SEATTLE UNIVERSITY

Air In Action

Business Plan and Technical Report
Collegiate Wind Competition 2018

Business Team Members

Clara Cordova (Business Report)
Patrick Curtis (Market Research)
Bayley Guy (Pitch Manager)
Allison Saunders (Business Report)
Kavya Shamnuganatha (Market Research)
Braden Wild (Financials Manager)

Engineering Team Members

Barbara Medina (Project Manager)
Timothy LoPresto (Project Coordinator)
John Nelson (Senior Electrical Engineer)
Andrew Pfund (Senior Mechanical Engineer)
Yahya Alyami (Electrical Engineer)
Ty Huot (Electrical Engineer)
Alisha Piazza (Mechanical Engineer)
Kyle Seeberger (Mechanical Engineer)

Faculty Advisors

Matthew Shields, PhD
Kevin Lybarger, MEE

COLLEGIATE WIND COMPETITION
U.S. DEPARTMENT OF ENERGY

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Executive Summary

Air in Action is a renewable energy company that eliminates the need for diesel generators in remote, off-grid locations by utilizing a combination of easily deployable wind turbines, solar panels, and lead acid batteries. The environmentally conscious nature of our product will enable new projects to avoid restrictions of diesel generators, providing significant value to our customers. Air in Action will offer 6-month to 2-year plus contracts with a flat premium at competitive prices.

The target market for these services are construction sites, housing developments and mining sites with daily energy consumption greater than 400 kWh and a minimum of $1 million in yearly projected revenues across the Western United States. Air in Action will provide a surveying and resource assessment service which will customize turbine siting, hub height, and solar power contribution for each customer.

Air in Action produced a conceptual design of a 3-blade, horizontal axis, 20 kW, direct drive, variable speed wind turbine for use in the specified market. The market turbine uses materials with increased fatigue life, a tilt-up guyed lattice tower, and a small foundation to facilitate the re-deployable and quick installation requirements of the market. The turbines will return briefly to a central warehouse between each short-term project, providing additional maintenance opportunities outside of the field that are not typically available to small wind turbines. Additionally, a 1/25th scale test turbine was manufactured to validate the market turbine design and to evaluate the effects of different design changes on turbine performance.

Contents

1 Business Plan

1.1 Business Overview

Air in Action is a Business to Business (B2B) company offering short term integrated renewable energy systems combining wind turbine, solar panels, and battery energy storage for remote, off-grid locations, including construction sites, infrastructure projects, and exploratory mining sites. Our system offers redundant energy production methods for increased reliability at competitive prices as an alternative to diesel generators and for applications where using diesel generators is infeasible.

Diesel power is inefficient, expensive, noisy, and harmful to the local and global environment. Despite this, it dominates in construction because of its availability, transportability, and stability. Air in Action seeks to replace diesel power on construction sites offering relativity compact solutions that are easily deployable, scalable, and cost-competitive. Benefits of our renewable energy solution include that it produces zero carbon emissions, eliminates diesel fuel tanks and storage, reduces permitting, reduces health and safety insurance premiums, improves air quality, allows for environmental advertising, and is an attractive alternative for environmentally conscious customers.

Our renewable energy solutions will allow many types of projects including mining, quarrying, development, and construction previously impossible or cost prohibitive due to diesel generators, creating dramatic operating cost savings and new profit-making opportunities for customers. Air in Action will also target off-grid sites that have temporary power needs for a typical 2-year period where permanent wind turbine installations are not normally viable. Using this business model, we project a 9-year breakeven point with fully depreciated equipment.

1.2 Business Model

Air in Action is a B2B service offering 6-month to 2-year plus leases of easily deployable renewable energy solutions for customers that require environmentally-friendly solutions to operate under their customized energy load profiles. These off-grid solutions offer the same grid independence as diesel generators while keeping sites as environmentally pristine as possible and generating sufficient energy, which only diesel generators are currently able to do. By utilizing third party distribution, well maintained turbines, and innovative and robust turbine design, we will provide customized renewable energy solutions to meet customers' unique energy needs. No wind turbine-focused competitors or utility companies currently offer a comparable product in the United States.

Air in Action is using a single channel leasing service targeted at the Western United States to drive sales from off-grid sites. The Western United States was selected as our initial target market because it had the highest mineral and energy production in 2016[1]. Additionally, steady growth in the region's construction sector, increased numbers of environmentally conscious business and customers, and harsher regulations on fossil fuel usage make it an appealing market. We will utilize regional third-party logistics partners to help distribute our product to off-grid locations. We will focus on locations that are unable to operate because of diesel generators impact on the permitting process, including mining, sensitive construction sites, and environmentally fragile sites with sustained energy needs ranging from a 400 kWh to 600 kWh average daily load for lighting and construction equipment per installed unit. The permitting process is challenging for many companies that operate in environmentally sensitive areas due to the pushback from environmental groups and local government. If companies were able to offer an alternative to the noisy,

[1] Demas, Alex. "The Top 5 Mineral-Producing States." Department of the Interior, U.S. Geological Survey, Apr. 14, 2017.

dirty, and polluting diesel generators at a competitive price point, these permits would not get the same kind of pushback they would otherwise get with a diesel generator, allowing firms to operate in areas that they would otherwise not be able to. For sites with higher energy needs, multiple units could be installed to scale the energy production and build redundancy into the system. We will deploy two horizontal-axis 20 kW wind turbines as well as scalable solar voltaic arrays to match customers energy profiles and site conditions (windspeed, solar irradiance, etc.) with battery storage solutions supporting up to 600 kWh daily consumption. Wind turbines will be supported with temporary, quickly installable and removable small concrete support bases and guy wires.

Our wind/solar solution comes in the form of a three-part system, one-part battery, one-part solar, and one-part wind turbine, the ratios of which will be decided on a site-by-site basis by our siting team. Our turbine will be a horizontal-axis, three-blade turbine with a variable speed generator supported by a passive yaw system. Our turbine tower will be based on a tilt up system, which will allow us to save money on installation and decommissioning of the wind turbine by avoiding renting a crane for each installation. See Sections 2.1-2 for further detail about the market turbine design.

Air in Action's re-deployable solution offers a consistent energy solution with competitive pricing factoring in holistic operating costs, additional set up, and associated risk with diesel generators. Most wind turbine solutions are designed for 15-20 years of use at one site, and there are limited opportunities for temporary sites to take advantage of wind energy. Our approach allows us to charge competitive rates compared to existing diesel generator solutions through leasing while also reducing the maintenance costs with our innovative design that eliminates environmental impact compared to diesel generators.

We are confident in our ability to build and expand our customer base as we gain a reputation over the next 5 years. We also expect to build healthy cash flow and manageable expenses as we scale the business up over the next 5 years. In expanding our operations, we anticipate seeking asset-backed debt to finance the purchasing of 20 kW turbines, solar panels, and batteries. The institutional partner debt market has been expanding since the early 2000's to increase the availability of debt financing, but it remains a major risk for our business. We have used the industry standard of 10% return on investment over 10-year loans to finance the acquisition of our capital equipment and anticipate paying off all debt by end of year 7 and having positive returns on investment.

Throughout the investment period, Air in Action has maintained an average debt to equity ratio of 2.72. While this is above the industry standard, we project strong cash flows without a need to seek additional financing after year 3 to fund new capital equipment acquisitions that help mitigate this risk. Despite having a higher debt ratio, we will reduce the Return on Investment (ROI) for paying the loans down to 7 years versus the traditional 10 to 12 years by ensuring we purchase enough capital equipment to grow our customer base.

Our key cost drivers will be assembly and disassembly of the wind/solar solution onsite, recurring maintenance, depreciation costs, and financing the upfront capital equipment (wind turbines, solar panels, and batteries). We will mitigate these concerns by conducting the majority of maintenance during redeployment time to lower maintenance costs, prioritize paying down debt, and investing in high quality materials.

1.3 Market Opportunity

The last 20 years has seen massive growth in the US wind sector, representing roughly 6 percent[2] of all utility scale energy in the United States. This has been primarily driven by large commercial wind farms with limited residential growth. To date, no firm has implemented leasable and removable wind turbines necessary to offset the energy profile from 400 - 600 kWh diesel generators that are typically required at off-grid locations. This market remains largely untapped with few firms operating in this space. With rural development and exploration increasing in the United States, Air in Action has a growing target market that is actively seeking an alternate to diesel-based power and options that allow for development in environmentally sensitive sites.

Air in Action targets infrastructure and off-grid location contractors who depend on large amounts of energy for their projects. Air in Action's product provides contractors with the benefits of marketing themselves as environmentally-friendly and conscious of social impacts while decreasing their expenses. Our renewable energy is not dependent on fluctuating diesel prices, are cost effective, and create long term savings.

1.4 Competitive Advantage

Air in Action is using existing transportation infrastructure with innovative highly mobile wind/solar solutions to meet the reliable energy needs of off-grid locations. We will be leasing affordable wind/solar solutions at comparable rates to diesel generators accounting for diesel costs and maintenance.

We face some competition from hybrid generator companies that seek to reduce diesel consumption, but do not entirely replace them. Companies such as Firefly Construction (based in the UK) offer a hybrid diesel and wind energy solution, Bergey Energy provides off-grid residential wind turbines not typically for commercial applications and Fortis Wind Energy supplies three different kinds of off-grid turbines but lack sufficient scale and power generation for larger construction sites.

1.5 Sales & Marketing Strategy

We will target sales to the Western United States with a receptive customer base focused on environmental solutions and reducing diesel usage. We can charge a premium to replace current generators while providing reliable energy solutions, saving firms money, and reducing carbon emissions. We will utilize industry presentations, tradeshows, and advertising to construction firms to off-grid locations to create staged growth in the Western United States over the next 5 years. We also intend to use the advantages green power brings to the permitting process in our marketing and sales opportunities. Many firms have a difficult time being awarded diesel generator permits on public land and in environmentally fragile areas. This is where our solution eliminates emission concerns, allows new projects to move forward and allows firms to market the reduced emissions. We are seeking up to 90 single year contracts by year 5 with 6-month, 1-year, and 2-year leases filling a niche in the US construction industry. We plan to do this by allowing a new group of construction, renovation, and mining projects to occur that were previously environmentally restricted or were not financially feasible to deploy alternative solutions. By focusing channel sales at sensitive or previously rejected off-site locations we can create a new niche in an established market disrupting the diesel rental market by focusing on customers wanting to gain energy certifications and reduce environmental impact while still being financially attractive. By focusing channel sales at off-site grids, we can create a new niche in an

[2] "Electric Power Monthly" Department of Energy, U.S. Energy Information Administration, March, 2018.

established market, disrupting the diesel rental market by focusing on customers wanting to gain energy certifications and reduce environmental impact.

1.6 Management Team

The management team that Air in Action has is composed of mechanical engineers, electrical engineers, energy resource siting experts, skilled mechanics, and a leasing sales force team that allows us to deploy the wind/solar energy solutions with corresponding batteries and create a niche in the market. This includes:

Chief Executive Officer: In charge of strategic direction of the company and overall vision

Chief Mechanical Officer: In charge of overall operation of energy solutions

Chief Financial Officer: In charge of company finance and associated tasks

Head of Sales: Manages sales team doing business outreach and promotional channels

Maintenance Coordinator: Maintenance of the integrated wind/solar system, ensure efficient use of down time and training for employees

Logistics Coordinator: Manages set up and deployment of the energy solutions

Head of Engineering: Overall design and creation of the mobile energy solutions

1.7 Development and Operations

Air in Action will be contracting local Pacific Northwest firms to build 20 kW wind turbines brought to our central location to serve the Western United States. We will use locally produced solar panels to reduce shipping costs and allow for continued contract maintenance. High quality industry standard lead acid batteries will be imported from Germany to ensure maximum reliability and recharge rate for our integrated renewable energy solution capable of receiving power from both wind and solar solutions.

Partnering with the Seattle University School of Science and Engineering we will sponsor senior design projects to improve maintenance and iteratively improve our maintenance schedule and improve the reliability and redundancy in the renewable energy solution.

We have allocated a robust 22% yearly O&M budget benchmarked against industry averages for 20 kW turbines that are traditionally very difficult to perform maintenance on due to the height of the turbine, the stress placed on the blade and the fixed nature of the turbine. Our model of short term deployments with an average of 1-2 years of use will allow for more routine maintenance to be conducted on the wind turbine blades for wear and tear when they return to the warehouse between deployments, increasing the useful time and reducing the associated costs. With an average of 10 to 15 redeployments over the lifespan of the wind turbine ample preventive maintenance can be conducted, efficiency of the turbine will be improved, and the output of energy wind turbine will be run more consistently and reliably.

Our turbine has been designed with fastening and a support structure created to be taken apart easily without damaging the shaft, blade, or structure and to allow for transport. More robust and fatigue resistant materials will be used to extend the useful life of the turbine. By hiring additional staff to be on site for deployment and re-deployment, to perform maintenance, and paying for premium ample accident/weather insurance, we will ensure coverage while providing a high quality integrated renewable energy solution.

1.8 Financial Analysis

Air in Action has constructed a robust 5-year Profit & Loss assessment and cash flow analysis to determine how much capital will be needed for the business, the gross margin, and the profit margin of the business. Currently we are projecting a long run gross margin after year 5 of 40% and a 25-26% profit margin. Growth after year 5 will be organic with cash flows from existing rentals driving the number of new renewable energy solutions purchased alongside customer demand with debt-to-equity ratios at or below the industry standard of 1.7 compared to the current average of 2.7 during the startup phase of the company.

