U.S. Department of Energy (DOE) Collegiate Wind Competition

University of Massachusetts Lowell

GoJuice

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Design Objective

The engineering design of the GoJuice wind turbine-kiosk-phone system (Figure 1) aligns with its business objective – to provide a streamlined smartphone battery exchange experience using batteries charged by renewable energy sources. Consumers lead busy lives and demand immediate gratification, so the engineering design must account for the intermittent wind source and slow battery charge rate of mobile electronic devices. GoJuice provides a business value proposition to the consumer offered by no other competitor via a seamless engineering approach that transforms intermittent wind energy sources into immediately available power for mobile devices via GoJuice's simple and convenient battery exchange.

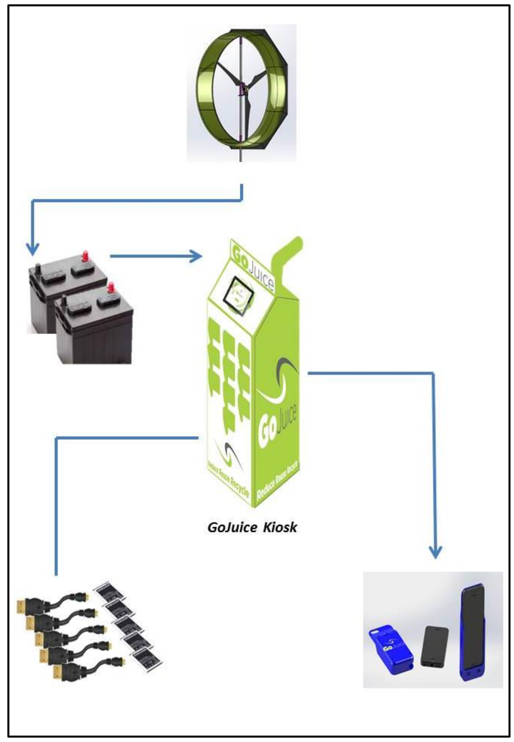


Figure 1. GoJuice System Diagram

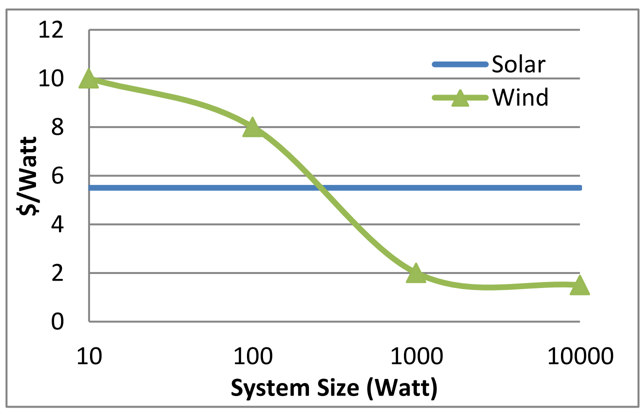


Figure 2. Energy Cost per Watt

The GoJuice system technical design responds to the economics of renewable energy, the practical limitations of wind/solar power generation for smartphones and the technological constraints of transportable solutions for charging portable electronic devices. The economics of wind energy strongly disfavor small installed system sizes due to the dramatic increase in the cost per installed capacity (Figure 2). The GoJuice team recognizes that to avoid being a niche player in the renewable energy space, the engineering design must progress toward larger capacity systems in order to minimize the cost differential with solar and other renewable energy resources. Simultaneously the turbine must be transportable between seasonal deployment locations; as such, the team has carried prototype systems and found that an installed rotor diameter of 2.5 meters balances the needs of economics with transportability.

In light of the economics discussed above, several generic GoJuice Kiosk deployment sites were considered (Figure 3). Here, we focus on applications with wind resources. Popular outdoor locations, such as ski slopes, beaches, or open parks offer ready access to fully wind or wind-solar hybrid deployments. In order to meet the estimated 150 user interactions per day, a fully wind-powered 2.5 meter diameter system requires 5.5 m/s average wind speed assuming a Weibull distribution.

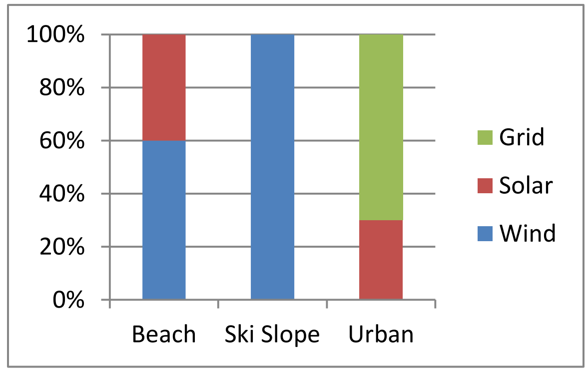


Figure 3. Energy Source by Site

Design Team

Figure 4. Organizational Chart

System Design Overview

The unique design features include: (1) an efficient and non-intrusive energy transfer via a one-minute auxiliary battery exchange (2) an efficient shrouded downwind turbine and direct drive Permanent Magnet Generator (PMG) system that exploits the benefits of larger-scale wind generation and (3) a cost-competitive wind/solar, community based smartphone charging strategy that exploits the beneficial economies of community and scale.

Wind Turbine Technical Documentation

The wind turbine engineering design is described in three sections: (1) Full-Scale turbine, (2) Wind Lens Diffuser, and (3) Validation (i.e., competition) Scale Turbine.

Full-Scale Turbine

Design and Analysis

Design Objective: The purpose of the wind turbine is to generate the power required by the kiosk for auxiliary battery charging and kiosk functions while being easy to transport, install and maintain. To meet this goal, the turbine should (1) be efficient, lightweight and transportable (2) passively align with the wind (3) operate safely in high traffic areas and (4) exploit efficiency augmenting wind lens research.

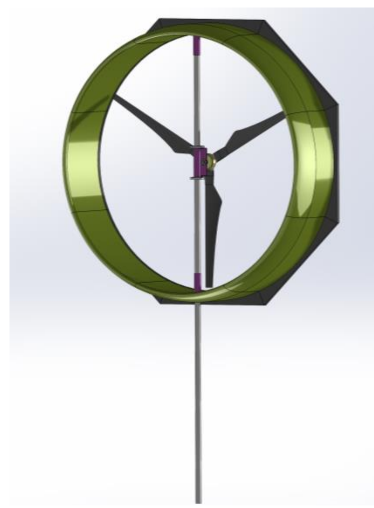


Figure 5. Full Scale Turbine Design

Design Overview: The GoJuice wind turbine is a three-bladed, downwind, shrouded rotor design (Figure 5). An efficient blade design was determined using in-house, ideal Betz-analysis and Blade Element Momentum Theory computer software. A relatively large tip speed ratio (TSR = 6.0) and low solidity (Solidity = 0.11) was selected to achieve higher coefficient of performance and reach the rotational velocities required by direct-drive permanent magnet generators. To ensure safety at high wind speeds, electromagnetic braking is applied. The overall wind turbine system specifications are listed in Table 1.

