

UBC Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

**AMS/SEEDS Energy Producing Mobile**

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**MECH 457**

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**AMS/SEEDS Energy Producing Mobile**

**MOBILE<sup>2</sup>**

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# 1.0 Objectives

Mobile<sup>2</sup> is a vertical axis wind turbine that will be placed in the UBC Plaza between the AMS Student Nest and the Robert H. Lee Alumni Centre. The project aims to educate the public on sustainable energy and act as a gathering place to promote community building; additionally, as an art piece inspired by Alexander Calder, it will add to the aesthetic appeal of the plaza. Though Calder's pieces were not designed to generate electricity, Mobile<sup>2</sup> will harness wind power using leaf shaped airfoils to drive a shaft connected to a generator. The major mechanical components have been designed and analysed to fit inside the structure: this includes the airfoils, rotor, and shaft. However, due to low wind speeds in the UBC Plaza, it is recommended that more optimization be done to reduce the starting torque of the system.

The main objectives of this project were the design, manufacture and implementation a vertical axis wind powered turbine while collecting, transforming and storing wind energy. The project will also output power to charge at least one cell phone device around the UBC Plaza, as shown in Figure 1, while educating the public about sustainable energy methods and building a sense of community by providing seating space.

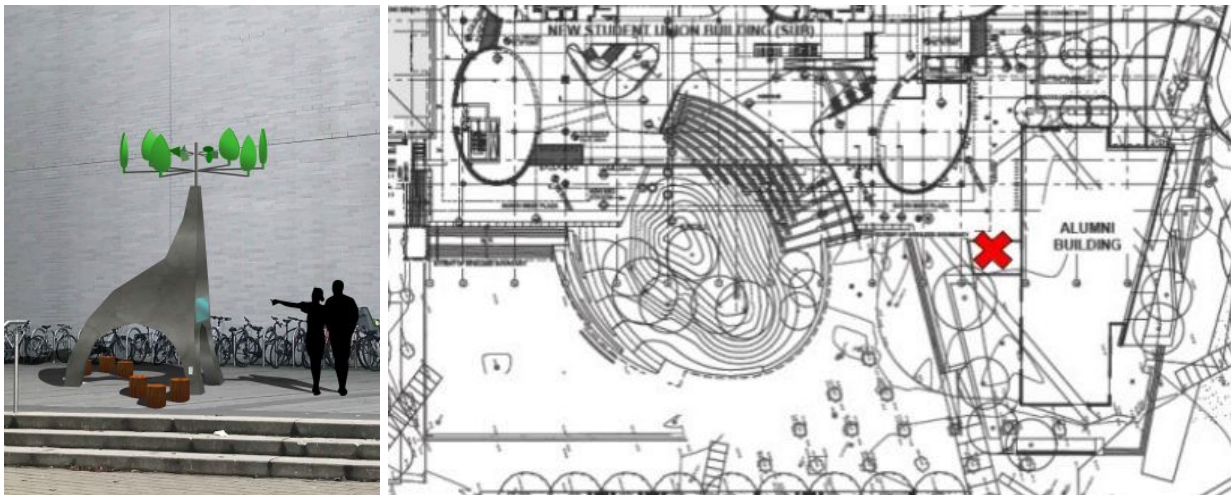


Figure 1. Left: final product. Right: location of system.

## 1.1 Overall Project Process

Below is a description of the overall process that the project has taken. Steps 1 through 9 have been completed, step 10 is perform recommendations and steps 11 onward are the next steps to take following completion of the recommendations.

1. Determine location
2. Secure funding
3. Design structure
4. Detailed location to avoid underground services
5. Footing designed based off of structure
6. UBC consultations
  - a. Campus and Community Planning
  - b. Robert H. Lee Alumni Centre
  - c. UBC Building Operations
7. Prototyping and design
  - a. Airfoils
  - b. Shaft
  - c. Rotor and power transmission components
  - d. Electrical circuit
8. Development permit application
9. Public open house
10. Perform recommendations as stated in section 4.0 of this report
11. Manufacturing methods
12. Footing construction
13. Structure fabrication and installation
14. Fabrication of airfoils and mechanical system
  - a. Bearing selection
  - b. Safety mechanism
15. Installation of mechanical and electrical components
16. Testing and commissioning

## 2.0 Design and testing

The following sections describe the final specifications and processes in the development of the Mobile<sup>2</sup> project.

