
Alternator / Generator*	Bicycle Dynamo Generator	Varied Widely
	Motor Cycle Stator	12 V, 750 rpm, 60 – 90 W
	Car Alternator	14 V, 2000 rpm

* The final alternator/ generator component will be determined based on the available parts, which will be selected during prototype construction phase.

5.3 Cost Analysis

The following table contains a list of the parts and/or materials used in the final wind turbine design. Prices were determined based on cost averages found for each part.

Table 8: Cost Analysis

Part / Material Use	Cost
Battery *Note that pricing is based on recycled parts*	\$20.00
Generator/Alternator *Note that pricing ranges are defined based on recycled vs. new parts*	\$20.00 - \$200.00
PVC Pipe (Turbine Blades, Generator to Turbine Interfacing Component)	Scrapped
Aluminum Cans (Weather Vane)	Scrapped
Lumber – Spruce (Turbine Blade Base, Generator Base, Post)	Scrapped
Wires (DC power adapter for appliances, overall electrical wiring, etc.)	\$5.00
Screws, fastenings, etc.	\$5.00
Total Cost	**\$50.00 – \$232.00**

7 Future Tasks

Table 9: Future Tasks and Task Descriptions

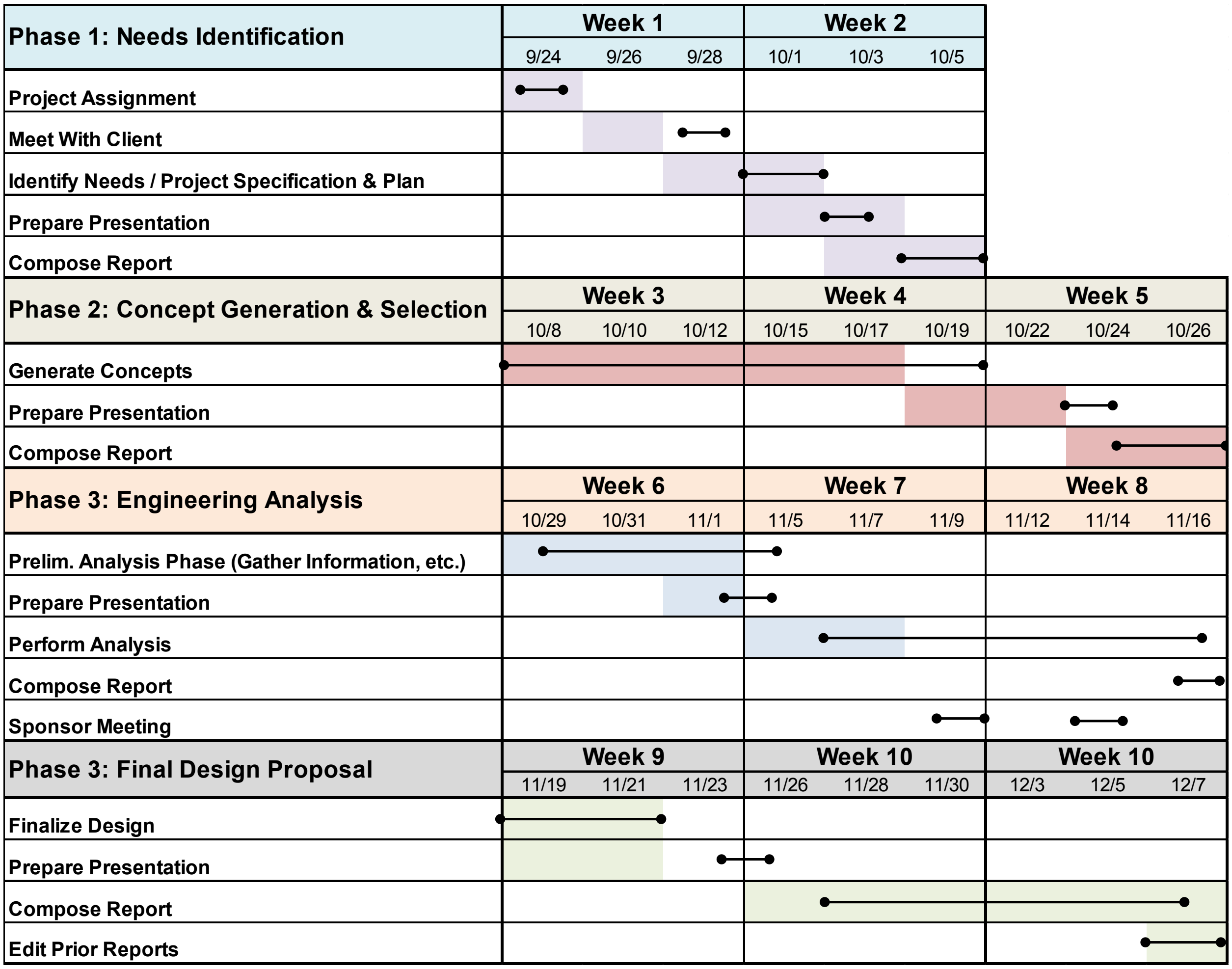
Task	**Task Description**
Gather Prototype Materials	Collect the following major deisgn materials and components from junkyards/ other suppliers (per design specificatoins): 1) Generator 2) Battery 3) Circuitry Parts (Appliance ports, Wiring, etc.) 4) Appliance DC Ports 5) PVC Pipe 6) Lumber 7) Fastenings 8) Aluminum Material (Cans) 9) Castor Wheel 10) Fastenings
Build Major Prototype Parts	Build the following parts: 1) Turbine Blades 2) Wooden Block (Turbine Blade Attachment) 3) Generator Base Plate 4) Turbine Blade Attachment Plate 5) Turbine to Generator Connector 6) Weather vane 7) Turbine Stand
Assemble Prototype	Perform the following: 1) Assemble Turbine system 2) Assemble Electrical system 3) Connect Electrical and Turbine Systems
Prototype Testing	Testing the completed prototype for the following: 1) Varrying wind speeds 2) Varrying Heights (Earth to Hub) 3) Assembly Time
Prototype Revision	Redeisgn/ Rebuild prototype to meet design critera as necessary.