Table 1. Wind Turbine Specifications

Rated Capacity	1.5 kW @ 11 m/s
Rotor Diameter	2.5 m (8.2 ft)
Swept Area	4.91 m^2 (52.81 ft^2)
Type	Downwind shrouded rotor
Direction of Rotation	Clockwise looking upwind
Blades	(3) Fiberglass reinforced composite
Rated Speed	500 RPM
Maximum Tip Speed	66 m/s (178 mph)
Alternator	Permanent magnet generator
Yaw Control	Passive
Max Wind Design Speed Axial Loading	1500 N @ 60 m/s (135 mph)
Braking System	Electromagnetic braking from generator
Cut-in Wind Speed	3 m/s (6.7 mph)*
Rated Wind Speed	11 m/s (24.6 mph)
Survival Wind Speed	60 m/s (135 mph)

Modeling and Testing: Several candidate blade airfoils were considered during the design process. Lift and drag coefficients were found for each using XFOIL [Drela]. From this the angle of attack corresponding to a maximum lift-to-drag ratio was determined (Figure 6).

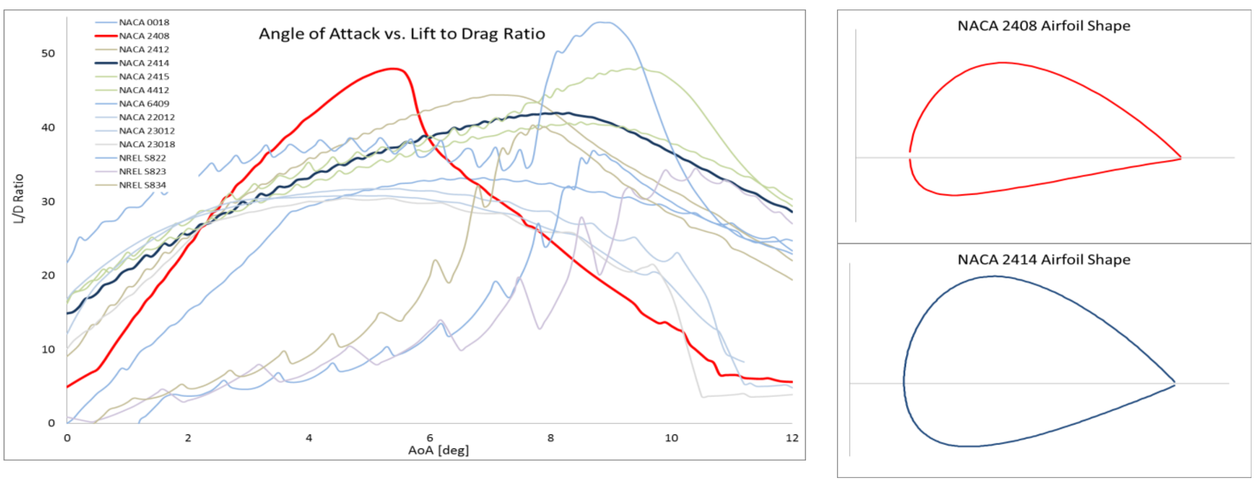


Figure 6. Angle of Attack vs. Lift Drag Ration for Various Airfoils

The lift and drag coefficient as a function of angle of attack were calculated using XFOIL [Drela] and imported into a Betz-optimal blade approximation from which the span-wise blade chord and twist were determined. Next an in-house Blade Element Momentum Theory Code (BEMT) was used to compare the coefficient of performance for different designs at the design wind speed (Table 2).

Table 2. Theoretical Coefficient of Performance for various airfoils

Airfoil	0006	0018	2408	2414	2415	22012	23012	23018	S822	6409
Optimal AoA	Not conv.	7	5.3	8.3	8.5	5.9	5.5	6.1	9.8	3.7
Cp	Not conv.	32.14	36.35	36.12	35.74	29.11	29.98	31.13	32.53	34.02

A NACA 2414 airfoil was selected due to its high coefficient of performance, its structurally advantageous thickness and its moderate stall behavior. A turbine rotor diameter of 2.5 meters will deliver the required 1,565 W-h to the kiosk at a mean wind speed of 5 m/s (11mph). The turbine has a target rated power of 1,560 W at a wind speed of 11 m/s. The desired cut-out speed is 20 m/s (45 mph) and the turbine blades are designed to withstand maximum sustained winds of up to 60 m/s (135mph). Between the cut-in and cut-out wind speeds, the blades were analyzed using the BEMT code (Reynolds number: Re = 421500 and tip speed ratio: TSR = 6). Above the cut-out speed, turbine blade loads were approximated using an equivalent arrangement of flat plates perpendicular to the flow. The maximum axial load is 1,500 N at 60 m/s (135 mph). The predicted axial load and power generation as a function of wind speed are shown in Figure 7.

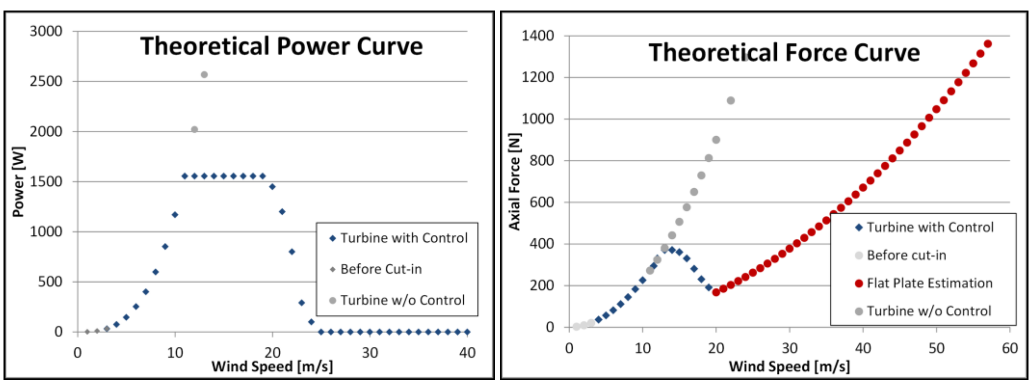


Figure 7. BEMT Results for Power and Axial Load at Varying Wind Speeds

Careful siting is critical to the success of wind turbine installations. The time required for a functional kiosk to recharge 150 auxiliary batteries as a function of time is shown in Figure 8. A wind-only solution should only be considered when daily power-average wind speeds of 5 m/s (11.2 mph) and greater are available; however, a hybrid wind-solar strategy should be considered at sites with lower average wind speeds.