This estimate accounts for accurate costs of running a leasing service for the renewable energy solutions with accompanying fees for removal of noise and pollution from diesel generators, upkeep costs, and our $50,000 flat fee per site charged as an expense for allowing new projects to be created in sensitive environmental regions. This fee is unique in the industry but still represents a win-win for Air in Action by increasing profitability and customers by allowing for previously infeasible projects to be started. More information on detailed income statements can be found in Appendix A.

Summary Financials

Table 1: Consolidated Income Statement (in 1000's of Dollars)

Year	2019-20	2020-21	2021-22	2022-23	2023-24
Revenues	$ 1,376	$ 6,399	$ 12,712	$ 23,595	$ 25,639
Operating Expenses	$ 3,748	$ 3,586	$ 8,105	$ 9,182	$ 9,751
Capital Expenses	$ 2,053	$ 6,480	$ 11,045	$ 16,200	$ 5,575
Gross Margin	$ (4,390)	$ (3,666)	$ (6,437)	$ (1,785)	$ 10,313
Interest and Tax Expense	$ 94.32	$ 1,081	$ 2,437	$ 3,263	$ 3,616
Net Profit	$ (4,485)	$ (4,748)	$ (8,875)	$ (5,048)	$ 6,696
Gross Margin %	-319%	-57%	-51%	-8%	40%
Net Profit %	-326%	-74%	-70%	-21%	26%

Revenues: Reflects annual rental fees including opportunity costs, diesel fuel costs, diesel generator rental costs, built in to help acquire customers, and environmental fees. Includes 3% rental discount cost to acquire customers, federal wind and solar energy tax breaks with annualized rental rates.

Operating Expenses: All expenses have 3% annualized inflation, Seattle area labor costs for full time non-maintenance 13 to 15 employees, warehouse rental, 12 to 20-year depreciation expenses, 22% annual maintenance expense, integrated renewable energy solution construction or purchasing costs, insurance set at 5% of construction costs, employee travel, installation costs at $9,000 per transfer, advertising set to 5% of revenue, capital debt servicing, and 3% purchasing discounts.

Capital Expenses: Holistic purchasing costs for 2, 20 kW wind turbines per deployed site at $5,900 per kW, 30 kW Solar panels for each solution at $3,000 per kWh, and a 400 kWh lead acid battery at $300 per kW.

Interest and Tax Expenses: Set base repayment schedule to pay back principle of loan over 10-year period with $10,000,000 loan in 2019-20 and a $13,500,000 loan in 2021-22. Tax rate with no state income tax set at 10% of revenue.

Table 2: Statement of Cash Flows (in 1000's of dollars)

Year	2019-20	2020-21	2021-22	2022-23	2023-24
Starting cash	$ -	$ 5,515	$ 767	$ 5,391	$ 342
Net Profit	$ (4,485)	$ (4,748)	$ (8,875)	$ (5,049)	$ 6,696
Asset Backed Loan	$ 10,000	$ -	$ 13,500	$ -	$ -
Free Cash Flow	$ 5,515	$ 767	$ 5,391	$ 342	$ 7,039
Remaining Debt	$ 9,000	$ 8,000	$ 18,359	$ 15,218	$ 12,077
Retained Depreciation funds	$ 125	$ 662	$ 1,914	$ 4,224	$ 6,956

Starting Cash: Includes retained funds from last year as the carry over for free cash flow

Asset Backed Loan: Both are institutional asset back loan over 10 years with a 10% interest rate

Free Cash Flow: Combined Net Profit and asset backed loans issued in that given year

Retained Depreciation Funds: Represents flat line depreciation at 10 years for the battery solution and 20 years for the wind turbines and solar panels.

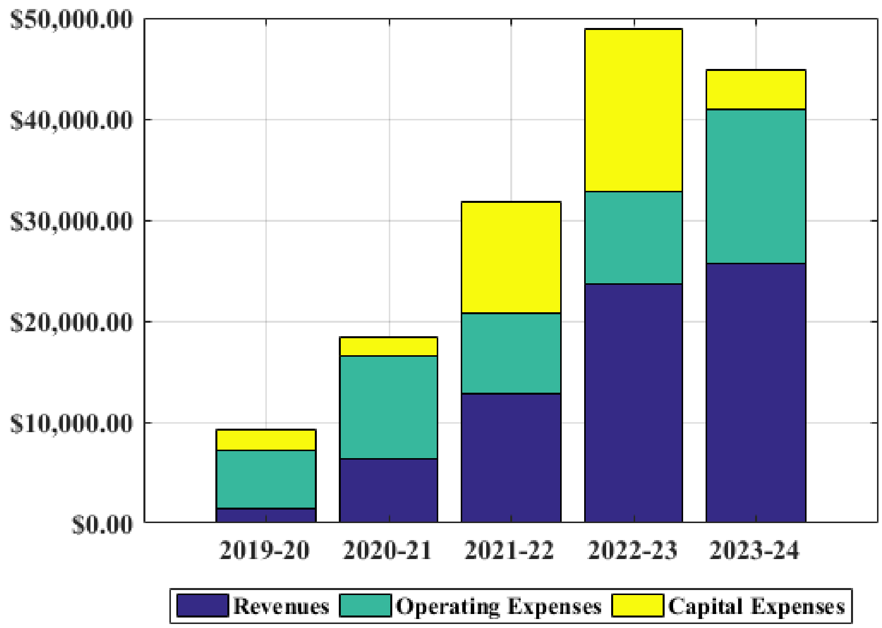

Figure 1: Yearly Revenues, Operating Expenses, and Capital Expenses (1000's of dollars)

2 Technical Design

2.1 Market Turbine Design Objectives

This section will focus on a conceptual level design of the three-blade, horizontal-axis wind turbine discussed in Section 1 and how the design supports the business model. Table 3 shows general specifications for the turbine. The main design objective was to match the load demands of infrastructure and off-grid locations contractors outlined in Section 1.2. The AEP of each turbine will meet a minimum threshold of 40 MWh to be fiscally viable. The secondary driving object is production cost. The short-term projects that Air in Action is targeting involve a large degree of non-typical wear and fatigue on the system from repeated construction, disassembly, and transport. Additionally, due to the short deployment of these turbines, the installation and removal times and cost need to be minimized. The turbine must operate at its maximum power coefficient over a variety of wind speeds because wind regimes will vary by site location.

Table 3: Market Turbine Specifications

Parameter	Value
Rated Power at 11 m/s	21.35 kW
Required AEP	40 MWh
Cut-in Wind Speed	3 m/s
Blade Diameter	10 m
Lifespan	20 Years
Maximum Wind Speed	20 m/s
Yaw System	Passive
Pitch System	Fixed

2.2 Market Turbine Conceptual Design

Market Turbine Blades

The blade design team selected Selig and Giguere's SG6040 airfoil to serve as the baseline airfoil due to its relatively large thickness to chord ratio and low camber. SG6040 meets both the structural strength requirement of the market turbine and the efficiency requirement for small-scale turbines. The chord-position and twist-position distributions of the blade are detailed in Figure 2.

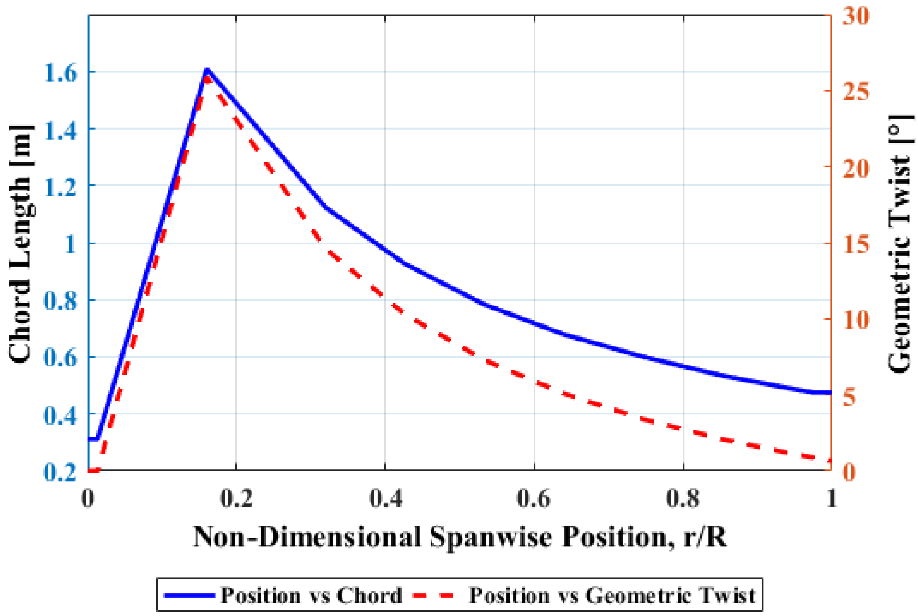

Figure 2: Chord-position and twist-position distributions for final blade design

QBlade, an open-source wind turbine design software, was utilized for the computational aerodynamic analysis of the Air in Action turbine. The conceptual QBlade analysis yielded the coefficient of power and tip speed ratio curve (C_p-λ) curve presented in Figure 3. The coefficient of power (C_p) is the ratio of the captured mechanical power and the available power of the wind. The tip speed ratio (λ) is the ratio between the tangential speed of the tip of the blades and the upstream wind speed.

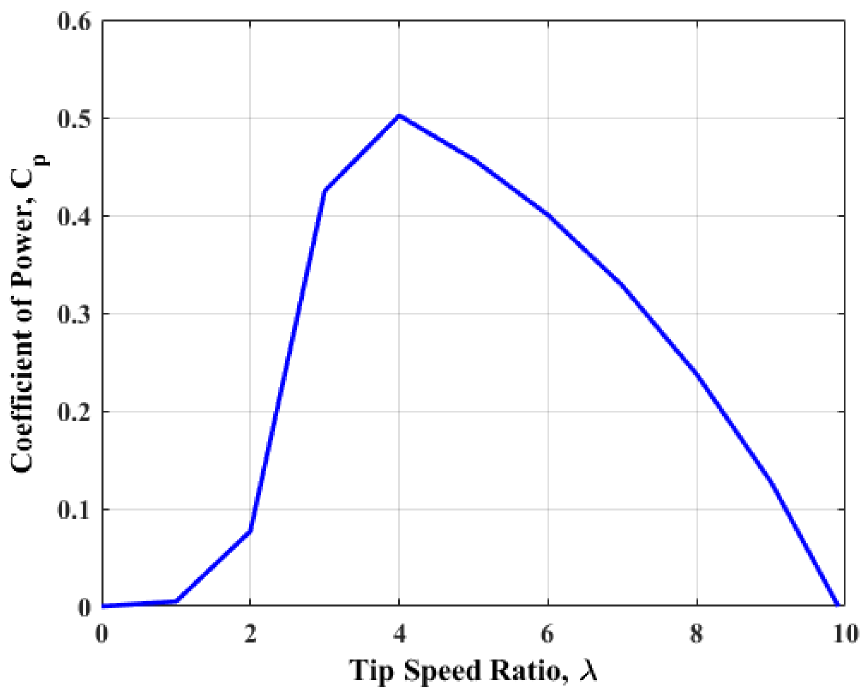

Figure 3: QBlade aerodynamic C_p-λ performance curve

The market wind turbine will use a steel, guyed, tilt-up lattice tower. The turbine features a passive yaw system and fixed-pitch blades because it is the most design- and cost-effective solution. A custom-designed, permanent magnet generator will be used. A permanent magnet generator was selected because it can operate in islanded mode. Additionally, a direct-drive mechanism will be used to reduce manufacturing and maintenance costs and reduce transmission losses. The turbine will be variable speed and use stall regulation methods to regulate power because the blades are fixed pitch. A mechanical brake will stop the rotor during fault conditions.

A static performance analysis of the QBlade model yielded a computational aerodynamic power curve of the market turbine. The purely aerodynamic analysis is an insufficient indicator of the overall turbine performance as it neglects both mechanical and electrical system losses, as well as non-ideal wind flow. Instead, the output power between the rotor shaft and the connection to the electrical load was selected as the main static performance analysis parameter. As a result, the computation of a correction factor to include system losses in the computational QBlade power curve was necessary.

The Air in Action market turbine is similar to the commercial 20 kW Polaris P-10-20 turbine[3], in terms of rotor diameter, operational rotational speed, and rated power. Field testing data of the P-10-20 turbine served as a rough experimental estimate of the market turbine's real-world performance. The market turbine aerodynamic power and the Polaris operational power were compared for 11 wind speeds to determine an average correction factor of 0.60. The correction factor was applied to the market turbine QBlade results to yield a more realistic power curve seen in Figure 4. The correction yielded a rated power of 20.6 kW at the rated wind speed of 11 m/s.