### 2.1 Design Process

The design process started with multiple meetings with the clients to determine the objectives for the project<sup>1</sup>. Once the scope was determined, concepts were brainstormed and evaluated based off the requirements and evaluation criteria<sup>2</sup>. Once the choices were winnowed and a concept was selected, it was technically analyzed and designed in detail<sup>3</sup>. Lastly, a list of recommendations have been put together from the results and is summarized at the end of this report.

### 2.2 Functionality

The wind turbine collects wind energy and converts it into electrical energy for users to charge their phone. The footing will function as a base for supporting the structure, energy capturing system (airfoils and rotor arms), the power transmission system (main shaft, gearbox) and the energy conversion system (generator, battery, supporting electrical system). The structure will function as a storage system and prevents the internal components from weathering effects. The power transmission system transfers the rotational kinetic energy from the energy capturing system to the energy conversion system. The energy conversion system converts the rotational kinetic energy from the airfoils and turns it into electrical energy that can be used to charge phones. The energy capturing system collects wind energy and converts it into kinetic rotational energy through its airfoils.

### 2.3 Major Components

During the development of this project, there were five major areas that were identified to be essential components for the final implementation of the project.

#### 2.3.1 Footing and structure

The structure design was selected based on the “Big Crinkly” mobile from Calder’s designs<sup>4</sup>, which originated from various brainstorming meetings with the clients in the early stages of the project. The construction of the model shown in figure 1 and its drawings sent to RJC were

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<sup>1</sup> Refer to Dossier 1 and 2 for the project description, requirements and evaluation criteria.

<sup>2</sup> Refer to Dossier 6 for project concepts and evaluation.

<sup>3</sup> Refer to Dossier 8 for technical analysis of components and Dossier 11 for the detailed designs.

<sup>4</sup> Refer to Dossier 4 for formal proposal to client

developed by Michael Kingsmill and his assistant Julia to design the final footing at the location specified in the project proposal<sup>5</sup>. The design was submitted to Holaco construction for an initial quote that turned out to be \$16,000, which included excavating the location, forming the molds and installing the footing, while fabrication of the body was submitted to West Arc with a final quote of \$16,000.