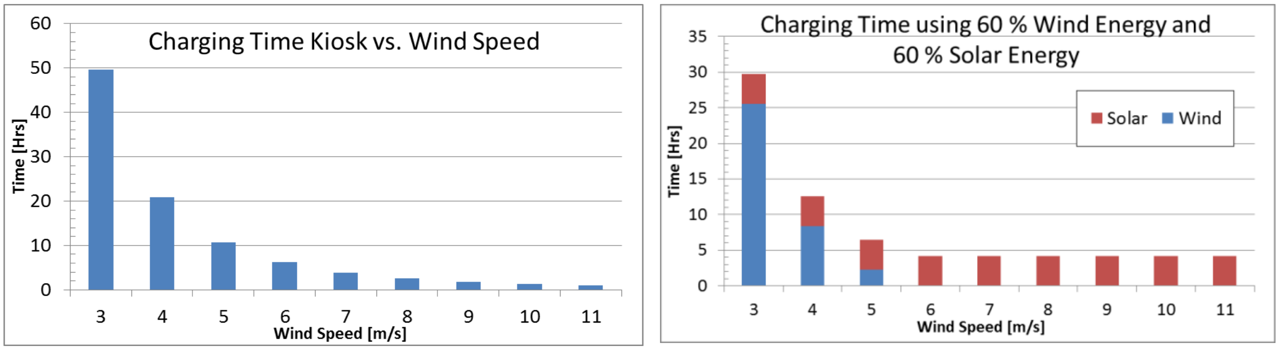
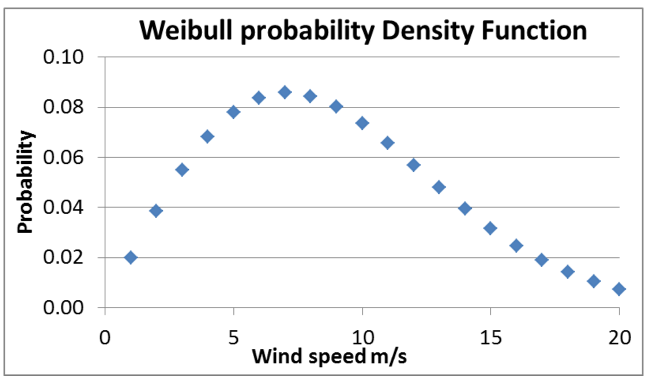


Figure 8. Time Dependence of Wind Speed for Charging the GoJuice Kiosk

A modular 250 W solar panel can be attached to the turbine, reducing charging times significantly in areas with a lower power-average wind speeds ranging from 4-5 m/s. The times calculated in Figure 8 can be reduced when looking at the Weibull distribution of wind speed. When a Weibull distribution (Shape Factor= 2) is employed, these power average velocities are increased and should be considered in the selection of kiosk sites with wind turbines (Figure 9).



Average wind u	Weibull average wind u	Power output Wind	Power output Weibull	% Difference
3.10	3.85	35.89	68.55	0.48
4.87	6.05	139.27	265.99	0.48
7.09	8.80	428.59	818.53	0.48
8.86	11.00	837.10	1598.71	0.48
10.19	12.64	1273.10	2431.43	0.48

Figure 9. Weibull Probability Distribution of Wind Speed.

Turbine Blade Manufacturing: To minimize weight and improve blade-to-blade consistency, the full scale turbine blades are manufactured from molded fiberglass. The pressure and suction sides of the blade were fabricated separately using two female molds. A desktop CNC machine with a ¼" ball mill was used to machine the blade molds from blocks of machineable Urethane foam (Ultra Machinable Prototyping foam, McMaster-Carr).

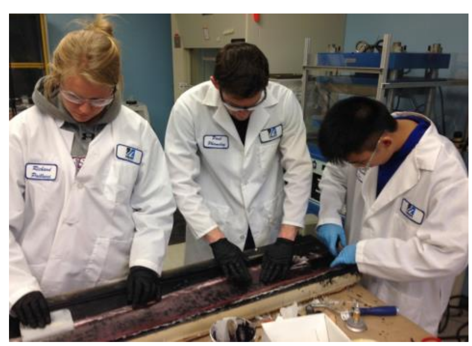


Figure 10. Release Film Application

Two layers of black pigmented gel coat were applied to the mold surfaces to create a hardened, smooth and impermeable surface. Prior to the fiberglass layup, a layer of mold release wax and Polyvinyl Alcohol (PVA) was applied to prevent the epoxy from adhering to the molds. An epoxy resin (2000, Fiberglass) was mixed with a cure hardener (2060, Fiberglass) and a 5 percent black epoxy pigment (43 Black Polyester, Fiberglass). Once mixed, a thin layer of resin was spread over the blade mold surface and four sheets of fiberglass fabric were layered onto the mold (Figure 10). The pressure side of the blade was reinforced using sheets of 3/32" balsa core. A layer of a perforated release film and a breather fabric was layered on top of the blades and vacuum bagged to compact the composite and to remove the excess resin. (Figure 11)

Figure 11. Blade Assembly

The blade was cured at ambient temperature, after which the bagging was removed from the blade halves and the blades were removed from the mold. A dremel tool with a diamond-reinforced cutting wheel was used to cut along the edges of the blade. To reinforce the root as well as attach the blades to the hub, a 3.75" by 0.75" piece of oak was glued to the root of each blade section.