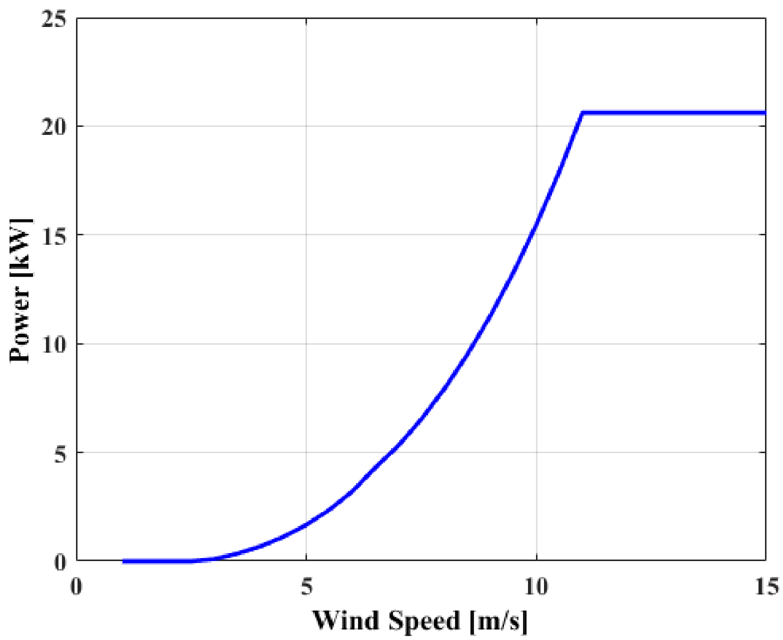

Figure 4: Variable speed power curve (power delivered from generator)

Figure 5 displays the market turbine's calculated annual energy production (AEP) for a range of average wind speeds, assuming the proposed site's wind resource adheres to a Rayleigh distribution. This AEP

[3] Model: P10-20 Wind Turbine Technical Specifications. Polaris America.

was plotted against average wind speed to graphically display the minimum thresholds of a fiscally viable site. The minimum average wind speed for a proposed site is 5.7 m/s, which yields an AEP of 40 MWh.

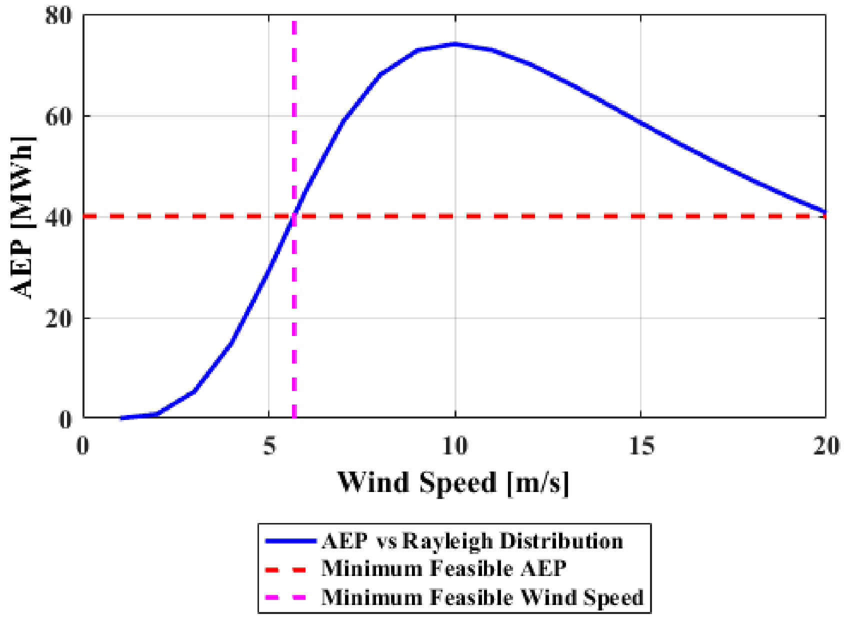

Figure 5: AEP vs Rayleigh Shape Factor

2.3 Test Turbine Design Objectives

A small-scale prototype of the market turbine, the "test turbine," was built to validate the conceptual market turbine design. The available wind tunnel and desired experimental results mandated that the test turbine satisfied the following requirements. Not all requirements are listed, but those listed were the primary requirements that drove the design.

1. Rotor and non-rotor turbine parts must be constrained to the size of a cube with 45 cm sides.
2. The turbine must withstand sustained wind speeds up to 20 m/s.
3. The turbine must yaw at rates up to 180°/s.
4. The turbine must deliver DC voltage to the load.
5. The voltage must remain below 48V at all times.
6. No batteries or excessively large capacitors may be used.
7. The turbine must be able to shut down both manually and due to an electrical load disconnect.
8. The turbine must be able to start in islanded mode.

2.4 Test Turbine Variations

Where possible, elements of the test turbine were made identical to the market turbine. However, due to unavoidable scaling difficulties such as maintaining the same Reynolds number for the full-scale turbine, and impractical or unnecessary scaling difficulties such as making the test turbine blades out of fiberglass, some variations between the two turbines were necessary. Table 4 outlines the major similarities and differences between the test and market turbines. While the test turbine is not a perfect model of the market turbine, it provides useful insights into the expected performance of the full-scale market turbine and it enabled us to rapidly and economically assess the effects of design alterations. Improvements to the test turbine will continue to be made to increase its performance and the validity of the test results compared to the expected market turbine performance.

Table 4: Comparison of market turbine and test turbine elements

Component	Market Turbine	Test Turbine	Justification of Difference (If Applicable)
Turbine Axis Type	Horizontal Axis		
Number of Blades	Three (3)		
Airfoil	SG6040		
Generator Type	Permanent magnet, 3-phase		
Control	Stall regulation using generator current control		
Yaw	Passive		
Pitch	Fixed		
Scale	Full-scale	1/25th of market turbine scale	Wind tunnel size constraints
Transmission	Direct Drive	Geared	Off-the-shelf generator selection prevented a direct drive system
Speed	Variable	Fixed	Small scale system does not have wind speed sensors or control capability
Over speed Protection	Furling	Dump Load	Unnecessarily moving mechanical parts are impractical at small-scale
Storage Element	Lead Acid Battery	Capacitor	Capacitor charge and discharge time reduced overall testing time
Reynolds Number [Root, 75% Span, Tip]	$[6.0 \times 10^5, 1.0 \times 10^6, 1.5 \times 10^6]$	$[4.2 \times 10^4, 5.7 \times 10^4, 6.0 \times 10^4]$	Reynolds numbers could not be matched at the small-scale, tip speed ratios were matched instead
Blade Material	Fiberglass	SLA Resin	Stereolithography (SLA) was sufficient for the design requirements of the small-scale blades and were faster and cheaper to manufacture
Tower Material	1024 Steel	6061 Aluminum	Aluminum was sufficient for the design requirements of the small-scale turbine, was less expensive, and was easier to manufacture
Tower Type	Tilt-up Guyed Lattice	Fixed Base Tubular	Sufficient for design requirements of the small-scale turbine, requirements of attaching to the wind tunnel

2.5 Market Turbine and Test Turbine Scaling Procedure

The test turbine was scaled to 1/25th the size of the market turbine, which made matching the two turbines through complete similarity impossible. Reynolds numbers could not be matched between the turbines due to competing effects with the tip speed ratio. Instead, tip speed ratios were matched between the turbines as this provided testing results that were most representative of the market turbine performance.

2.6 Test Turbine Mechanical Systems

A rendering of the assembled turbine is shown in Figure 6. An assembly drawing and mechanical drawings of all major components are in Appendix B.

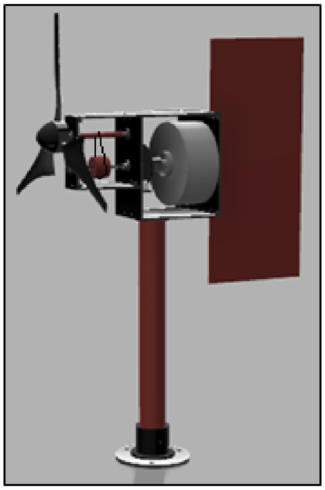

Figure 6: Test Turbine Assembly

Nacelle

The main body of the nacelle (Figure 7) was manufactured out of sheet aluminum due to its ease of manufacturing, relatively low density and cost, and strength, which was particularly a concern to support the generator. The back plate of the nacelle was required to be large to support the generator, but the nacelle narrowed toward the front to reduce drag. The sides were left open to reduce the weight and cost of materials and to facilitate heat dissipation.

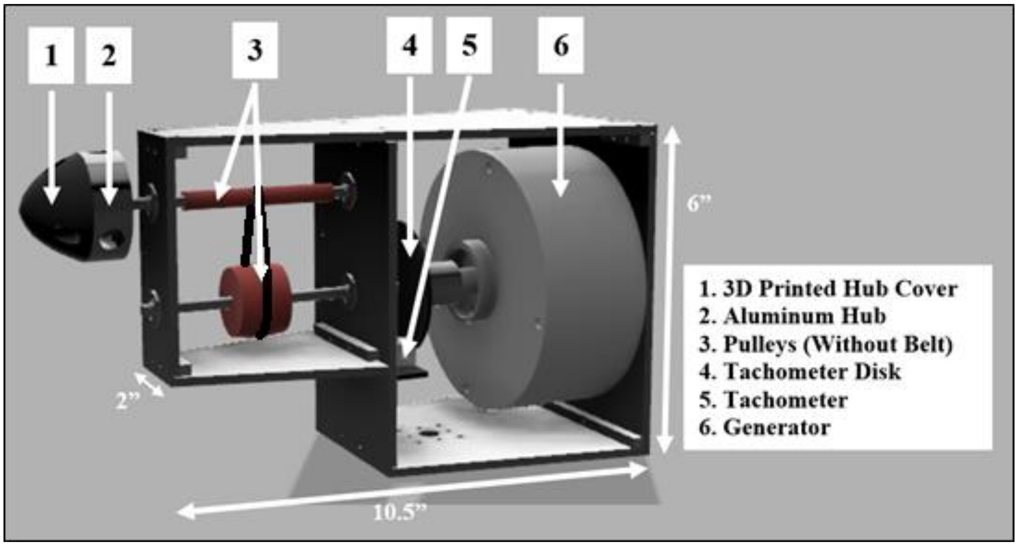

Figure 7: Conceptual test turbine nacelle design

The hub consists of three parts. The aluminum part of the hub (Figure 7, 2) is made of two identical parts (Figure 8) that face each other and secure the blades and it is capped by a 3D printed part to reduce drag (Fig. 7,1). The hub is directly threaded onto the shaft to reduce energy losses between the blades and shaft.

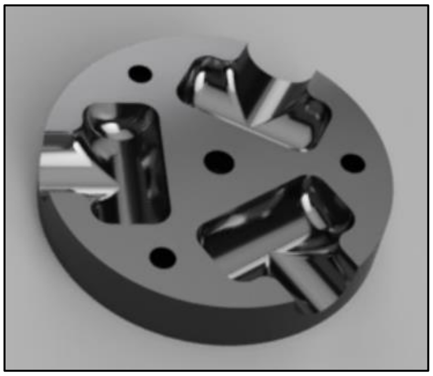

Figure 8: Aluminum hub part

While the market turbine will use a custom-designed generator and will be direct-drive, the test-turbine used an off-the-shelf generator and a pulley system (Fig. 7, 3) to match the rotor and generator speed ranges. In general, the blades spin faster than the generator can handle, so the rotational speed from the shaft connected to the blades to the shaft connected to the generator was geared down. This design was favorable because it reduced starting torque, and therefore reduced cut-in wind speed. The primary gear ratio used in testing was 1:4, but improvements are expected with an increase in gear ratio. Pulleys were used instead of gears because they are easier, faster, and cheaper to manufacture; do not come in discrete sizes and are therefore customizable; and they offer more slack in assembly. Knurling finishes and epoxy were utilized to minimize energy losses due to slipping.

Further information about the tachometer, disk, and generator (Fig. 7, 4-6) can be found in section 2.7.

Yaw

A passive yaw system consisting of a large piece of sheet metal and a flange attached to the nacelle that rotated within the tower. A notch was cut out of the flange and a bolt was placed through the tower that lined up with the notch as a safety mechanism to prevent the nacelle from lifting out of the tower. Electrical connections from the nacelle were fed through the hollow flange and tower with sufficient slack for 720° of rotation. This yaw system provides a representative model for the market turbine's similar passive yaw system.

2.7 Test Turbine Electrical Analysis

The electrical systems described in this section pertain exclusively to the test turbine. These systems allowed the test turbine to be tested under different conditions to validate the development of the market turbine design. The electrical system for the test turbine can be divided into three main sections: Load, Dump Load, and Storage Element. Each will be referenced in the analysis along with their corresponding resistors, R1, R2, R3; MOSFETS, M1, M2, M3; and DC/DC converters, DC/DC (1), DC/DC (2), and DC/DC (3) as shown in Figure 9. The test turbine's electrical system converts the AC power into DC with a rectifier. The input voltage range at the DC link, generated by the turbine, varies from 0 V – 35 V. The output voltage at the load is regulated to 5 V with the use of DC/DC converter. Each component had a current rating of at least 10 A.

As shown in Figure 9, the test turbine includes power electronics that converts the variable frequency, variable amplitude AC of the generator to a fixed DC output, which is achieved with a DC/DC converter output stage. The market wind/solar solution will include power electronics that output 60 Hz 120/240 VAC, which will be achieved with an inverter output stage. The test turbine stores energy by charging a capacitor using a pulse width modulation (PWM)-based charge controller. The market wind/solar solution will store energy in lead acid batteries, using a battery charge controller. For the market turbine, the wind turbine and the photovoltaic arrays will be able to provide power to the load and the battery depending on demand and battery charge. The load will be supplied by the wind, solar and battery depending on the environmental conditions.