The preceding table contains each task and associated descriptions for the upcoming spring semester. The project timeline for the upcoming spring semester was based on these tasks.

8 Project Plan

The following table contains a timeline of the project progression for the fall semester. Note that the color-shaded region indicates the pre-determined allotted timeslot for the associated task, while the bold lines with round endpoints indicate the actual date(s) the specific tasks occurred.

Table 10: Project Timeline, Fall 2012



The following table contains a projected timeline for the upcoming semester (Spring 2013). The color-shaded region indicates the pre-determined allotted timeslot for the associated task. The allotted times were determined based on anticipated needs for each phase.

Table 11: Projected Timeline, Spring 2013

Phase 1: Material Collection	Week 1			Week 2			Week 3		
	1/14	1/16	1/18	1/21	1/23	1/25	1/28	1/30	2/1
Meet with EE Professor	■	■							
Gather Hardware Materials			■	■					
Gather Electrical Components					■	■	■	■	■

Phase 2: Part Construction	Week 4			Week 5			Week 6		
	2/4	2/6	2/8	2/11	2/13	2/15	2/18	2/20	2/22
Build Hardware Components	■	■	■	■					
Build Electrical Circuit					■	■	■	■	■

Phase 3: Assembly Construction	Week 7			Week 8			Week 9		
	2/25	2/27	3/1	3/4	3/6	3/8	3/11	3/13	3/15
Assemble Turbine System	■	■	■	■					
Connect Electrical System to Turbine System					■	■	■	■	■

Phase 3: Testing / Finalize Design	Week 10			Week 11			Week 12			Week 13			Week 14		
	3/18	3/21	3/23	3/25	3/27	3/29	4/1	4/3	4/5	4/8	4/10	4/12	4/15	4/17	4/19
Test Prototype	■	■	■												
Redesign & Retest Prototype				■	■	■	■	■	■						
Prepare Deliverables										■	■	■	■	■	■

9 Conclusion

The goal of the H-WERM project is to provide inexpensive electricity to third world country citizens who need electricity, by designing an inexpensive, portable wind turbine system to harness wind energy. The wind turbine system will include both a wind turbine to generate electricity, and a means of storing the electricity generated. The objectives for this project are to design a wind turbine system that is portable, easy to assemble, able to withstand high wind speeds, and can extract enough energy to store and/or provide 0.5 kWh per day.