Hub and Tower Assembly

Objective: The wind turbine hub and tower provide the critical connection between the wind turbine and the ground. This assembly must enable passive wind-alignment and be able to withstand the maximum wind loads from the turbine and shroud. Finally, the system should be lightweight and easy to install. Overview: A 4.0 meter tower structure supported by four guy-wires was designed to position the wind turbine for improved wind power extraction and maintain a ground clearance of just under 3 meters. A tower structural analysis has been performed to ensure the lightweight tower can sustain the maximum design wind loading. Modeling and Testing: A minimum tower height of 4.0 meters was selected to provide sufficient clearance for the average human male (1.8 meters). To maintain a cost effective design, standard steel tubing was considered. Considering this tower height, a beam bending analysis was performed to determine the basic tower dimensions. For wind speeds up to 15 m/s, a minimum of 48.3 mm OD and 3 mm thickness is required for the steel pipe. This was determined by modeling the turbine blade as a thin disk perpendicular to wind flow and calculating the drag force as shown in Figure 12. A maximum bending stress of 209.6 MPa is expected 1.25 m below the mounting position of the turbine. It is at this location where 4 steel guy wires with a 4.8 mm minimum diameter will attach to reduce the bending stresses in the tower (3.6 kN of tension per wire). The tower base can either be secured using a steel ground spike if the ground conditions are suitable enough or using bolts through a flange if operating over concrete. The guy-wires will be anchored outward similarly and tightened with tensioning devices. For purposes of testing, the built tower was 2.5 meters tall with an adjustable hub mount. The tower is welded to a flange and bolted to a wooden platform where the guyed wires are also attached. The entire structure is then to be weighted down. A prototype 2.0 meter tower has been constructed using galvanized scaffold tube/steel pipes for structural strength and corrosion resistance.

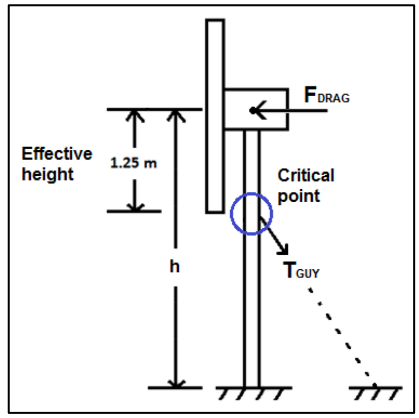


Figure 12. Support Structure

Electrical Generation and Control

Objective: The electrical power generation and control system converts the wind energy into direct current (DC) power, while maintaining safe operating conditions across a range of wind speeds.

Overview: An off-the-shelf electrical generation and control system has been specified for the full-scale wind turbine. A three phase, permanent magnet generator (currently specified as an EnergyStar 1kW generator) is used to convert the turbine mechanical enegy to AC power. An off-the-shelf emergency braking switch is installed, followed by a high current three-phase rectifier. Initially, an off-the-shelf Maximum Power Point Tracking controller will be prescribed for the product to achieve optimal wind power extraction and govern turbine operation in high winds; however, over time GoJuice will design and source a custom MPPT controller of its own.

Wind Lens

Design Objective: The purpose of the wind lens is to improve the wind turbine's power generating capability by, (1) increasing the wind kinetic energy through the rotor while maintaining reasonable wind turbine system axial loads, (2) reducing variation in wind speed, and (3) providing improved wind-alignment capability.

Design Overview: The overall design is inspired by recent research into shroud[i] and wind lens[ii] flow augmentation. An annular ring with an airfoil cross section is used to channel the flow toward the turbine rotor. A diffuser or brim portion behind the annular channel is designed to generate vortices behind the turbine rotor, which in turn create a lower pressure region behind the wind lens that augments the flow through the rotor.

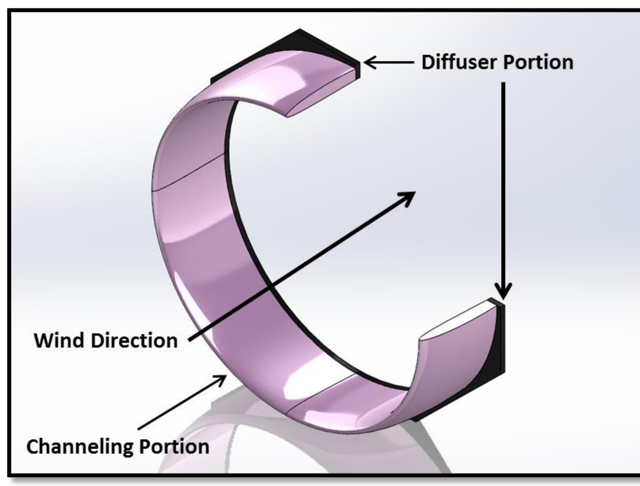


Figure 13. A Cut-Away CAD Rendering of the Wind Lens

Table 3. Velocity and Pressure Airfoil Comparison

	NACA 2408	NACA 2412	NACA 2414	Prototype 1	Prototype 2
Maximum Velocity (m/s)	20.8	20.7	20.7	20.9	20.2
% Increase in Velocity	18%	17%	17%	18%	14%
Minimum Pressure (Pa)	-39.0	-26.6	-23.2	-33.3	-54.4

Based on AutoDesk FlowDesign CFD studies, a truncated NACA 2408[iii] airfoil for the channeling section combined with an octagonal diffuser yields the optimal performance. Figure 13 is a computer aided design (CAD) rendering of the wind lens design.

Modeling and Testing: Simulations were performed comparing circular, rectangular, and octagonal shaped diffusers. An octagonal diffuser yielded the best performance increase (seen in Table 3); the rectangular design created the best flow augmentation, but unfortunately also generated prohibitively large axial forces. A comparative analysis of three airfoils was performed (Figure 14). The flow simulations were performed at 17.7 m/s, the maximum competition test speed in the wind tunnel. Table 3 exhibits the maximum velocity, minimum pressure, and percent increase values of the NACA 2408, NACA 2412, and NACA 2414 airfoils as well as the first and second prototypes. The NACA 2408 slightly outperformed the other airfoils under consideration, therefore it was selected. AutoDesk FlowDesign simulation results are shown in Figure 14.

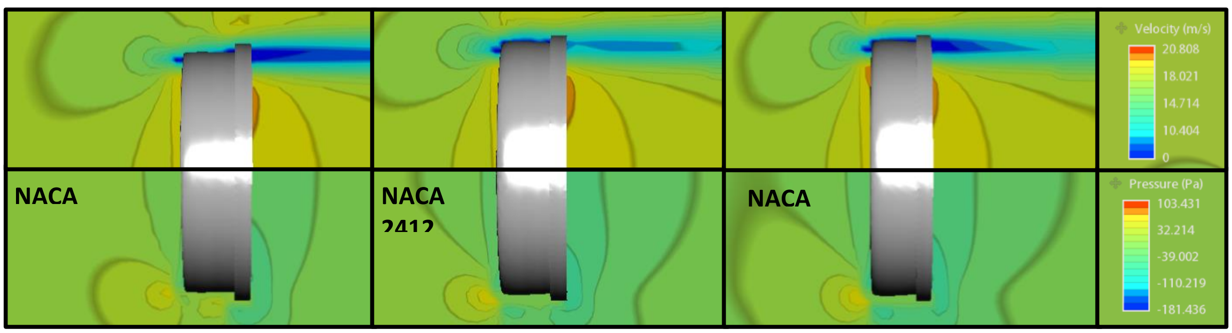


Figure 14. Airfoil Simulation Results for Velocity (Top) and Pressure (bottom)

The evidence in support of the wind lens is clear with increased power ranging from 36-47% when going from no lens to with lens at the same wind speed.