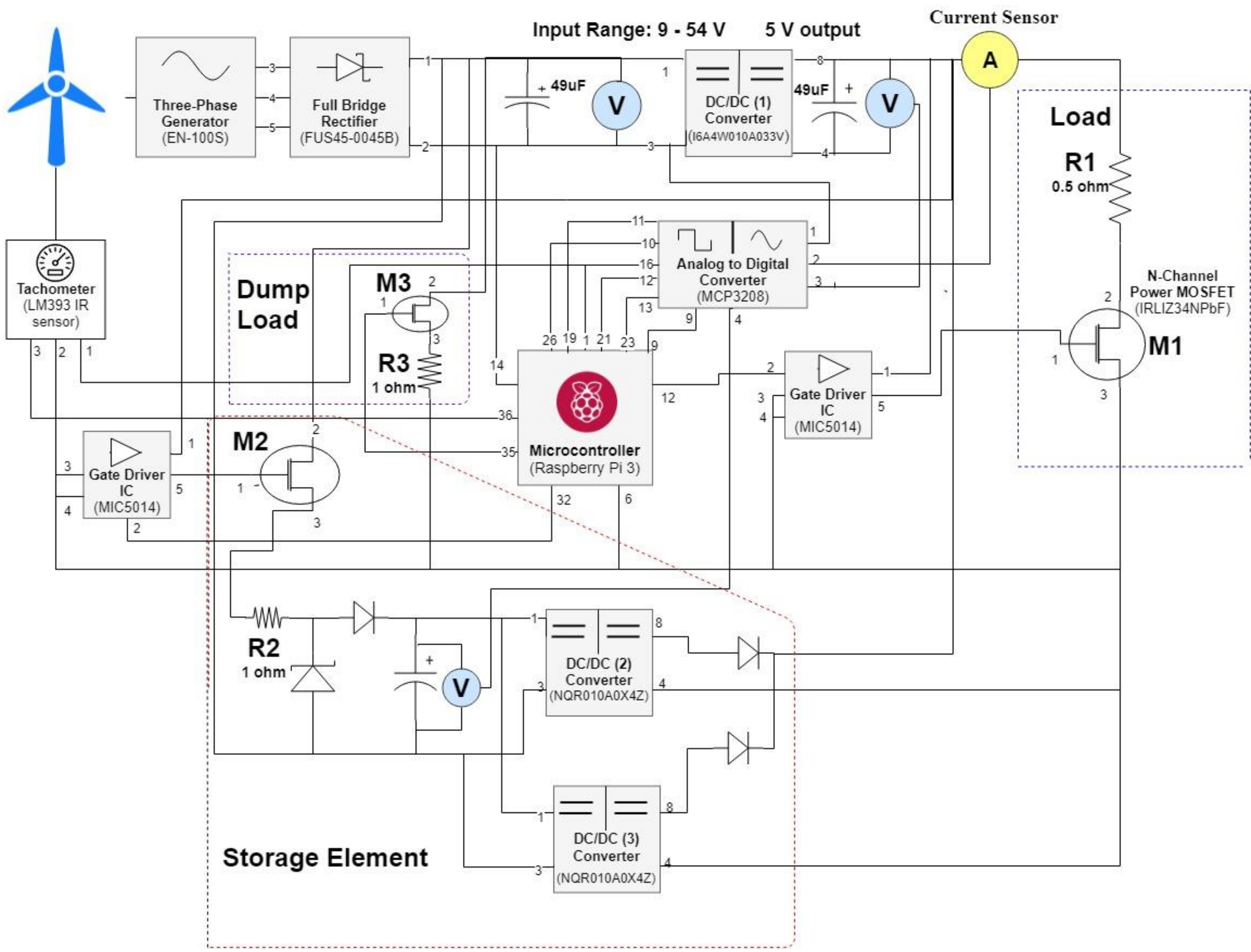

Figure 9: Electrical One-Line Diagram

Generator

A permanent magnet generator (PMG) was selected for its ability to operate in islanded mode. The PMG model selected for the test turbine has a rated speed of 700 RPM, rated output voltage of 24 V, rated power of 100 W, and starting torque of 0.08 N-m.

Rectifier

A full-bridge Schottky three-phase rectifier was selected to convert the variable frequency AC out of the generator to DC. This was an ideal rectifier since its diodes have a low forward voltage. Therefore, the overall voltage drop across the component was only about 0.6 V. A smoothing capacitor was added to filter the rectifier output, so the input to the DC-DC converter was more consistent.

DC/DC converter

Two types of high efficiency DC/DC converters were used in the system. The primary function of the DC/DC converter was to maintain a constant 5 V at the load. DC/DC (1) has an input voltage range of 9 V–54 V. DC/DC (2) and DC/DC (3) found in the storage element section, have input ranges of 4 V-14 V.

Microcontroller

The Raspberry Pi 3 was selected as the microcontroller because of it high processing speed, wide range of communication protocols, energy efficiency, low cost, and quantity of software libraries. The wiringPi library, developed in C, was used create programs in the Raspberry Pi 3.

Sensors

Three sensors were used in the system. First, a LM393 IR sensor was used as a tachometer to measure the rotational speed of the turbine. An analog to digital converter, was used to measure different voltages in the system. It was also used in conjunction with a current transducer, LTS 15-NP, to measure the load current.

MOSFET

Three N-channel Power MOSFETs were implemented in the system: M1, M2, M3. The primary function of the MOSFETs was to control the generator current. All the MOSFETs were driven by a gate drive integrated circuit (IC), MIC5014, and the PWM signal for each MOSFET was generated by the Raspberry Pi 3.

Load

Rotor speed is controlled by manipulating the generator current. The sources of generator current include the current in the load (R1) and dump resistor (R3) and the flowing to the storage element. When the load current can be controlled to match the turbine output, the load is a fixed resistor, and the MOSFET (M1) is used to control the average voltage of the load, which controls the output load current. The dump load (R3) in series with MOSFET (M3) is used to shut down the turbine on demand or during fault conditions.

Storage Element

When the load current cannot be controlled to match the turbine output, a storage element is used, as shown in Storage Element section of Figure 9. In this configuration, a 5 V output is maintained as the load current varies. A second MOSFET (M2) is used to control the charging current of the storage element. The resistor (R2) was implemented as a current-limiter when charging the storage element, and a 15V Zener diode was installed in parallel with the storage element device to limit voltage of the device. The DC/DC converters (2) and (3) are used to buck or boost the voltage from the storage element device to deliver 5 V to the variable load. These converters have a low input voltage range of 4 V-14 V. The low input voltage range was selected for these converters in the case at which the storage element device does not charge to the minimum 9 V required to turn on DC/DC (1).

2.8 Control Analysis

The generator speed control was selected to be the main method for controlling the rotor speed and the output power of the turbine. The control was designed to operate the turbine in three different regions as shown in Figure 10.

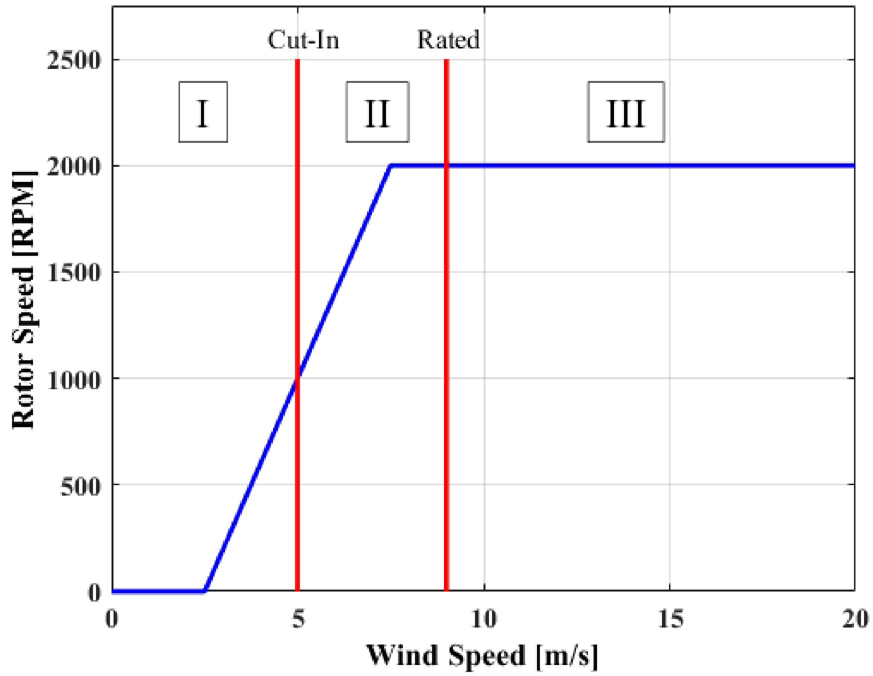

Figure 10: Operating regions of the turbine.

In region I, turbine is in idle mode due to low wind speeds. In idle mode, no generator current is commanded to reduce the starting torque. In region II, the turbine is in startup mode. In this mode, the turbine is spinning fast enough to start generating power. A small amount of generator current is commanded. In region III, the turbine is in a fixed-speed mode. The turbine maintains a constant operating rotational speed by using a proportional-integral control algorithm. This method of regulating the rotational speed involves controlling the generator current. The rotor speed is held constant over all windspeeds in this region, so that the blades are forced deeper into stall as the wind speed increases; this results in a decrease in power coefficient. A dump load (R1) is used to ensure the output power does not exceed rated power at wind speeds above the rated wind speed. This control method is also used to control the charging of the storage element device. As the wind speeds vary, the rotor speed is regulated, and the generator current is adjusted accordingly. MOSFET (M2) is used to adjust the generator current. In addition to the three modes, the turbine can also go into a shutdown mode if a shutdown signal has been initiated, or the load has been disconnected. In shutdown mode, the rotational speed of the turbine is slowed to about 10% of the operating rotational speed measured in the fixed-speed mode.

Software Program

A control algorithm, written in C, was designed and programmed to the Raspberry Pi 3. The program focuses on managing shutdown and rotational speed of the turbine. By modifying the duty cycle of a PWM signal, the program can operate the turbine in different modes. Figure 11 shows the control flow diagram of the program.

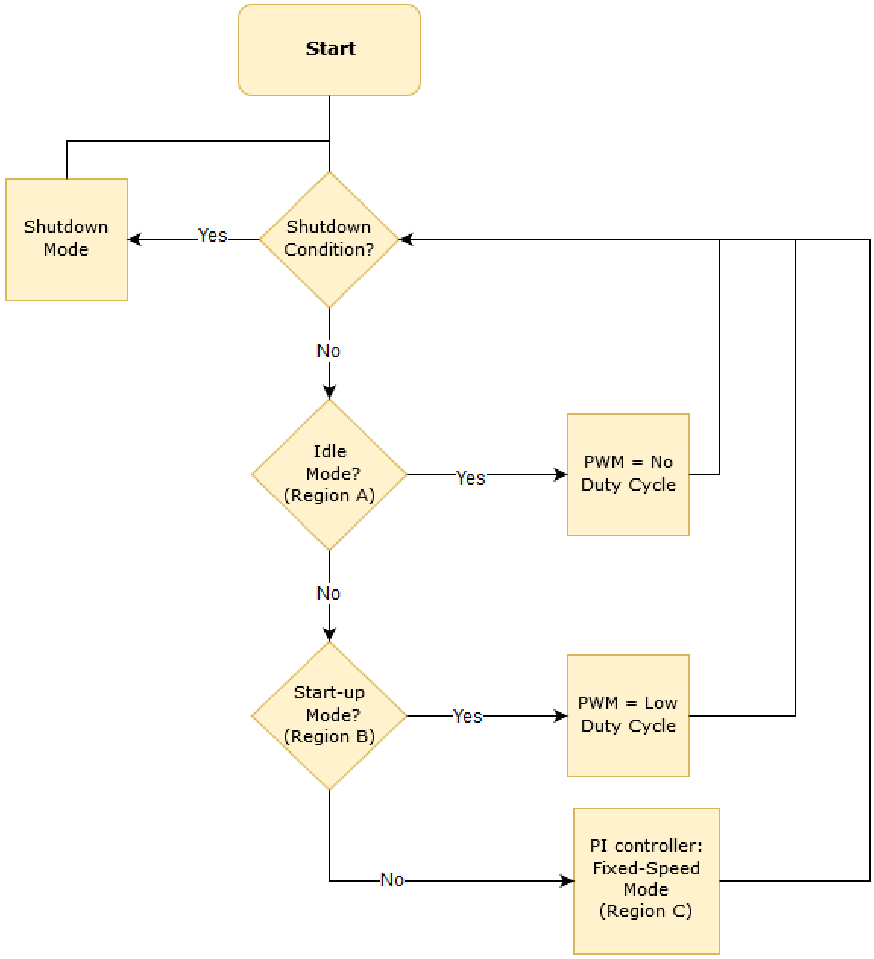

Figure 11: Control Flow Diagram

To ensure a quick and safe shutdown of the turbine, the conditions for shutdown mode are checked at the beginning of the control loop. The first condition for shutdown is a signal from the manual shutdown switch circuit. When the switch circuit is pressed, a signal is sent to the Raspberry Pi 3 to initiate the shutdown. The second condition for shutdown is the voltage signal from the load. If no voltage is detected at the load, then the load has been disconnected. In shutdown mode, a dump load (R3) will be used to apply a brake to the turbine by dissipating the output power. The turbine will be able to restart once the shutdown condition is no longer detected. The condition for other modes is the rotational speed of the turbine, which is monitored by LM393 IR sensor. At low rotational speed, the program will place the turbine in an idle mode by setting the duty cycle of PWM signal to 0%. As the rotational speed increases, the program will change from idle mode to start-up mode. A low duty cycle will be set for the PWM signal to command a small amount of current from the turbine. Once the turbine is spinning at a reasonable speed, the program will use a proportional-integral controller strategy to regulate the speed of the turbine. The same control strategy will also be used to charge the storage element device. However, the duty cycle of the PWM will be scaled differently. During the charging period, the voltage level of the storage element will be monitored. The scaling for the duty cycle of PWM will be based on the voltage of the storage element and the output voltage of the rectifier.