Below is a summary of the project objectives and constraints:

Table 12: Design Objectives

Objective	**Basis for Measurement**	**Units**
Portable	Total Weight	kg
Portable	Total volume when disassembled	m^2
Easy to assemble and disassemble	Time required to assemble and disassemble without power tools	min
Withstand high wind speeds	Stress on turbine at 50 mph	MPa
0.5 kWh of energy extraction/storage per day	Energy generation rate and storage capabilities	kWh
Low cost	Cost analysis of material used for design	$

Constraints:

- The total budget must not exceed $50.
- The total weight must not exceed 100 lbs.
- The system must generate and store at least 0.5 kWh per day.

Based on these objectives and constraints, the team brainstormed five different turbine concepts:

- 55 Gallon Steel Drum
- Horizontal PVC Turbine
- Vertical Turbine
- Rubber Wind Belt
- Horizontal Bike Wheel Turbine

Each design was evaluated using a decision matrix, shown in Table 3. As seen in Table 3, the 55-gallon steel drum and the horizontal bike wheel turbine scored highest in the decision matrix. However, after performing the engineering analysis and speaking with the project sponsor, the H-WERM team ultimately chose the horizontal PVC turbine as the final design, as shown in Figure 10. Detailed drawings of the major turbine components are included in Appendix 1. Since the wind turbine system will be constructed from recycled and scrapped materials, the part drawings show estimated dimensions for the major turbine components. The estimated cost of this wind turbine system is between \$50 – \$230, based on the availability of used electrical components. Construction of the final system will take place starting in January 2013.

10 References

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"PVC Pipe Size Dimensions, Identification & Pressure Ratings." FlexPVC.com. Web.