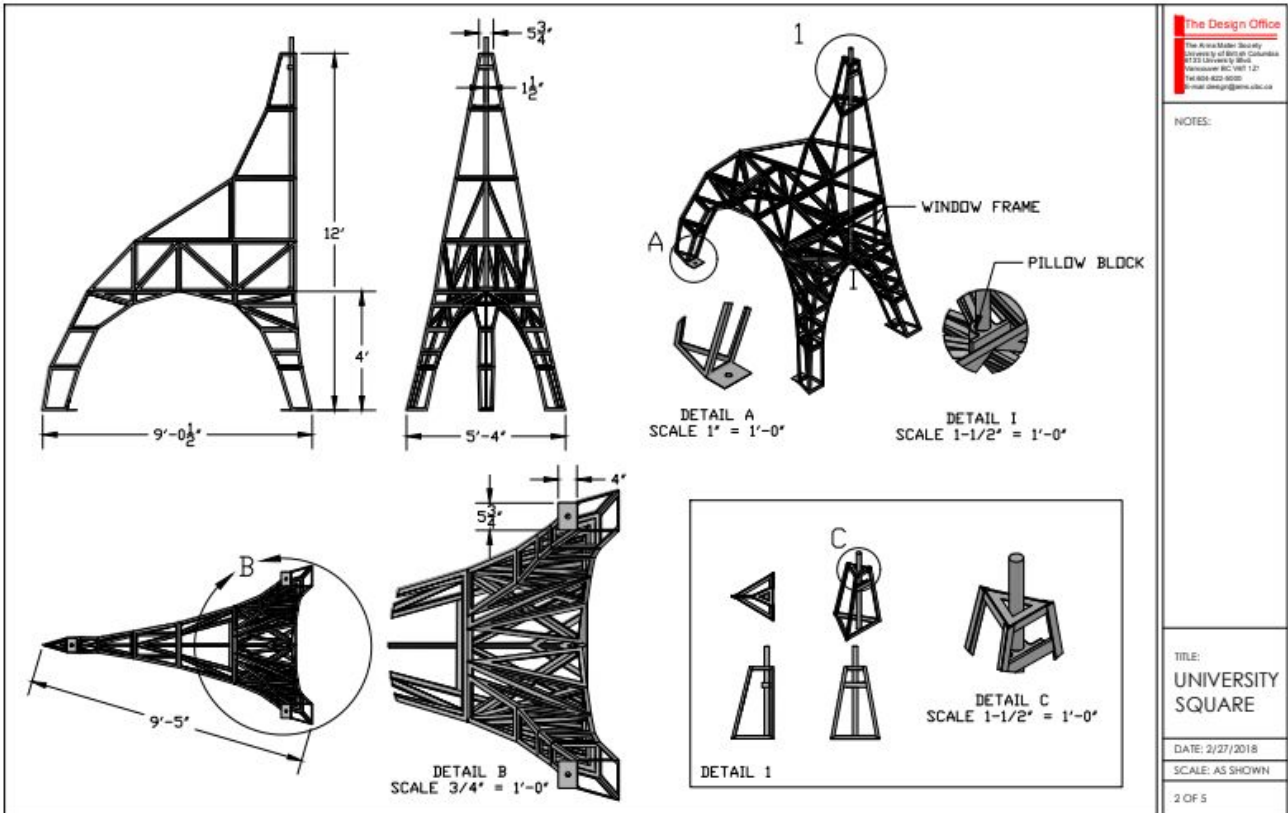


Figure 1. Sample drawings

## 2.3.2 Shaft

### Shaft design

Technical analysis was performed on the shaft using both Shigley's Mechanical Engineering Design as well as using ANSYS R.18.1. For the shaft, the fatigue safety factor is found to be 79, the yield safety factor is 105 and the maximum deflection of the shaft is 0.00057mm<sup>6</sup>.

<sup>5</sup> Refer to Dossier 10: Construction Process

<sup>6</sup> Refer to section 3.0 Mechanical Analysis in Dossier 8 for the full technical analysis of mechanical components.

## Rotor Arm and Power Transmission

The rotor arms that attach the airfoils to the hub has been designed and analyzed for yield and deflection. The hub that attaches the rotor arms to the shaft has also been designed. Lastly, a key has been sized and analyzed to transfer power from the rotor arms to the shaft<sup>7</sup>.

### 2.3.3 Power generation

The final electrical system implemented in the wind turbine consist of the AC generator, the wind turbine charge controller, an sealed lead-acid battery and the control circuit.