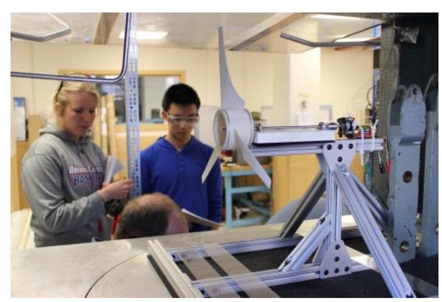


Figure 15. Prototype of Validation Turbine

Validation (Competition)-Scale Turbine

Blade Design: The test turbine blades were designed according with the sizing constraints placed by the Collegiate Wind Competition and are used to validate the design process used for the full-scale wind turbine. At this lower Reynolds number (Re ~ 80,000) and reduced turbine rotor diameter several design modifications were made, including: (1) a thinner NACA 2408 airfoil was used to compensate for the thicker boundary layer at this lower Reynolds number (2) new blade chord and twist distributions are required to maintain an optimal rotor design with a tip speed ratio of 6 (3) a gearbox was used to increase the generator rotational velocity and (4) appropriately different manufacturing techniques were adopted. These adjustments were made to allow testing and validation of the design process. The blades for the validation turbine were designed using Solidworks and 3D printed using ABS (Figure 15).

Testing and Design Validation: The objective of the testing was to verify the BEMT code outputs, measure the effectiveness of the wind lens, and to measure the optimal load at varying wind speeds. The turbine was installed in UMass Lowell's 2ft x 3ft x 4ft subsonic Wind Tunnel. For these tests, a 5-ohm rheostat was used to provide an adjustable load for turbine performance tuning. These results illustrate the importance of low electrical circuit resistance on increasing energy output efficiency.

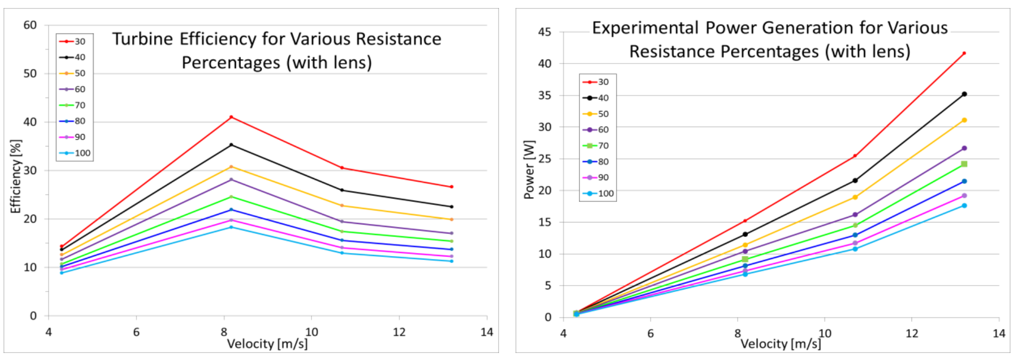


Figure 16. Effect of Wind Velocity and Electrical Resistance to Efficiency and Power

The left hand side of Figure 16 shows Efficiency vs. Velocity for the optimal velocity range of 6-10 m/s. This corresponds to an efficiency range of 27-42% with a 1.5-Ohm load and 13-18% with a 5-Ohm load. The experimental power curves exhibit a non-linear wind speed-power relationship that bears some resemblance to the expected cubic behavior. The tunnel-scale turbine power output varied from 6-23 W at 30% loading in the optimal velocity range and 4-9 W with a 5-Ohm load in the optimal velocity range.

Nacelle Design Overview: The main objective of the test nacelle design (Figure 17) was to enclose a gearing system to improve the stability of torque transfer. By providing a gear ratio of 2.5:1, the angular velocity of the generator can be improved, resulting in a larger power output. The final design is comprised of a motor housing that mounts to a rear plate which sandwiches the gear system between. The majority of the nacelle has been manufactured in 3D printed ABS material; however it was designed to be fabricated out of aluminum stock if durability or heat transfer from the motor became a concern.

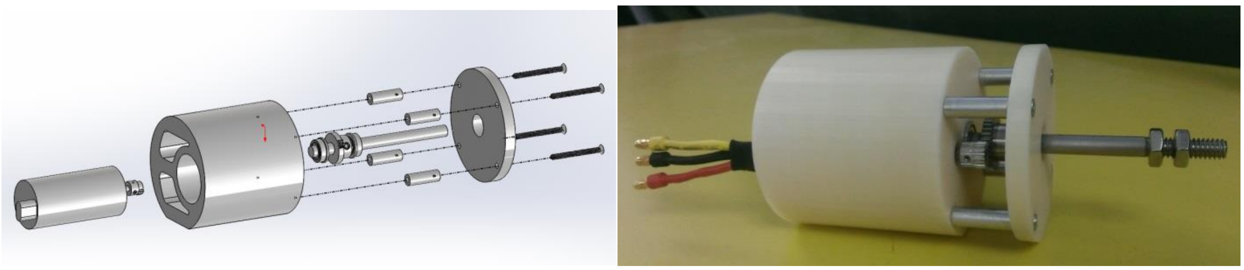


Figure 17. Exploded View and Final Prototype of Nacelle Design

Wind Lens Validation: Wind tunnel tests were performed to compare the forces on the turbine support structure. Figure 18 provides the force versus wind speed data for prototype one (a circular diffuser) and prototype two (an octagonal diffuser) (Figure 19).

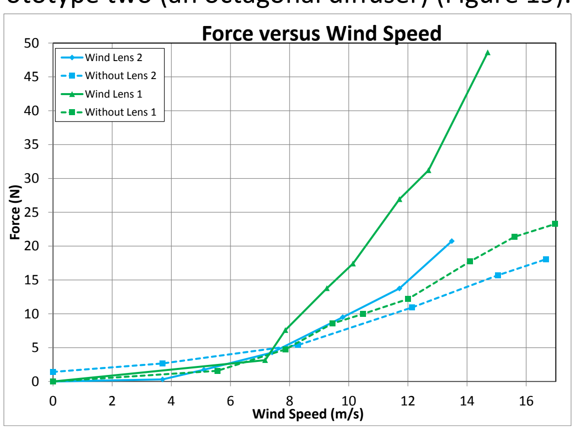


Figure 18. Force on turbine with, without wind lens.