Professor Srinivas Kosaraju – Northern Arizona University

Professor David Willy – Northern Arizona University

APPENDIX 1: Details Part Drawings for Major Components

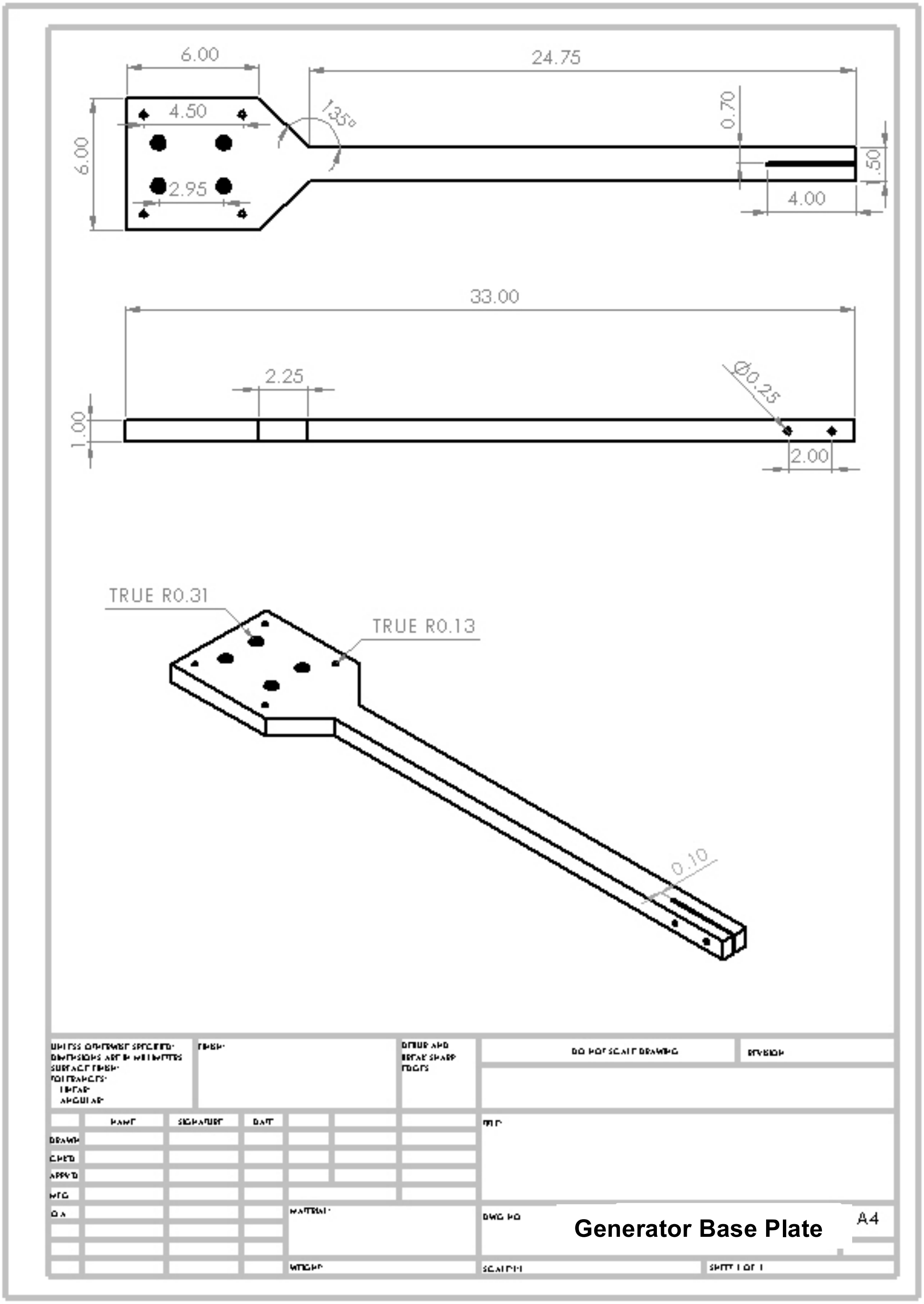

Figure A.1: Generator Base Plate