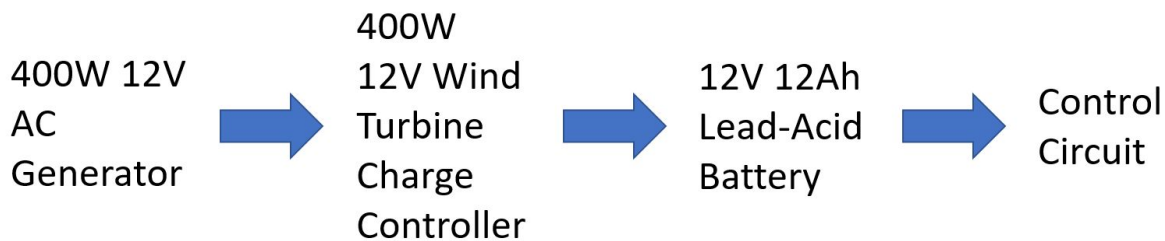


Figure 2. General electrical system block diagram

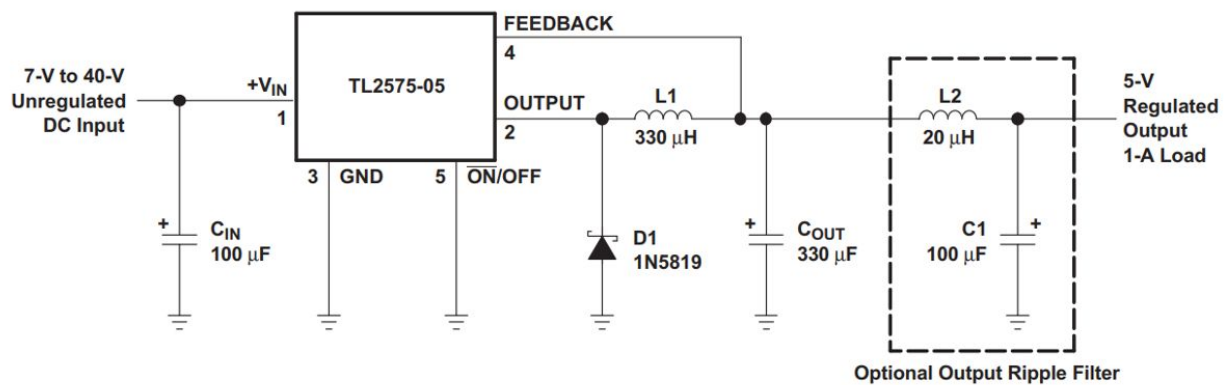


Figure 3. Control circuit diagram

The wind turbine chosen is the 400W AC12V Rare Earth Wind Turbine Generator Permanent Magnet Alternator from AliExpress. This turbine is chosen due to its low starting torque and startup speeds. The wind turbine charge controller chosen is the 400W 12V Controller Waterproof Wind Turbine Generator Charge Controller. It will prevent overcharging the lead-acid battery and act as an electronic brake when the wind turbine is subjected to higher wind speeds. For energy storage, we chose PBS's 12-Volt 12AH Sealed Lead-Acid Battery. They require minimal maintenance and have lower internal resistance than similar flooded batteries. The control circuit allows us to output 5V, 1A of DC current so that users can charge their phones safely from the wind turbine.<sup>8</sup>

<sup>7</sup> Refer to Dossier 11: Detailed Design for full designs of the mechanical components.

<sup>8</sup> Refer to Electrical System in Dossier 11 for the full specifications of electrical components.



### 2.3.4 Airfoils and turning mechanism

The final shape design for the airfoils was determined to be a vertical leaf shape as shown in figure 4 due to its aesthetic appeal to the client and better performance than other candidates during wind tunnel tests<sup>9</sup>. The final turning mechanism consists on a combination of this shape, five rotor arms and five airfoils that provide 21% more power than a four airfoil configuration system<sup>10</sup> with an internal connection as shown in Figure 5 that will fix the airfoils in position to prevent changes in angle of attack<sup>11</sup>.

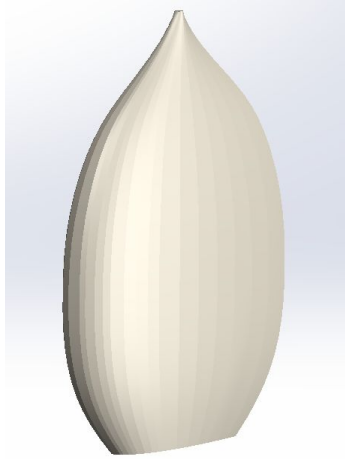


Figure 4. Vertical leaf shape airfoil

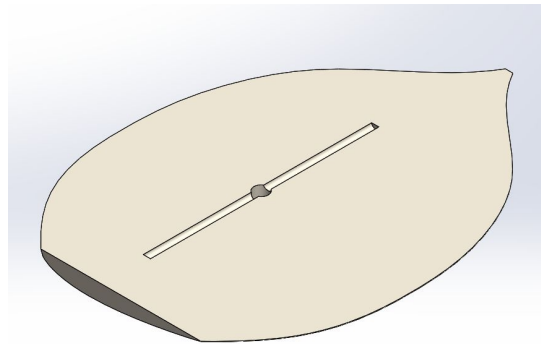


Figure 5. Internal connection mechanism to fix airfoil

The manufacturing of this airfoils for both testing purposes<sup>12</sup> and final product were investigated by the team and documented<sup>13</sup>. It is recommended that the final airfoils are formed using a CNC method, for which a quote was requested, and covered them with carbon fibre to make them

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<sup>9</sup> Refer to section 2.0 Airfoil Analysis in Dossier 8 for single airfoil analysis

<sup>10</sup> Refer to section 2.0 Airfoil Analysis in Dossier 8 for number of airfoil analysis

<sup>11</sup> Refer to section 3.5 Mechanical Analysis in Dossier 8 for welding connection analysis

<sup>12</sup> Refer to section 2.1 Prototype iteration #1 in Dossier 7 Concept function prototype

<sup>13</sup> Refer to section 3.1 Manufacturing of airfoils in Dossier 11 Detail design

durable and resistant to weather changes. Further analysis has been recommended to proceed with final construction of the system.