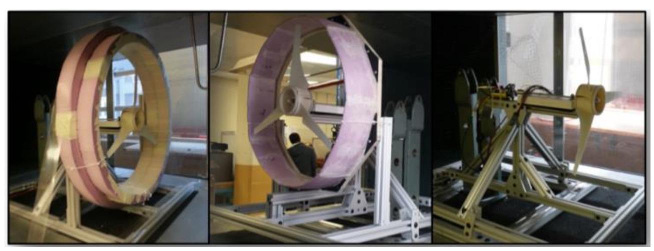


Figure 19. Prototype 1 with lens (Left), Prototype 2 with lens (Middle), Prototype with no lens (Right).

A significant force difference was observed between the two prototypes above a velocity of 7.66 m/s. After reaching this critical wind speed, the observed forces are higher with the lens than without.

Wind tunnel tests were performed evaluate the effect of the wind lens on generator rotational speed. The wind lens increases the average generator speed by a minimum of 12% across the three wind speeds. A range of wind speeds were tested for the turbine with and without the lens. The evidence in support of the wind lens is clear with increased power ranging from 36-47% when going from no lens to with lens at the same wind speed (Figure 20,21).

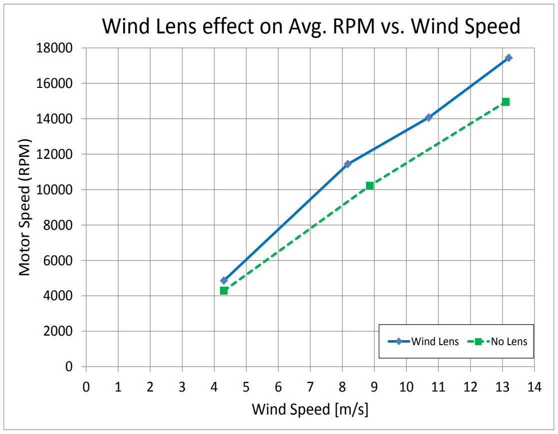


Figure 20. Effect of wind lens on avg. rpm vs. wind speed.

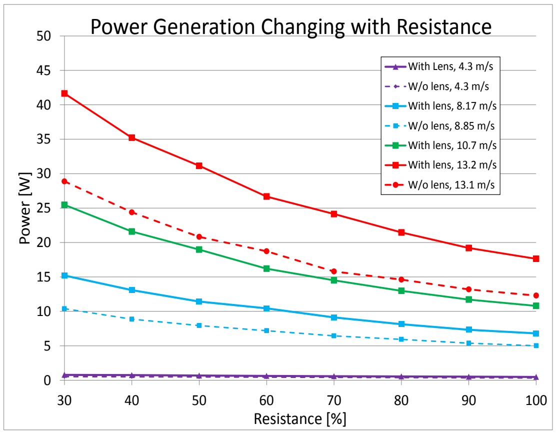


Figure 21. Power Measurements with Increasing Resistance and Wind Speed with and without Wind Lens.

Electrical Power System and Control

The prototype power system consists of a three phase rectifier bridge. Rectified power is supplied to a power conditioner module and a separate buck/boost converter. Current monitoring from the power conditioner is performed via low resistance current sensing resistor in line with power output. An operational amplifier is used to determine current flow through the sense resistor. When turbine shutdown is necessary, the controller activates a set of normally open relays, which impose a short circuit across the three phase generator output. Under normal wind conditions, the high load placed on the generator causes sufficient back-torque to stop the turbine rotor. The relays are latching and require intervention to reset, as the controller will lose power during the shutdown. Off-the-shelf parts will be used for the initial prototype design. Figure 22 shows a basic system schematic.

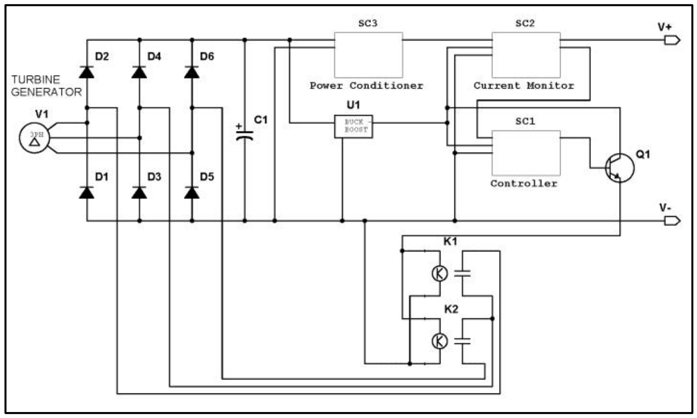


Figure 22. System power and control schematic.

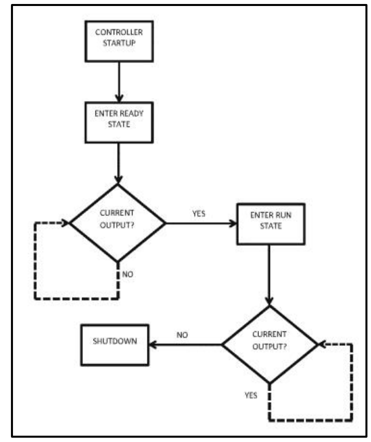


Figure 23. Basic Controller Logic

Modeling and Testing:

On startup, the turbine controller enters a ready state. In the ready state, the controller monitors current output from the power conditioner. Once current output is detected, the controller enters a run state. In the run state, the controller continues to monitor current output. When current is no longer detected, the controller shuts down the turbine by activating the shutdown relays. Figure 23 shows the basic controller logic.

Kiosk Technical Documentation

Design Objectives: The primary goals of the GoJuice kiosk are (1) to provide an effective user experience through a professionally-designed, interactive user interface; (2) to provide a nearly instantaneous auxiliary mobile phone battery exchange; (3) to protect and recharge auxiliary and station batteries both outdoors and indoors; and (4) to provide a fourth-generation internet connection between the station and GoJuice's user database/advertisement servers. A team of 3 were tasked for the concept, design, user-interface and interaction, and construction of the GoJuice kiosk.

Figure 24. GoJuice Kiosk

Engineering Specifications

Table 5 below, represents the daily energy requirement for a GoJuice Kiosk that will be powered by 100% Wind, and/or a hybrid system including solar and grid.