2.9 System Analysis

Mechanical Loads Analysis

Blade Loading

An analysis of the stress in the blades was done to ensure that the blades would not fracture during testing. For the calculation of drag, an assumption was made that the blades were a flat rectangle measuring 20 cm x 5 cm x .3 cm. This assumption simplified the calculations and was conservative because it increased the expected force on the blades, as the actual cross-section is smaller. Equation 1[1] was used to calculate the drag coefficient (C_d) of 1.18. The force on the blades was calculated using the drag coefficient, maximum freestream velocity, and swept area of the blades. These forces were run through Finite Element Analysis (FEA) to calculate the maximum stress and safety factor. Acrylic was used as the blade material for the FEA because the software did not have the properties of SLA resin[4] and it had a similar tensile strength. This analysis shows a safety factor of 15 relative to the ultimate tensile strength of the material.

$$C_d = 1.1 + .02\left(\frac{L}{D} + \frac{D}{L}\right) \qquad \text{(Equation 1)}^5$$

Tower Deflection

An analysis of the deflection and stress of the tower was conducted to ensure the tower would not break while testing. The force on the tower has three components, the drag on the nacelle, the drag on the tower, and the thrust produced by the blades. For this analysis, it was assumed the nacelle was a rectangle measuring 23 cm x 20 cm x 15 cm. This simplifies the calculation of drag, and increases the safety factor, as the real nacelle should have a lower drag coefficient. The drag on the nacelle and tower were calculated using equations 5 and 6. The thrust due to the blades was found to be 22 N, which was calculated through a QBlade simulation. These forces were then put into FEA Simulation to calculate the stress and safety factor of the tower. The results showed a safety factor of 15 relative to the maximum strength of aluminum.

2.10 Test Turbine Results

Seattle University Wind Tunnel Testing

Air in Action used Seattle University's small wind tunnel for basic assessments of blade and controller performance and to compare effects of different design alterations. The flow quality, velocity, and flow uniformity were insufficient for detailed performance testing, so the University of Washington's Kirsten Wind Tunnel was used as well.

University of Washington Wind Tunnel Testing

Air in Action gathered critical information for the development of the market turbine by testing the test turbine in the University of Washington's commercial-grade Kirsten Wind Tunnel. The first testing condition maintained constant wind speeds (8 m/s and 11 m/s), the rotational speeds were set using the control system, and the maximum power output at each wind and rotational speed was measured. This data was used to develop a C_p-λ curve to compare the experimental test turbine results to the market

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[4] Formlabs Material Properties – Standard, Rev. 01

[5] Çenegal, Yunus, and John Cimbala. Fluid Mechanics: Fundamentals and Applications Third Edition.

McGraw-Hill, 2014

turbine with QBlade results shown in Figure 12. The second testing condition used a constant rotational speed, selected as the rotational speed that produced the maximum power output at 8 m/s for the first test condition. The rotational speed was held constant and the wind speed was varied to produce a power curve (Figure 13).

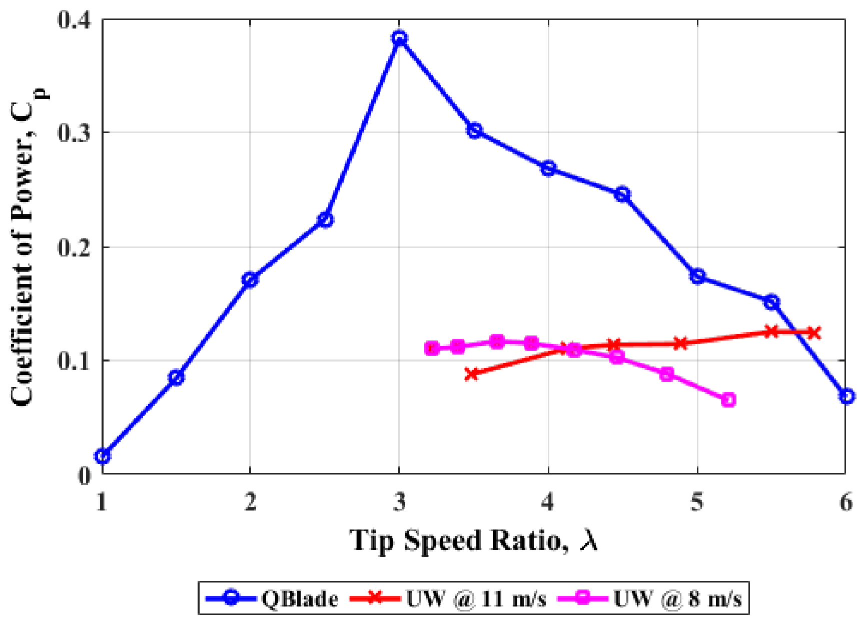


Figure 12: C_p-λ curve for QBlade and experimental results at 8 m/s and 11 m/s

The results in Figure 12 show a direct comparison of the C_p-λ curves for the test turbine blades, this aerodynamic comparison provides insight into the market turbine design. The 8 m/s curve is similar to the QBlade simulation with both peaks being at a tip speed ratio of around 3.5. These results are significant because it validates the simulation and allows for the market turbine design to be continued using QBlade. While the tip speed ratios matched, there are still major differences between the curves. The two experimental curves should theoretically be the same regardless of the wind speed. A reason for this discrepancy and for the difference in C_p with the QBlade simulation was found to come from a combination of mechanical issues and efficiency losses. These discrepancies were attributed to the slipping of the pulley belt on the system and a loose hub connection to its shaft, which resulted in the high rotor rotations to not be transmitted to the generator. This has two effects on the C_p-λ plot. First, since the data measured the rotational speed at the generator, the actual speed of the rotor is unknown. The gear ratio was used to approximate the rotor's rotational speed based on the measured rotational speed of the generator, but due to slipping, the actual rotational speed of the rotor was likely higher. Therefore, the tip speed ratios calculated from the experimental data were underestimated and the data in Figure 12 should be shifted to the right. Second, there are transmission losses that resulted in lost power output. It is important to note that the results obtained from the Kirsten Wind tunnel measured the output electrical power and QBlade predicts the captured mechanical power. While the results obtained had differences in relation to the design simulations, the areas for design improvement were identified. Moving forward further design iterations to improve the current results seen in Figures 12-13 can be continued for the advancement of the market turbine design.

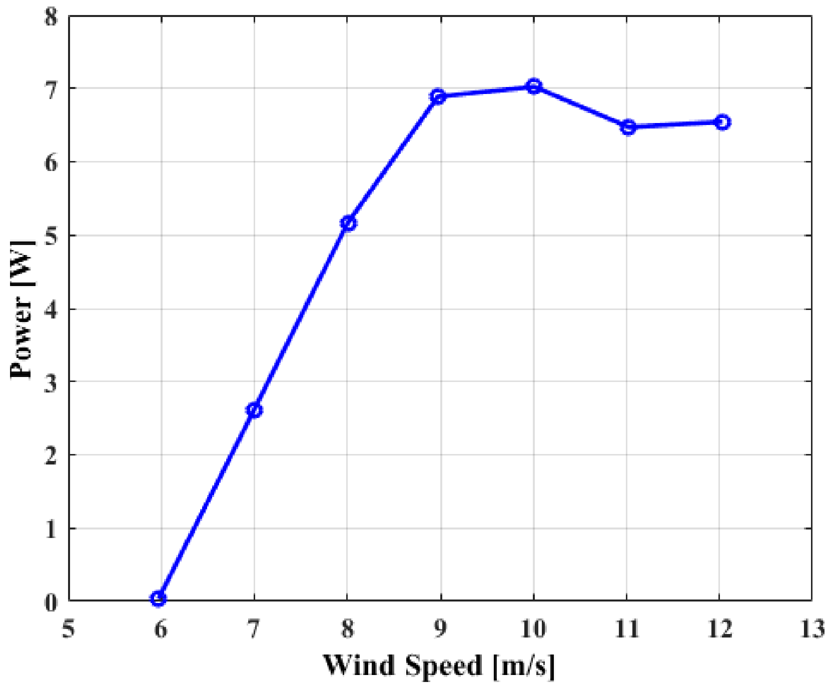


Figure 13: Power Curve at a constant 1300 Rotor Rotational Speed

From the C_p-λ curves in Figure 12 it can be noted that further experimental data is needed for a more in depth analyzes of QBlade as it guides the blade design for the market turbine. To do this the test turbine will be continued to be tested to obtain a power performance curve, to control rated power, to control rated speed, for cut-in windspeed, as well as a durability test and a safety test. These five different tests will fully validate the intended performance of the market turbine. As a starting point Figure 13 shows a power curve for a constant rotor rotational speed of 1300 at different windspeeds from the Kirsten Wind tunnel test. This rotational speed was chosen from the 8 m/s optimal power output data collected under the first testing condition. It can be noted from Figure 13 that power increases linearly with windspeed and there is a clear stall regulation above 9 m/s. This data in combination with the other tasks will provide important information about the market turbine as a whole.

3 Summary

Air in Action is a B2B company that provides renewable energy solutions for the needs of off-grid, remote construction sites, infrastructure projects, and exploratory mining sites. A combination of leased re-deployable wind turbines, solar panels, and batteries are used as an alternative energy source for projects that would typically use diesel generators, or for projects that do not currently have a viable energy source. The market turbine is rated for 21.35 kW at 11 m/s, uses a permanent magnet generator for off-grid energy production, uses robust fatigue-resistant materials, and uses a tilt up tower with a small concrete foundation and guy wires. A small-scale prototype test turbine was created to validate the performance of the market turbine and to assess the effects of different design alterations. Our test results have provided us with confidence that our market turbine will be successful and to proceed with the Air in Action company. Our financial projections indicate that we can be profitable in five years.

Appendix A: Detailed Income Statements

The following income statements demonstrate our financial model in more detail. Larger copies and complete financial documents are available upon request, but were not included due to space restrictions.

2019-2020 Revenue and Expenses

Revenue	January	February	March	April	May	June	July	August	September	October	November	December	Total
6 Month Rental	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
1 Year Rentals	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 471,597
2 Year Rentals	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 39,300	$ 471,597
Rental Discounts	$ (2,358)	$ (2,358)	$ (2,358)	$ (2,358)	$ (2,358)	$ (2,358)	$ (2,358)	$ (2,358)	$ (2,358)	$ (2,358)	$ (2,358)	$ (2,358)	$ (28,296)
Asset Backed Loan	$ 9,000,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 9,000,000
Tax Breaks	$ 462,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 462,000
Total Revenue	**$ 9,538,241**	**$ 76,241**	**$ 76,241**	**$ 76,241**	**$ 76,241**	**$ 76,241**	**$ 76,241**	**$ 76,241**	**$ 76,241**	**$ 76,241**	**$ 76,241**	**$ 76,241**	**$ 10,376,898**
Expenses	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Total**
Salaries & Wages	$ 104,514	$ 104,514	$ 104,514	$ 104,514	$ 104,514	$ 104,514	$ 104,514	$ 104,514	$ 104,514	$ 104,514	$ 104,514	$ 104,514	$ 1,254,165
Turbine Construction costs	$ 1,180,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,180,000
Warehouse Rent	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 116,667
Depreciation (Turbine, Solar, Battery	$ 10,417	$ 10,417	$ 10,417	$ 10,417	$ 10,417	$ 10,417	$ 10,417	$ 10,417	$ 10,417	$ 10,417	$ 10,417	$ 10,417	$ 125,000
Solar System Purchasing Costs	$ 360,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 360,000
Battery Solution costs	$ 480,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 480,000
Insurance	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 101,000
Travel & Vehicles	$ 5,226	$ 5,226	$ 5,226	$ 5,226	$ 5,226	$ 5,226	$ 5,226	$ 5,226	$ 5,226	$ 5,226	$ 5,226	$ 5,226	$ 62,708
Installation	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 24,000
Advertising	$ 86,474	$ 86,474	$ 86,474	$ 86,474	$ 86,474	$ 86,474	$ 86,474	$ 86,474	$ 86,474	$ 86,474	$ 86,474	$ 86,474	$ 1,037,690
Transportation costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Maintenance (Solar, Turbine, Battery	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 27,500
Capital Debt Servicing	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 900,000
Manufacturing Volume Discount	$ (101,000)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (101,000)
Total Expenses	**$ 2,223,061**	**$ 304,061**	**$ 304,061**	**$ 304,061**	**$ 304,061**	**$ 304,061**	**$ 304,061**	**$ 304,061**	**$ 304,061**	**$ 304,061**	**$ 304,061**	**$ 304,061**	**$ 5,567,729**
Gross Margin	**$ 7,315,181**	**$ (227,819)**	**$ (227,819)**	**$ (227,819)**	**$ (227,819)**	**$ (227,819)**	**$ (227,819)**	**$ (227,819)**	**$ (227,819)**	**$ (227,819)**	**$ (227,819)**	**$ (227,819)**	**$ 4,809,168**
Capital Interest Expense	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 527,220
Income Before Income Taxes	**$ 7,271,246**	**$ (271,754)**	**$ (271,754)**	**$ (271,754)**	**$ (271,754)**	**$ (271,754)**	**$ (271,754)**	**$ (271,754)**	**$ (271,754)**	**$ (271,754)**	**$ (271,754)**	**$ (271,754)**	**$ 4,281,948**
Business Tax Expense	$ 7,860	$ 7,860	$ 7,860	$ 7,860	$ 7,860	$ 7,860	$ 7,860	$ 7,860	$ 7,860	$ 7,860	$ 7,860	$ 7,860	$ 94,319
Net Income	**$ 7,263,386**	**$ (279,614)**	**$ (279,614)**	**$ (279,614)**	**$ (279,614)**	**$ (279,614)**	**$ (279,614)**	**$ (279,614)**	**$ (279,614)**	**$ (279,614)**	**$ (279,614)**	**$ (279,614)**	**$ 4,187,629**