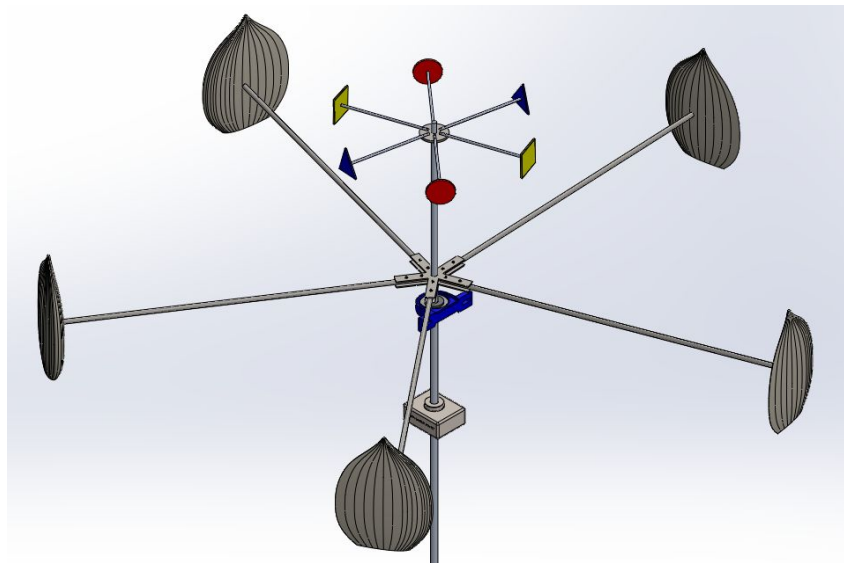


Figure 6. Final airfoil configuration and turning mechanism

## 2.4 Validation and verification

### 2.4.1 Validation

An initial user validation of the product was performed through a public consultation among the students, faculty, staff and visitors of UBC's community. The aesthetics and educational value of the product was evaluated through a public consultation which occurred on April 4th in the AMS Nest from 11:30 AM to 2:00 PM. Feedback was obtained through a survey form and conversations between the presenters and the public at the presentation. The project has initial public approval but requires additional work to verify whether the product will successfully increase the awareness of the UBC community about sustainable energy sources. For future validation, a recommendation is to keep track of users charging their phone over different periods of the year to determine whether users are receptive of the product.

### 2.4.2 Verification

The electrical system will undergo an electrical inspection by an accredited firm in BC to verify that everything follows the Canadian electrical code and is safe to use. The supervising engineer during installation will be responsible for ensuring the structure and the mechanical components are installed correctly. Once installed, the product can be verified by testing the USB ports to see if a charge is being supplied to a mobile device. It is recommended that it is first tested with a multimeter to ensure the correct voltage is being outputted.

## 3.0 Conclusions

There are many difficulties in designing a vertical axis wind turbine that is both aesthetically pleasing and operable in low winds. The key problem being the starting torque of the system and limitations in operation due to low wind speeds. In terms of design, the engineering analysis of the airfoils, power transmission system, electrical system, and structural elements has been completed. An overview of the project is follows:

- Airfoils: a five airfoil system with the vertical leaf shaped airfoil selected due to performance and aesthetic factors.
- Power transmission system: completed sizing of shaft, rotor arms, keys and bolts.
- Electrical system: specified components for charge regulation, energy storage and endpoint voltage regulation (control circuit).
- Structural system and footing: footing is ready to be constructed and structure is ready for manufacturing with assembly.

An initial user validation of the product was completed through a public consultation within the UBC community. The consultation gave insight on the feasibility of the project and how the public will react to its design. Everything was well received and it is strongly encouraged that the project continues to move forward.

## 4.0 Recommendations

The recommendations below are specified for the client as the next steps to follow to optimize the final system before construction:

- Optimize starting torque of the system to be as low as possible to maximize time the sculpture will be moving.
- Determine optimal gear ratio and manufacture gear box.
- Optimize energy conversion system through pulse width modulation and maximum power point tracking.
- Determine optimal mechanical brake mechanism - initial research suggests using a centrifugal brake.
- Design and manufacture free-spinning artistic element for the top of the structure.
- Airfoils: determine the best manufacturing method. Initial research suggests CNC machining of high density polyurethane foam with carbon fibre coating for durability to weather conditions.
- Power transmission system: determine and manufacture gearboxes with optimal gear ratio for maximum power output
- Electrical system: optimizing energy conversion system through pulse width modulation (PWM) and maximum power point tracking (MPPT).
- Mechanical safety system: determine optimal mechanical brake mechanism. Initial research suggests using a centrifugal brake as it adjusts its braking strength according to the rotational speed of the object.
- Aesthetic element: design and manufacturing of free-spinning artistic element on top of the energy-generating airfoils.
- User validation: Conduct study to determine the frequency of usage and the impact of the wind turbine in terms of raising awareness among the UBC community about sustainable energy.