Table 5. Kiosk Power Consumption and Daily Energy Requirements

Mode	Power Consumption	Hours/day	Daily Energy Requirement
Interface Mode	200 W	2.5 h[1]	500 W-h/day
Sleep Mode	10 W	21.5 h	215 W-h/day
Charging Mode	7.5 W per battery	0.75 h x 150 charges	850 W-h/day
Total			**1,565 W-h/day**

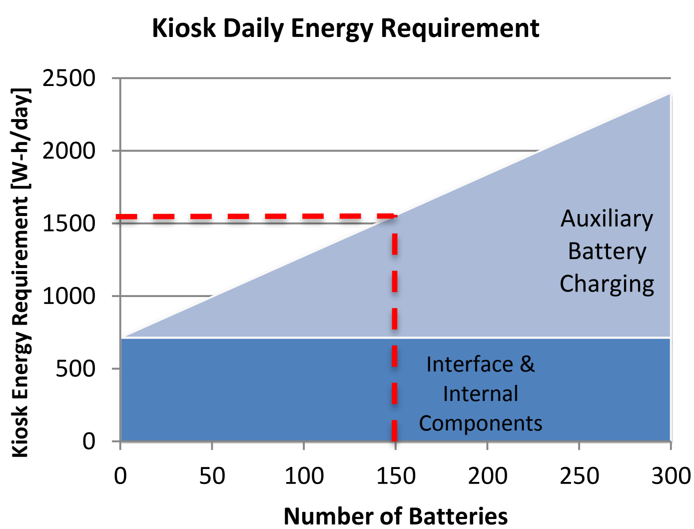


Figure 25. GoJuice Kiosk Required

The energy generated by the wind turbine and/or solar panels for off grid kiosk system will store generated energy in two deep-cycle batteries, each 12 Volt and 125 A-h. The deep-cycle batteries will provide the necessary power to charge 10 auxiliary batteries at any given time, which would be sufficient to support 150 auxiliary batteries over a 15-hour time period. These 12-Volt batteries are connected to the kiosk universal 12-V power bus. For kiosks connected to the electrical grid, there is no need for internal kiosk energy storage, and green power is exchanged with the grid through net metering; hence, AC wind power and DC solar power are transformed to 12 V-DC and directly connected to the internal kiosk power. The kiosk has two operational states: an interface mode, and a sleep mode, and a continuous charging mode. The interface mode is when the kiosk is in operation by playing an advertisement and exchanging auxiliary batteries. Sleep mode is during which the kiosk is running only the screensaver and the RFID embedded system.

During charging mode, most of the power harnessed is routed to recharge the batteries. Each station stores and manages 150 auxiliary mobile phone batteries, each 3.7 V and 1,200 mAh, which are directly recharged from the 12-V power bus. Depending on the number of battery exchanges occurring at a given kiosk, the daily energy requirement would increase incrementally by 5.625 W-h/charge, with a fixed energy cost of 715 W-h/day, as represented in Figure 25. The conversion of green power to usable energy will involve some losses. In the case of wind power, there will be losses due to the conversion to AC to DC current by a rectifier and voltage down-regulation to charge the auxiliary batteries. Losses of about 10% are typical for each conversion. This represents a 10% loss three times, or a loss factor of (1 – 0.1)3 = 0.729. This means around 73% of the power produced can be used for charging.

User Interface and Interaction: Kiosk users are first identified as they approach the station using the RFID tag embedded in the GoJuice phone case. The auxiliary battery exchange is performed efficiently (< 1 minute) with minimal user interaction. During the battery exchange, the customer views a targeted interactive advertisement streaming on the kiosk's low-power touchscreen, followed by a summary of their green energy savings (Figure 26). A detailed user experience flowchart is provided in Figure 27. The user experience is augmented by downloading the optional GoJuice phone application, which provides: (1) a synopsis of the environmental impact of phone charging behavior; (2) the locations of nearby GoJuice stations; and (3) storage of electronic coupons served by GoJuice.

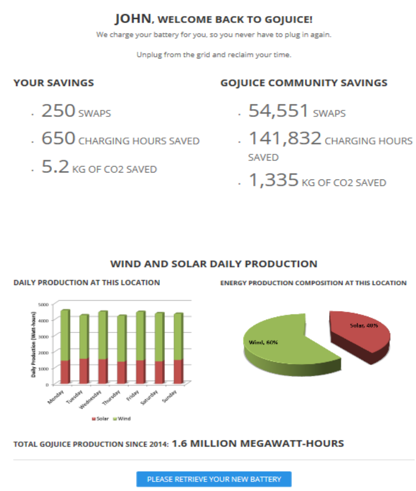


Figure 26. User Interface

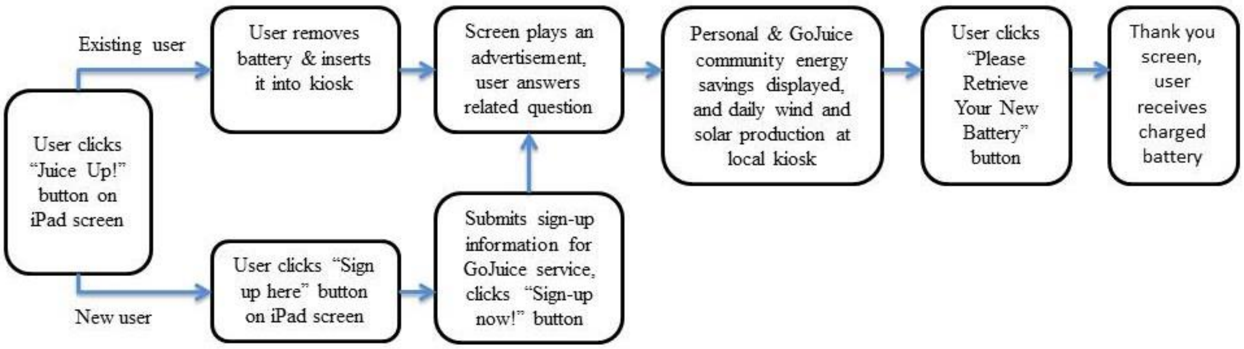


Figure 27. User Experience Flow Diagram

To provide user-interactivity, a touchscreen display, such as an iPad, will be used to handle all transactions. Internal to the kiosk, an automated robotic receiving mechanism will accept the customer's batteries and delivers them to an H-frame charging assembly (Figure 28). Subsequently, a fully charged battery is removed from the charging assembly and placed into a pick-up slot. A wireless access point will also be installed to provide network connectivity to the consumer.