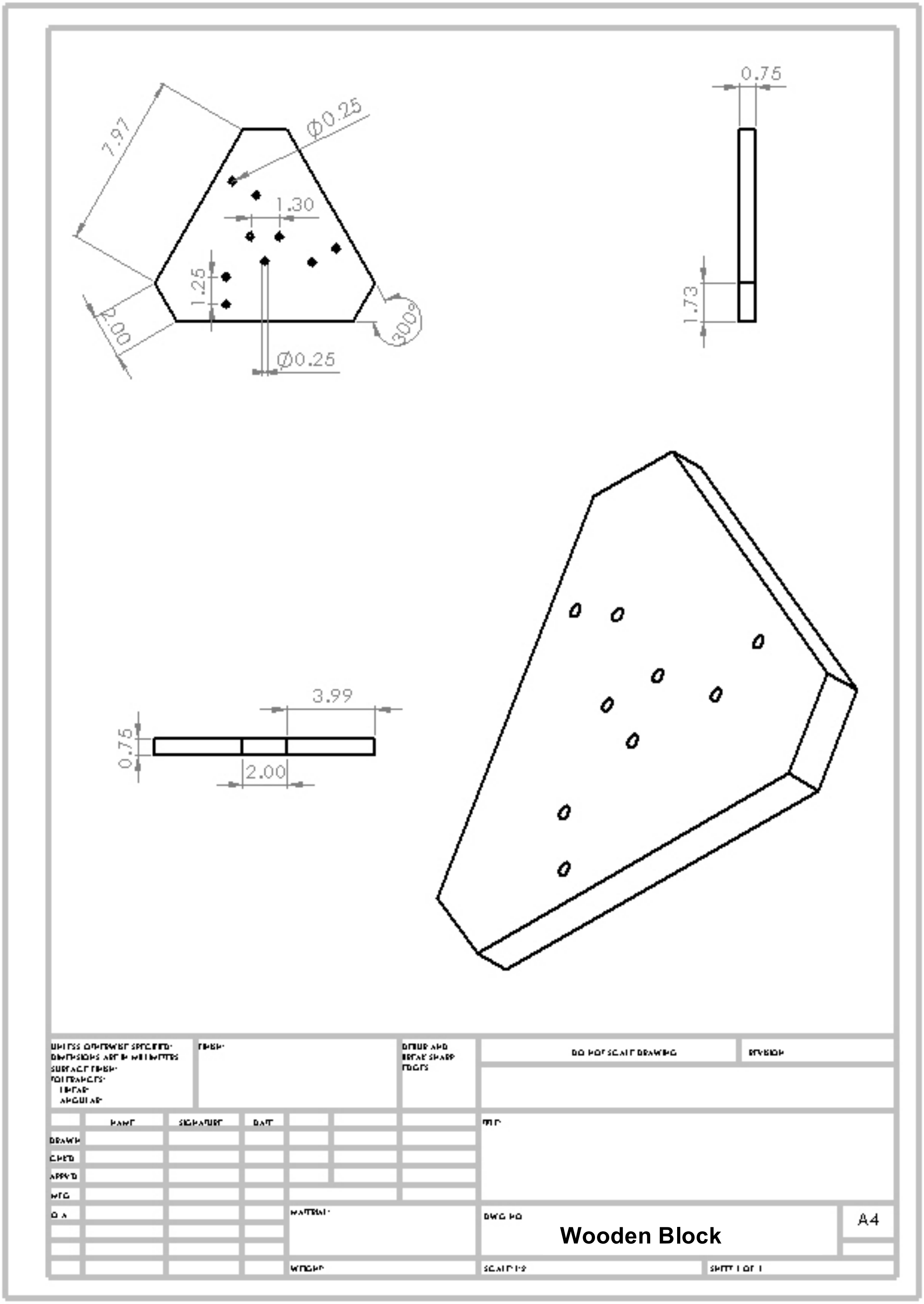

Figure A.2: Wooden Block

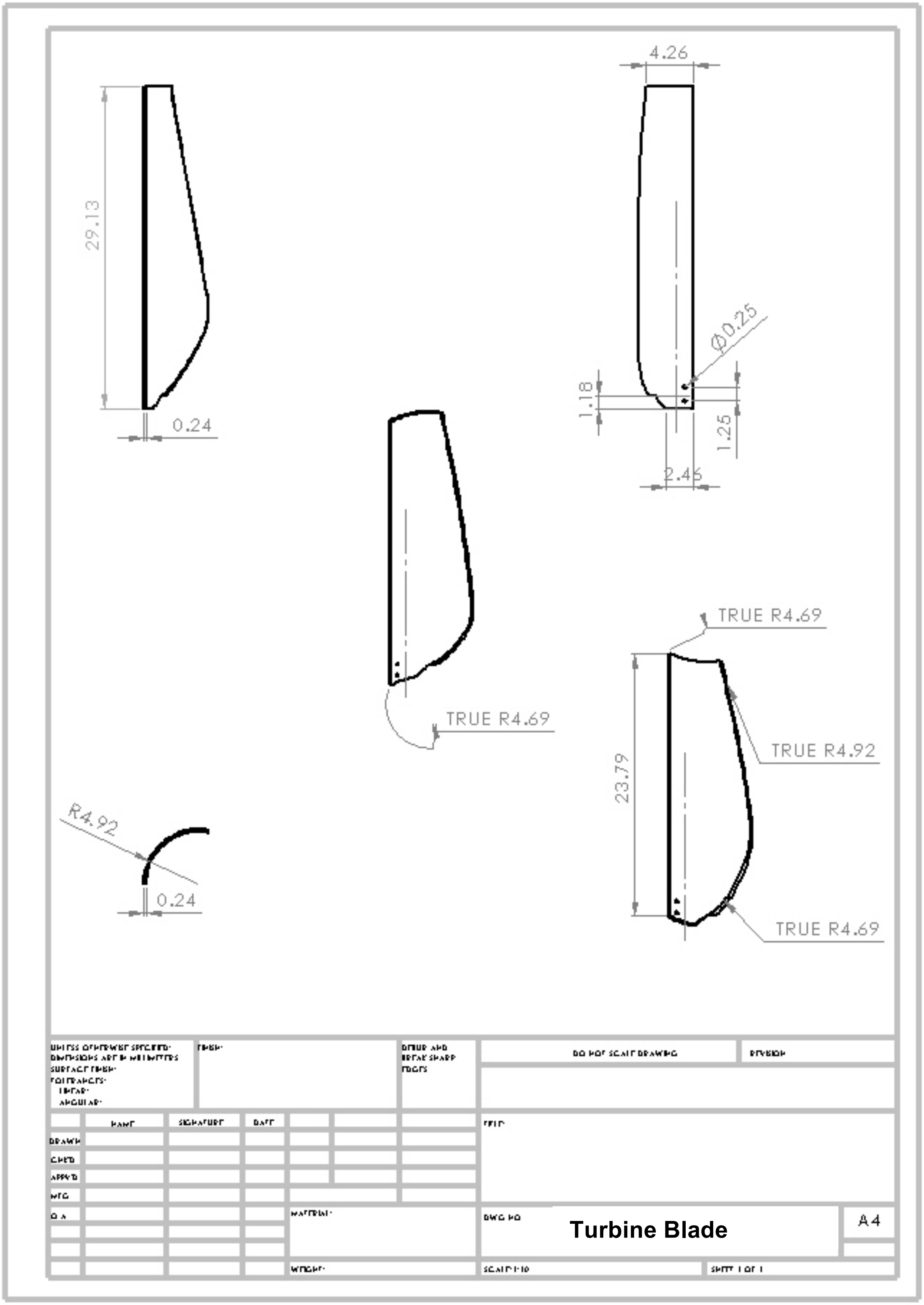

Figure A.3: Turbine Blade