2020-2021 Revenues and Expenses

Revenue	January	February	March	April	May	June	July	August	September	October	November	December	Total
6 Month Rental	$ 118,538	$ 118,538	$ 118,538	$ 118,538	$ 118,538	$ 118,538	$ 118,538	$ 118,538	$ 118,538	$ 118,538	$ 118,538	$ 118,538	$ 1,422,458
1 Year Rentals	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 1,178,992
2 Year Rentals	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 2,357,984
Rental Discounts	$ (12,399)	$ (12,399)	$ (12,399)	$ (12,399)	$ (12,399)	$ (12,399)	$ (12,399)	$ (12,399)	$ (12,399)	$ (12,399)	$ (12,399)	$ (12,399)	$ (148,783)
Asset Backed Loan	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Tax Breaks	$ 1,440,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,440,000
Total Revenue	**$ 1,853,286**	**$ 413,286**	**$ 413,286**	**$ 413,286**	**$ 413,286**	**$ 413,286**	**$ 413,286**	**$ 413,286**	**$ 413,286**	**$ 413,286**	**$ 413,286**	**$ 413,286**	**$ 6,399,434**
Expenses	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Total**
Salaries & Wages	$ 106,604	$ 106,604	$ 106,604	$ 106,604	$ 106,604	$ 106,604	$ 106,604	$ 106,604	$ 106,604	$ 106,604	$ 106,604	$ 106,604	$ 1,279,248
Turbine Construction costs	$ 3,540,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 3,540,000
Warehouse Rent	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 116,667
Depreciation (Turbine, Solar, Battery)	$ 44,417	$ 44,417	$ 44,417	$ 44,417	$ 44,417	$ 44,417	$ 44,417	$ 44,417	$ 44,417	$ 44,417	$ 44,417	$ 44,417	$ 533,000
Solar System Costs	$ 1,260,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,260,000
Battery Solution costs	$ 1,680,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,680,000
Insurance	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 8,417	$ 101,000
Travel & Vehicles	$ 5,330	$ 5,330	$ 5,330	$ 5,330	$ 5,330	$ 5,330	$ 5,330	$ 5,330	$ 5,330	$ 5,330	$ 5,330	$ 5,330	$ 63,962
Installation	$ 10,667	$ 10,667	$ 10,667	$ 10,667	$ 10,667	$ 10,667	$ 10,667	$ 10,667	$ 10,667	$ 10,667	$ 10,667	$ 10,667	$ 128,000
Advertising	$ 26,664	$ 26,664	$ 26,664	$ 26,664	$ 26,664	$ 26,664	$ 26,664	$ 26,664	$ 26,664	$ 26,664	$ 26,664	$ 26,664	$ 319,972
Transportation costs	$ 1,375	$ 1,375	$ 1,375	$ 1,375	$ 1,375	$ 1,375	$ 1,375	$ 1,375	$ 1,375	$ 1,375	$ 1,375	$ 1,375	$ 16,497
Maintenance (Solar, Turbine, Battery)	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 27,500
Capital Debt Servicing	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 900,000
Total Expenses	**$ 6,973,602**	**$ 299,202**	**$ 299,202**	**$ 299,202**	**$ 299,202**	**$ 299,202**	**$ 299,202**	**$ 299,202**	**$ 299,202**	**$ 299,202**	**$ 299,202**	**$ 299,202**	**$ 9,965,845**
Gross Margin	**$ (5,120,316)**	**$ 114,084**	**$ 114,084**	**$ 114,084**	**$ 114,084**	**$ 114,084**	**$ 114,084**	**$ 114,084**	**$ 114,084**	**$ 114,084**	**$ 114,084**	**$ 114,084**	**$ (3,566,411)**
Capital Interest Expense	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 43,935	$ 527,220
Income Before Income Taxes	$ (5,164,251)	$ 70,149	$ 70,149	$ 70,149	$ 70,149	$ 70,149	$ 70,149	$ 70,149	$ 70,149	$ 70,149	$ 70,149	$ 70,149	$ (4,392,607)
Business Tax Expense	$ 41,329	$ 41,329	$ 41,329	$ 41,329	$ 41,329	$ 41,329	$ 41,329	$ 41,329	$ 41,329	$ 41,329	$ 41,329	$ 41,329	$ 495,943
Net Income	**$ (5,205,579)**	**$ 28,821**	**$ 28,821**	**$ 28,821**	**$ 28,821**	**$ 28,821**	**$ 28,821**	**$ 28,821**	**$ 28,821**	**$ 28,821**	**$ 28,821**	**$ 28,821**	**$ (4,888,550)**

2021-2022 Revenues and Expenses

Revenue	January	February	March	April	May	June	July	August	September	October	November	December	Total
6 Month Rental	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 1,178,992
1 Year Rentals	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 2,357,984
2 Year Rentals	$ 589,496	$ 589,496	$ 589,496	$ 589,496	$ 589,496	$ 589,496	$ 589,496	$ 589,496	$ 589,496	$ 589,496	$ 589,496	$ 589,496	$ 7,073,952
Rental Discounts	$ (26,527)	$ (26,527)	$ (26,527)	$ (26,527)	$ (26,527)	$ (26,527)	$ (26,527)	$ (26,527)	$ (26,527)	$ (26,527)	$ (26,527)	$ (26,527)	$ (318,328)
Asset Backed Loan	$ 13,500,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 13,500,000
Tax Breaks	$ 1,783,100	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,783,100
Capital Line of Credit	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Revenue	**$ 16,193,871**	**$ 910,771**	**$ 910,771**	**$ 910,771**	**$ 910,771**	**$ 910,771**	**$ 910,771**	**$ 910,771**	**$ 910,771**	**$ 910,771**	**$ 910,771**	**$ 910,771**	**$ 26,212,356**
Expenses	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Total**
Salaries & Wages	$ 108,736	$ 108,736	$ 108,736	$ 108,736	$ 108,736	$ 108,736	$ 108,736	$ 108,736	$ 108,736	$ 108,736	$ 108,736	$ 108,736	$ 1,304,833
Turbine Construction costs	$ 5,900,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 5,900,000
Warehouse Purchase Cost	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 116,667
Depreciation (Turbine, Solar, Batte	$ 102,688	$ 102,688	$ 102,688	$ 102,688	$ 102,688	$ 102,688	$ 102,688	$ 102,688	$ 102,688	$ 102,688	$ 102,688	$ 102,688	$ 1,232,250
Solar System Costs	$ 2,205,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,205,000
Battery Solution costs	$ 2,940,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,940,000
Insurance	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 653,250
Travel & Vehicles	$ 5,437	$ 5,437	$ 5,437	$ 5,437	$ 5,437	$ 5,437	$ 5,437	$ 5,437	$ 5,437	$ 5,437	$ 5,437	$ 5,437	$ 65,242
Installation	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 240,000
Advertising	$ 109,218	$ 109,218	$ 109,218	$ 109,218	$ 109,218	$ 109,218	$ 109,218	$ 109,218	$ 109,218	$ 109,218	$ 109,218	$ 109,218	$ 1,310,618
Transportation costs	$ 1,147	$ 1,147	$ 1,147	$ 1,147	$ 1,147	$ 1,147	$ 1,147	$ 1,147	$ 1,147	$ 1,147	$ 1,147	$ 1,147	$ 13,764
Maintenance (Solar, Turbine, Batt	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 27,500
Capital Debt Servicing	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 3,040,836
Manufacturing volume discount	$ (552,250)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Expenses	**$ 11,829,420**	**$ 707,105**	**$ 707,105**	**$ 707,105**	**$ 707,105**	**$ 707,105**	**$ 707,105**	**$ 707,105**	**$ 707,105**	**$ 707,105**	**$ 707,105**	**$ 707,105**	**$ 19,049,959**
Gross Margin	**$ 4,364,452**	**$ 203,667**	**$ 203,667**	**$ 203,667**	**$ 203,667**	**$ 203,667**	**$ 203,667**	**$ 203,667**	**$ 203,667**	**$ 203,667**	**$ 203,667**	**$ 203,667**	**$ 7,162,397**
Capital Interest Expense	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 1,318,056
Income Before Income Taxes	$ 4,254,614	$ 93,829	$ 93,829	$ 93,829	$ 93,829	$ 93,829	$ 93,829	$ 93,829	$ 93,829	$ 93,829	$ 93,829	$ 93,829	$ 5,286,728
Business Tax Expense	$ 88,424	$ 88,424	$ 88,424	$ 88,424	$ 88,424	$ 88,424	$ 88,424	$ 88,424	$ 88,424	$ 88,424	$ 88,424	$ 88,424	$ 1,061,093
Net Income	**$ 4,166,189**	**$ 5,404**	**$ 5,404**	**$ 5,404**	**$ 5,404**	**$ 5,404**	**$ 5,404**	**$ 5,404**	**$ 5,404**	**$ 5,404**	**$ 5,404**	**$ 5,404**	**$ 4,225,636**

2022-2023 Revenues and Expenses

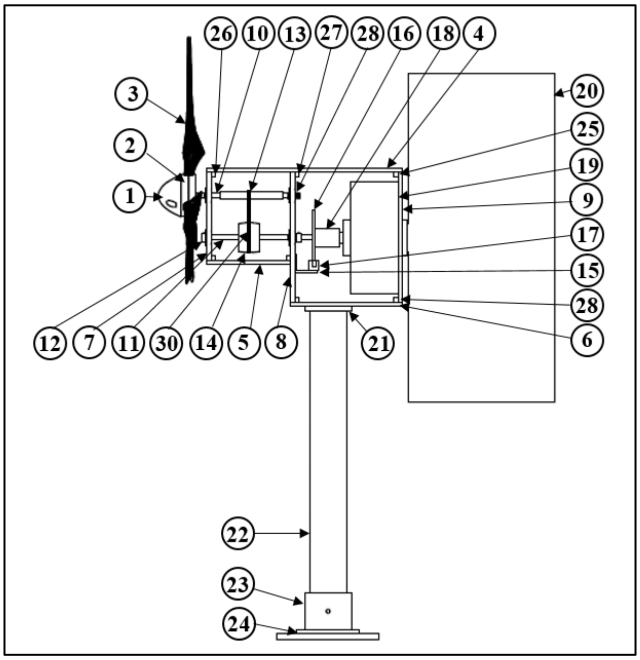
Revenue	January	February	March	April	May	June	July	August	September	October	November	December	Total
6 Month Rental	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 98,249	$ 1,178,992
1 Year Rentals	$ 294,748	$ 294,748	$ 294,748	$ 294,748	$ 294,748	$ 294,748	$ 294,748	$ 294,748	$ 294,748	$ 294,748	$ 294,748	$ 294,748	$ 3,536,976
2 Year Rentals	$ 1,178,992	$ 1,178,992	$ 1,178,992	$ 1,178,992	$ 1,178,992	$ 1,178,992	$ 1,178,992	$ 1,178,992	$ 1,178,992	$ 1,178,992	$ 1,178,992	$ 1,178,992	$ 14,147,904
Rental Discounts	$ (47,160)	$ (47,160)	$ (47,160)	$ (47,160)	$ (47,160)	$ (47,160)	$ (47,160)	$ (47,160)	$ (47,160)	$ (47,160)	$ (47,160)	$ (47,160)	$ (565,916)
Asset backed loan	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Tax Breaks	$ 3,600,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 3,600,000
	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Revenue	**$ 5,266,309**	**$ 1,666,309**	**$ 1,666,309**	**$ 1,666,309**	**$ 1,666,309**	**$ 1,666,309**	**$ 1,666,309**	**$ 1,666,309**	**$ 1,666,309**	**$ 1,666,309**	**$ 1,666,309**	**$ 1,666,309**	**$ 23,595,704**
Expenses	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Total**
Salaries & Wages	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 1,330,930
Turbine Construction costs	$ 8,850,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 8,850,000
Warehouse Rent	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 116,667
Depreciation (Turbine, Solar, Battery, Plant)	$ 187,688	$ 187,688	$ 187,688	$ 187,688	$ 187,688	$ 187,688	$ 187,688	$ 187,688	$ 187,688	$ 187,688	$ 187,688	$ 187,688	$ 2,252,250
Solar System Costs	$ 3,150,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 3,150,000
Battery Solution costs	$ 4,200,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 4,200,000
Insurance	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 653,250
Travel & Vehicles	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 66,546
Installation	$ 33,333	$ 33,333	$ 33,333	$ 33,333	$ 33,333	$ 33,333	$ 33,333	$ 33,333	$ 33,333	$ 33,333	$ 33,333	$ 33,333	$ 400,000
Advertising	$ 98,315	$ 98,315	$ 98,315	$ 98,315	$ 98,315	$ 98,315	$ 98,315	$ 98,315	$ 98,315	$ 98,315	$ 98,315	$ 98,315	$ 1,179,785
Transportation costs	$ 1,149	$ 1,149	$ 1,149	$ 1,149	$ 1,149	$ 1,149	$ 1,149	$ 1,149	$ 1,149	$ 1,149	$ 1,149	$ 1,149	$ 13,784
Maintenance (Solar, Turbine, Battery)	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 27,500
Capital Debt Servicing	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 3,040,836
Total Expenses	**$ 18,482,907**	**$ 824,907**	**$ 824,907**	**$ 824,907**	**$ 824,907**	**$ 824,907**	**$ 824,907**	**$ 824,907**	**$ 824,907**	**$ 824,907**	**$ 824,907**	**$ 824,907**	**$ 25,281,548**
Gross Margin	**$ (13,216,599)**	**$ 841,401**	**$ 841,401**	**$ 841,401**	**$ 841,401**	**$ 841,401**	**$ 841,401**	**$ 841,401**	**$ 841,401**	**$ 841,401**	**$ 841,401**	**$ 841,401**	**$ (1,685,843)**
Capital Interest Expense	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 1,318,056
Income Before Income Taxes	$ (13,326,437)	$ 731,563	$ 731,563	$ 731,563	$ 731,563	$ 731,563	$ 731,563	$ 731,563	$ 731,563	$ 731,563	$ 731,563	$ 731,563	$ (5,279,239)
Business Tax Expense	$ 157,199	$ 157,199	$ 157,199	$ 157,199	$ 157,199	$ 157,199	$ 157,199	$ 157,199	$ 157,199	$ 157,199	$ 157,199	$ 157,199	$ 1,886,387
Net Income	**$ (13,483,635)**	**$ 574,365**	**$ 574,365**	**$ 574,365**	**$ 574,365**	**$ 574,365**	**$ 574,365**	**$ 574,365**	**$ 574,365**	**$ 574,365**	**$ 574,365**	**$ 574,365**	**$ (7,165,626)**