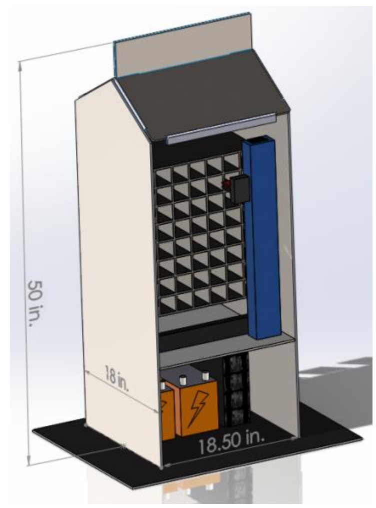


Figure 28. Kiosk Internal Structure

Figure 29 shows how the power generated by the three phase generator is sent to the rectifier, which converts AC to DC that is boosted or bucked as necessary. Then the power is transferred to a voltage controller regulator, which directly powers the display and the cell phone charging system and uses any additional power to charge the battery bank. Excess power is dissipated by a resistor bank. In hybrid systems, solar panels may provide a secondary DC power source. The system can also be integrated to the power grid to sell excess power produced rather than dumping it into a resistor bank.

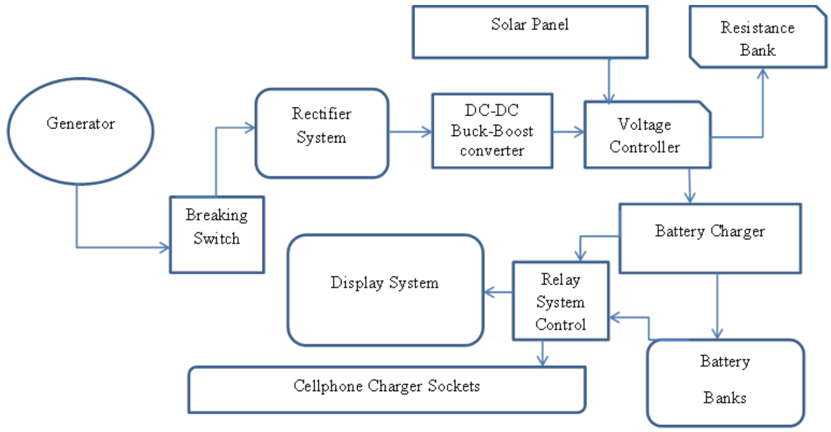


Figure 29. Electrical Block Diagram

Phone Case Technical Documentation

Design Objective: The main goal of the GoJuice phone case is to provide a seamless interaction between the GoJuice Kiosk and the user's phone while maintaining the traditional protective function of a phone case. The phone case's functionality includes: external battery storage, energy transfer by recharging the smartphone's internal battery, and providing protection and support by improving the ergonomics to better fit with the user's hands.

Design Overview: The prototype GoJuice phone case is modeled around the Apple iPhone 5 design. The case is designed for the smartphone to slide in from the top to connect with the built-in Lightning connector. A custom electronic circuit is embedded in the case to charge the phone's internal battery using the auxiliary GoJuice battery. The phone case provides space to house the external battery without hindering all OEM ports and buttons (Figure 30).

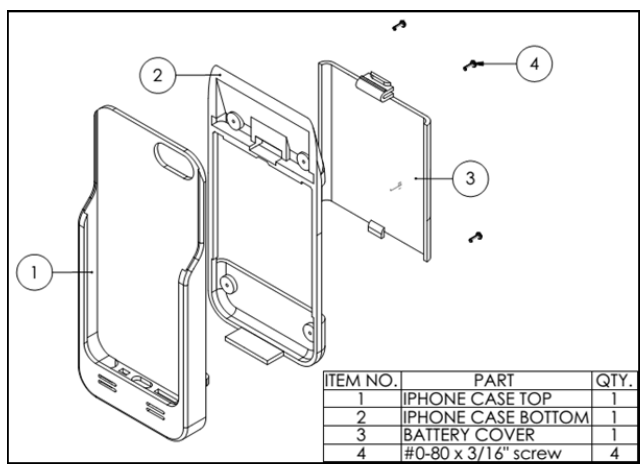


Figure 30. GoJuice Phone Case Assembly Diagram

Modeling and Testing: Having the phone slide in from the top of the case, as with this reference case, was decided to be the most appropriate method to connect the phone to the external battery. Features such as length, thickness, battery cavity size, cut-outs for OEM ports, and handling-grip were changed to better suit the needs of the user. Prototypes of the GoJuice phone case were manufactured from 3D-printed ABS plastic. An electrical circuit was created to allow for recharging of the smartphone by using the external battery. This was accomplished by satisfying two required inputs for the iPhone 5: an input 5.0 V_{DC} and an input 2.0 V_{DC} on the data terminals to communicate with the iPhone 5. A DC/DC boost converter was necessary to step-up the 3.7 V_{DC} output of the external battery to 5.0 V_{DC} while providing a maximum rated current of 600 mA. The standard Apple-issued power supply that is included with the iPhone offers a current draw of 500 mA. Major design improvements from student surveys include: making the battery cover easier to remove, additional space to house the electronics, and increased ergonomics for the user by rounding sides/corners and secure attachment of the phone and case.

Engineering Diagrams: The electrical schematic of the GoJuice phone case is shown in Figure 31.

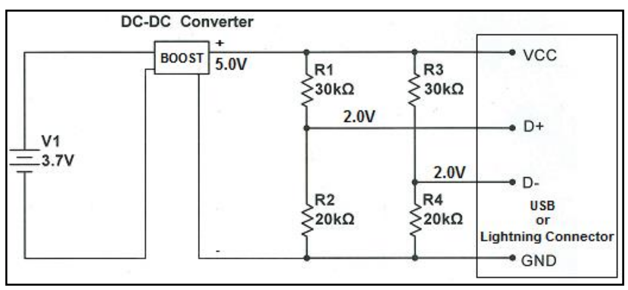


Figure 31. GoJuice Phone Case Electronics Schematic

[i] Aranake, Aniket C., Vinod K. Lakshminarayan, and Karthik Duraisamy. *Computational Analysis of Shrouded Wind Turbine*. N.p., n.d. Web.
[i] "Kyushu University RIAM Wind Engineering Section Homepage - Wind Lens." *Kyushu University RIAM Wind Engineering Section Homepage - Wind Lens*. N.p., n.d. Web. 11 Apr. 2014.
[i] "NACA 2408 (naca2408-il)." *NACA 2408 (naca2408-il)*. N.p., n.d. Web. 12 Apr. 2014.