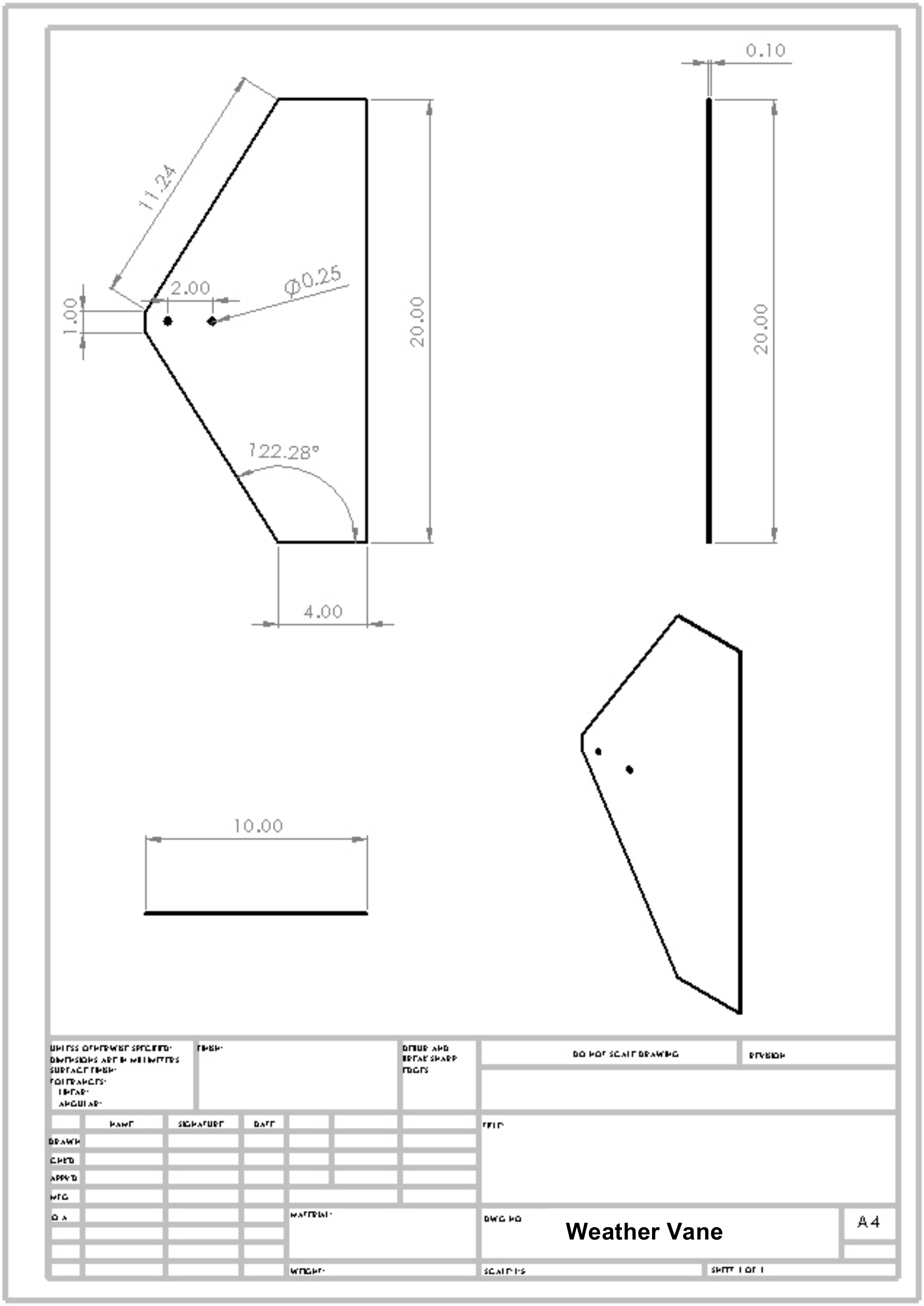

Figure A.4: Weather Vane

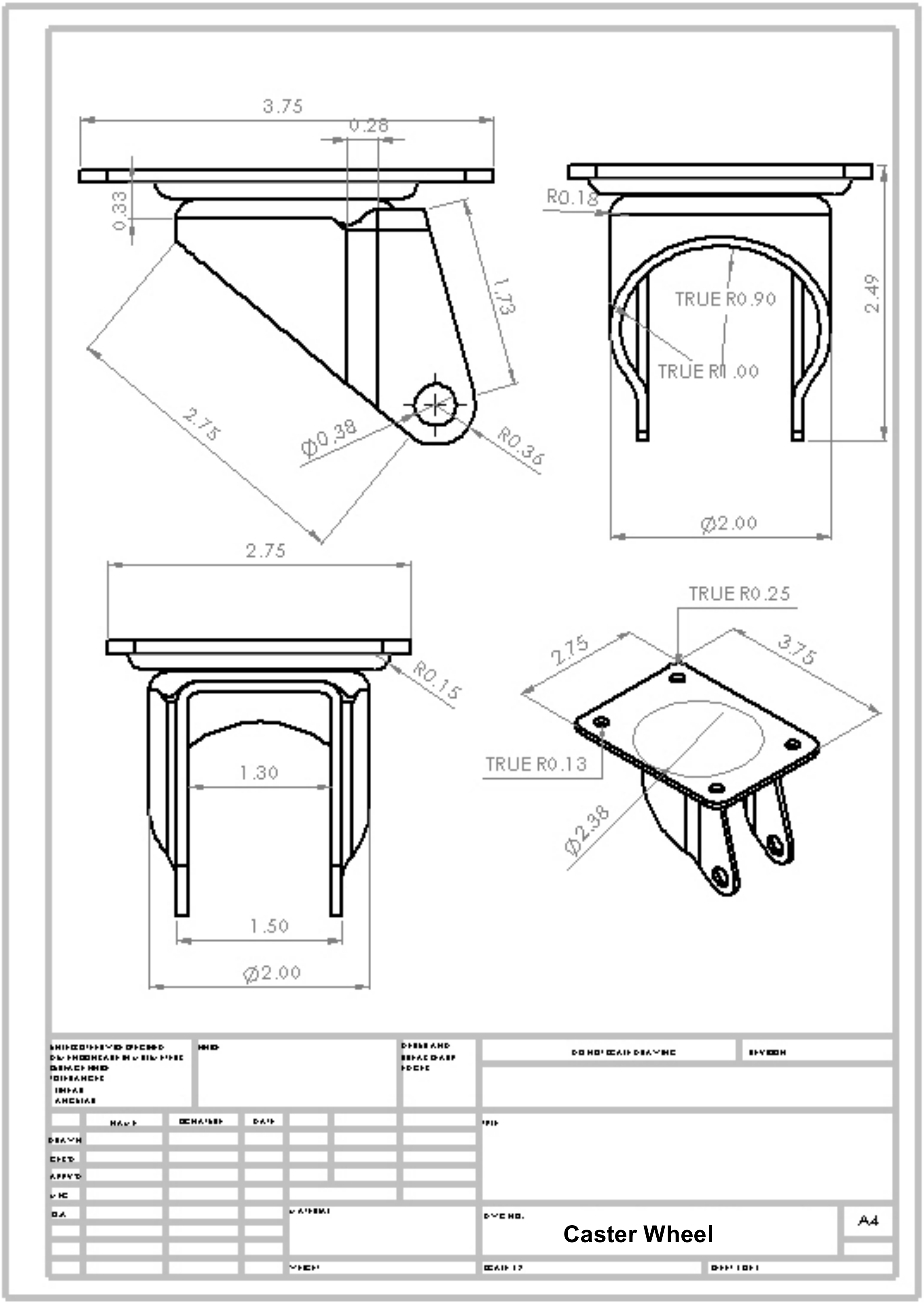

Figure A.5: Caster Wheel