2023-2024 Revenues and Expenses

Revenue	January	February	March	April	May	June	July	August	September	October	November	December	Total
6 Month Rental	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 196,499	$ 2,357,984
1 Year Rentals	$ 392,997	$ 392,997	$ 392,997	$ 392,997	$ 392,997	$ 392,997	$ 392,997	$ 392,997	$ 392,997	$ 392,997	$ 392,997	$ 392,997	$ 4,715,968
2 Year Rentals	$ 1,277,241	$ 1,277,241	$ 1,277,241	$ 1,277,241	$ 1,277,241	$ 1,277,241	$ 1,277,241	$ 1,277,241	$ 1,277,241	$ 1,277,241	$ 1,277,241	$ 1,277,241	$ 15,326,896
Rental Discounts	$ (56,002)	$ (56,002)	$ (56,002)	$ (56,002)	$ (56,002)	$ (56,002)	$ (56,002)	$ (56,002)	$ (56,002)	$ (56,002)	$ (56,002)	$ (56,002)	$ (672,025)
Asset Backed Loan	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Tax Breaks	$ 1,222,500	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,222,500
Total Revenue	**$ 3,257,244**	**$ 2,034,744**	**$ 2,034,744**	**$ 2,034,744**	**$ 2,034,744**	**$ 2,034,744**	**$ 2,034,744**	**$ 2,034,744**	**$ 2,034,744**	**$ 2,034,744**	**$ 2,034,744**	**$ 2,034,744**	**$ 25,639,424**
Expenses	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Total**
Salaries & Wages	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 110,911	$ 1,330,930
Turbine Construction costs	$ 2,950,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,950,000
Warehouse Purchase Cost	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 9,722	$ 116,667
Depreciation (Turbine, Solar, Battery, Plant)	$ 217,167	$ 217,167	$ 217,167	$ 217,167	$ 217,167	$ 217,167	$ 217,167	$ 217,167	$ 217,167	$ 217,167	$ 217,167	$ 217,167	$ 2,606,000
Solar System Costs	$ 1,125,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,125,000
Battery Solution costs	$ 1,500,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,500,000
Insurance	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 54,438	$ 653,250
Travel & Vehicles	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 5,546	$ 66,546
Installation	$ 41,667	$ 41,667	$ 41,667	$ 41,667	$ 41,667	$ 41,667	$ 41,667	$ 41,667	$ 41,667	$ 41,667	$ 41,667	$ 41,667	$ 500,000
Advertising	$ 106,831	$ 106,831	$ 106,831	$ 106,831	$ 106,831	$ 106,831	$ 106,831	$ 106,831	$ 106,831	$ 106,831	$ 106,831	$ 106,831	$ 1,281,971
Transportation costs	$ 2,294	$ 2,294	$ 2,294	$ 2,294	$ 2,294	$ 2,294	$ 2,294	$ 2,294	$ 2,294	$ 2,294	$ 2,294	$ 2,294	$ 27,530
Maintenance (Solar, Turbine, Battery)	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 2,292	$ 27,500
Capital Debt Servicing	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 253,403	$ 3,040,836
Total Expenses	**$ 7,144,781**	**$ 900,781**	**$ 900,781**	**$ 900,781**	**$ 900,781**	**$ 900,781**	**$ 900,781**	**$ 900,781**	**$ 900,781**	**$ 900,781**	**$ 900,781**	**$ 900,781**	**$ 15,226,230**
Gross Margin	**$ (3,887,538)**	**$ 1,133,962**	**$ 1,133,962**	**$ 1,133,962**	**$ 1,133,962**	**$ 1,133,962**	**$ 1,133,962**	**$ 1,133,962**	**$ 1,133,962**	**$ 1,133,962**	**$ 1,133,962**	**$ 1,133,962**	**$ 10,413,194**
Capital Interest Expense	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 109,838	$ 1,318,056
Income Before Income Taxes	$ (3,997,376)	$ 1,024,124	$ 1,024,124	$ 1,024,124	$ 1,024,124	$ 1,024,124	$ 1,024,124	$ 1,024,124	$ 1,024,124	$ 1,024,124	$ 1,024,124	$ 1,024,124	$ 7,267,991
Business Tax Expense	$ 186,674	$ 186,674	$ 186,674	$ 186,674	$ 186,674	$ 186,674	$ 186,674	$ 186,674	$ 186,674	$ 186,674	$ 186,674	$ 186,674	$ 2,240,085
Net Income	**$ (4,184,050)**	**$ 837,450**	**$ 837,450**	**$ 837,450**	**$ 837,450**	**$ 837,450**	**$ 837,450**	**$ 837,450**	**$ 837,450**	**$ 837,450**	**$ 837,450**	**$ 837,450**	**$ 5,027,906**

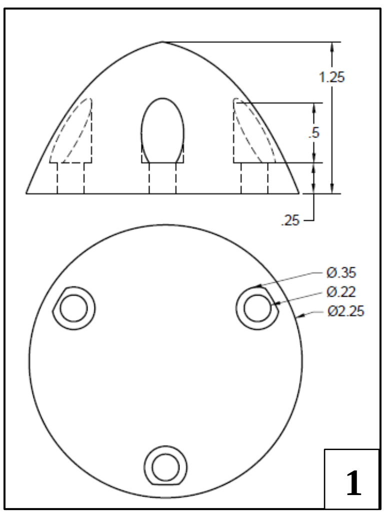
Appendix B: Mechanical Drawings

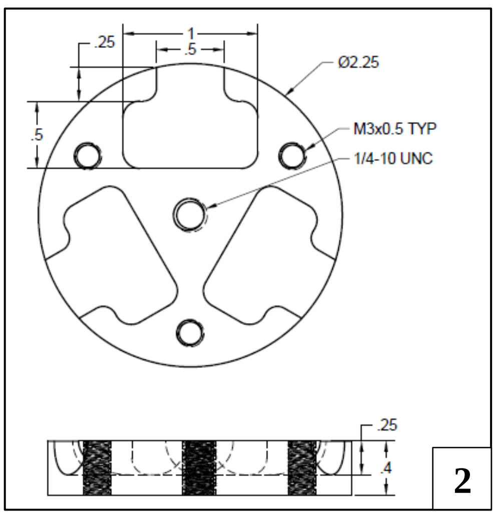
The assembly drawing of all mechanical components is given in Fig. A1. The drawings of parts denoted by the callouts are titled by their callout number, with the exception of the blades, generator, tachometer, fin, and belt. All units are in inches. Unless otherwise specified, tolerances are +/-0.01 in.

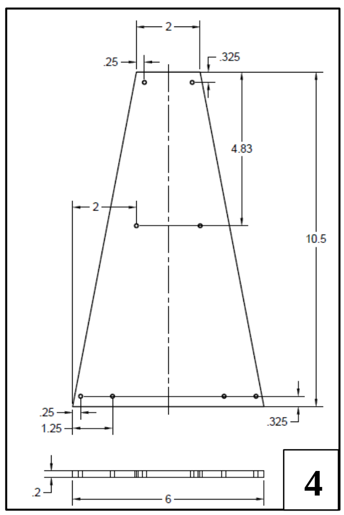


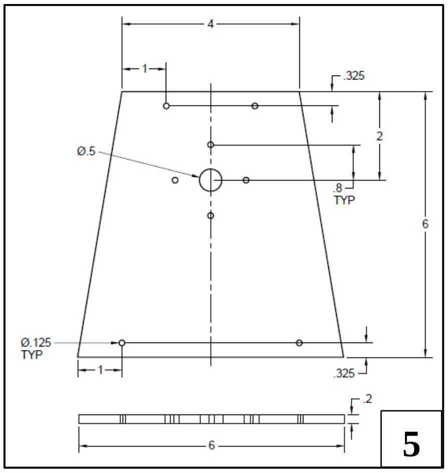
Part Number	Part Name	Required	Material
1	Hub Cover	1	PLA
2	Hub	2	Aluminum
3	Blade	3	SLA
4	Horizontal Plate 1	1	Aluminum
5	Horizontal Plate 2	1	Aluminum
6	Horizontal Plate 3	1	Aluminum
7	Vertical Plate 1	1	Aluminum
8	Vertical Plate 2	1	Aluminum
9	Vertical Plate 3	1	Aluminum
10	Top Shaft	1	Steel
11	Bottom Shaft	1	Steel
12	Shaft Collar	2	Aluminum
13	Small Pulley	1	Aluminum
14	Large Pulley	1	Aluminum
15	Tachometer Mount	1	PLA
16	Tachometer Disk	1	PLA
17	Tachometer	1	N/A
18	Shaft Adapter	1	Aluminum
19	Generator	1	N/A
20	Fin	1	Aluminum
21	Yaw Flange	1	Aluminum
22	Tower	1	Aluminum
23	Base Flange	1	Aluminum
24	Base	1	Aluminum
25	1.5" Block	2	Aluminum
26	2" Block	2	Aluminum
27	3" Block	3	Aluminum
28	6" Block	1	Aluminum
29	Bearing	4	N/A
30	Belt	1	Polyurethane Rubber

Fig. A1: Turbine assembly drawing and parts list





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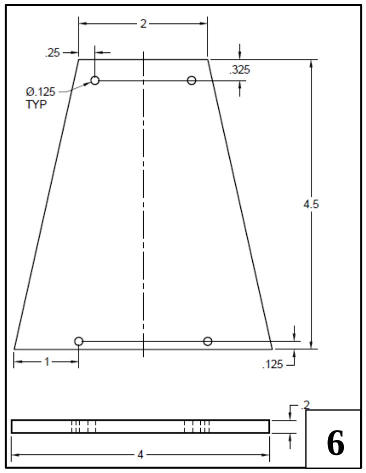
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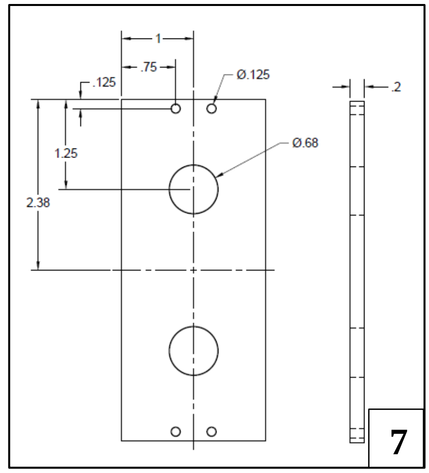
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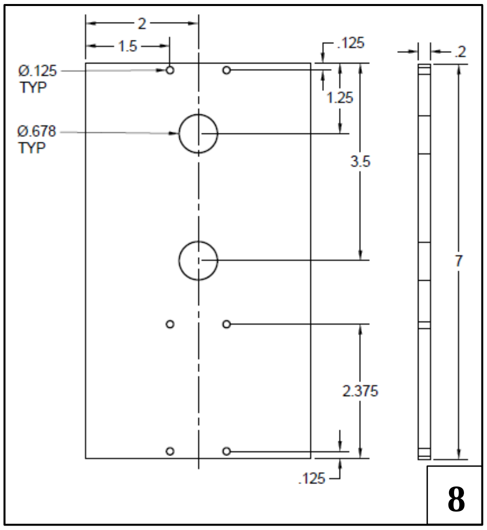
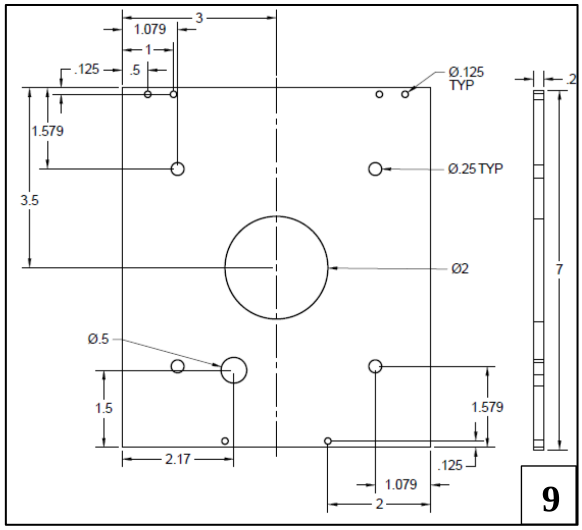
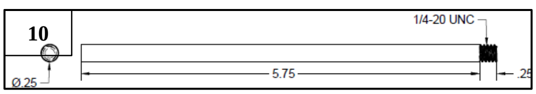
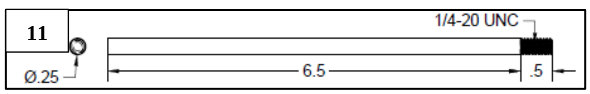
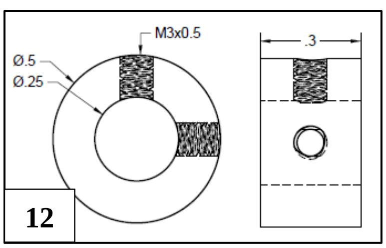
2.38
7

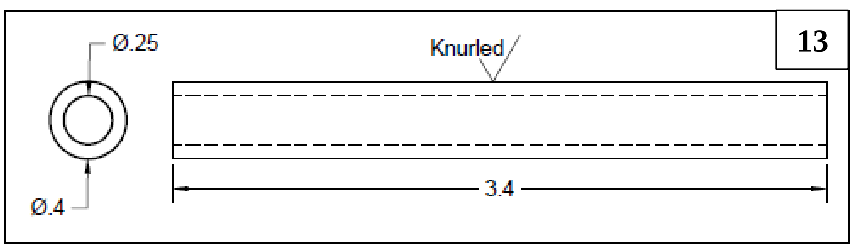

2
1.5
.125
.2
Ø.125
TYP
1.25
Ø.678
TYP
3.5
7
2.375
.125
8

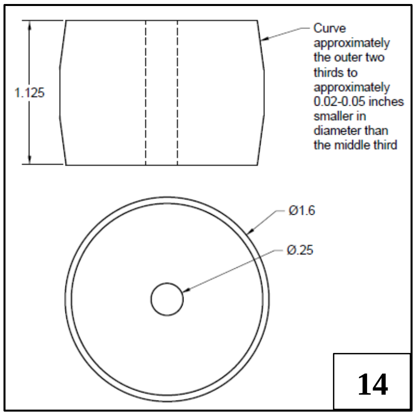

3
1.079
1
.125
.5
Ø.125
TYP
.2
1.579
Ø.25 TYP
3.5
Ø2
7
Ø.5
1.5
1.579
2.17
.125
1.079
2
9

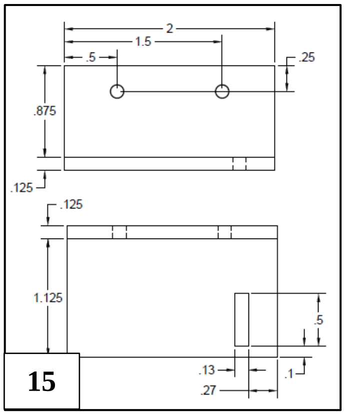

10
1/4-20 UNC
Ø.25
5.75
.25

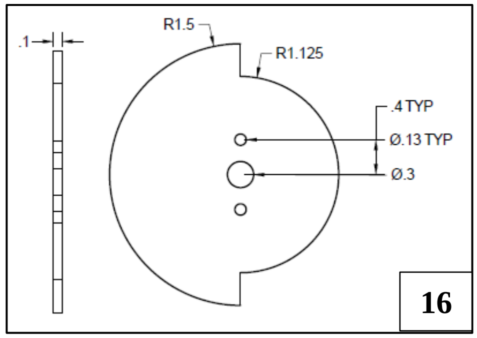

11
1/4-20 UNC
Ø.25
6.5
.5

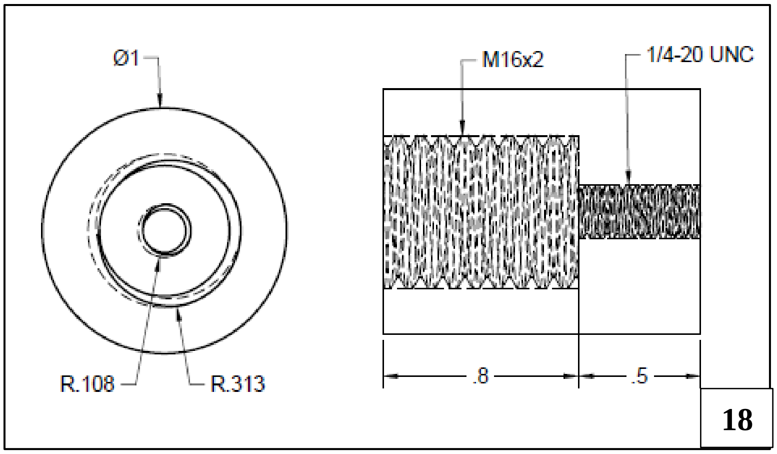

M3x0.5
.3
Ø.5
Ø.25
12

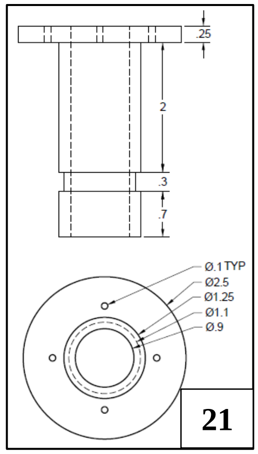

Ø.25
Knurled
13
Ø.4
3.4

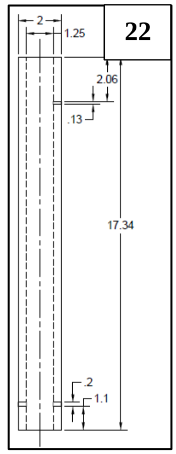

Curve approximately the outer two thirds to approximately 0.02-0.05 inches smaller in diameter than the middle third
1.125
Ø1.6
Ø.25
14

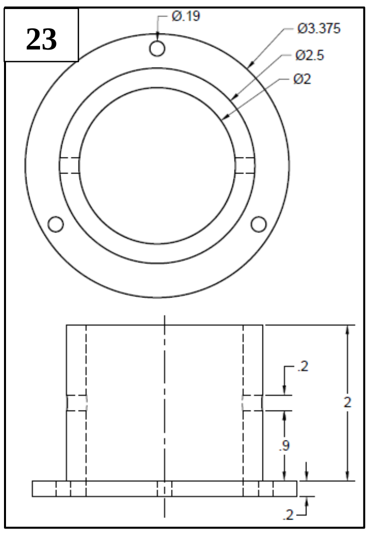

2
1.5
.5
.25
.875
.125
.125
1.125
.5
.13
.1
.27
15

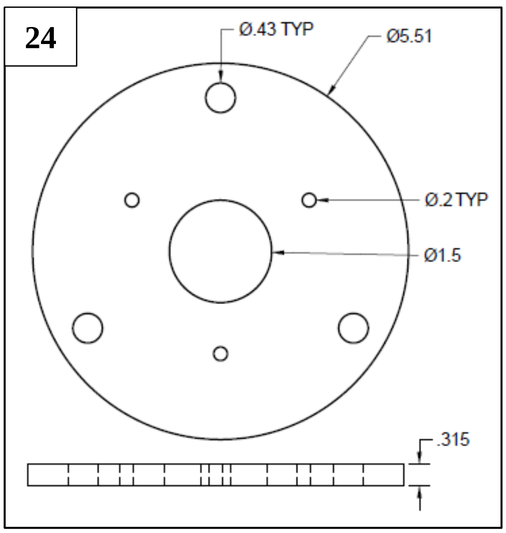

.1
R1.5
R1.125
.4 TYP
Ø.13 TYP
Ø.3
16

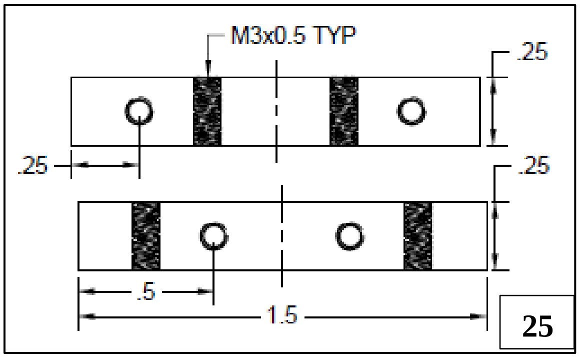

Ø1
M16x2
1/4-20 UNC
R.108
R.313
.8
.5
18

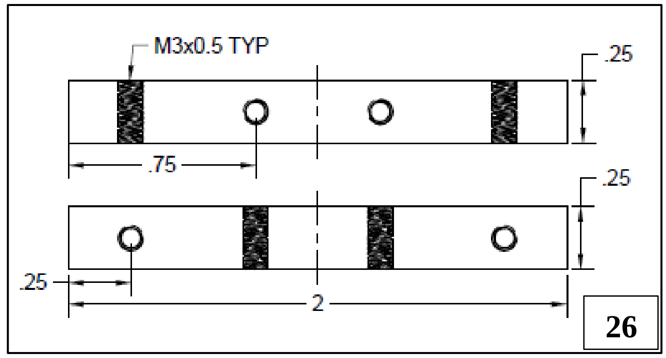

.25
2
.3
.7
Ø.1 TYP
Ø2.5
Ø1.25
Ø1.1
Ø.9
21

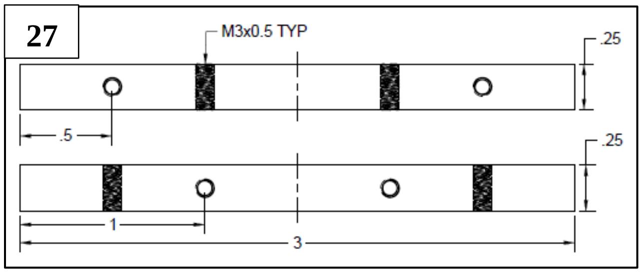

2
1.25
22
2.06
.13
17.34
.2
1.1

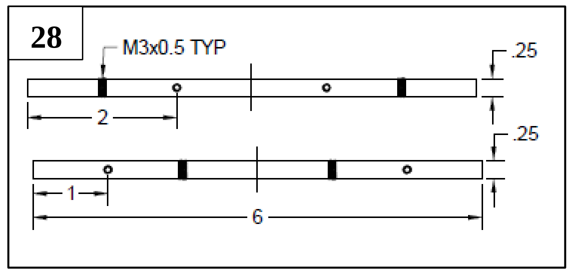

23
Ø.19
Ø3.375
Ø2.5
Ø2
.2
2
.9
.2

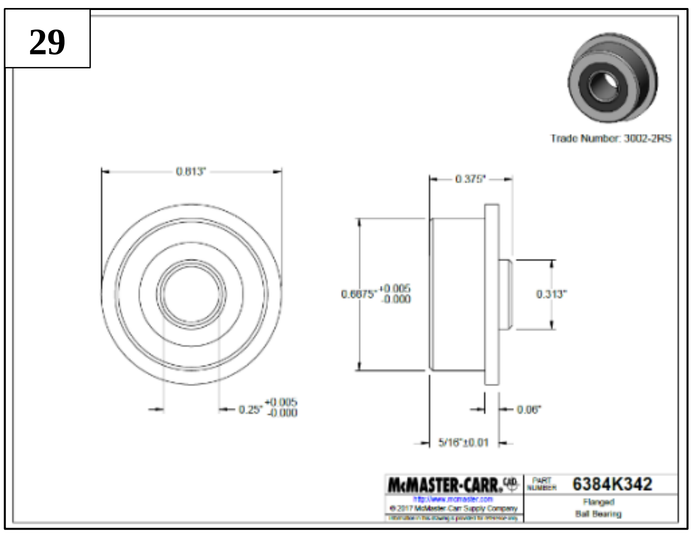

24
Ø.43 TYP
Ø5.51
Ø.2 TYP
Ø1.5
.315


M3x0.5 TYP
.25
.25
.25
.5
1.5
25


M3x0.5 TYP
.25
.75
.25
.25
2
26


27
M3x0.5 TYP
.25
.5
.25
1
3


28
M3x0.5 TYP
.25
2
.25
1
6


29
Trade Number: 3002-2RS
0.813"
0.375"
0.6875" +0.005 -0.000
0.313"
0.25" +0.005 -0.000
0.06"
5/16"±0.01
McMASTER-CARR
PART NUMBER
6384K342
Flanged Ball Bearing