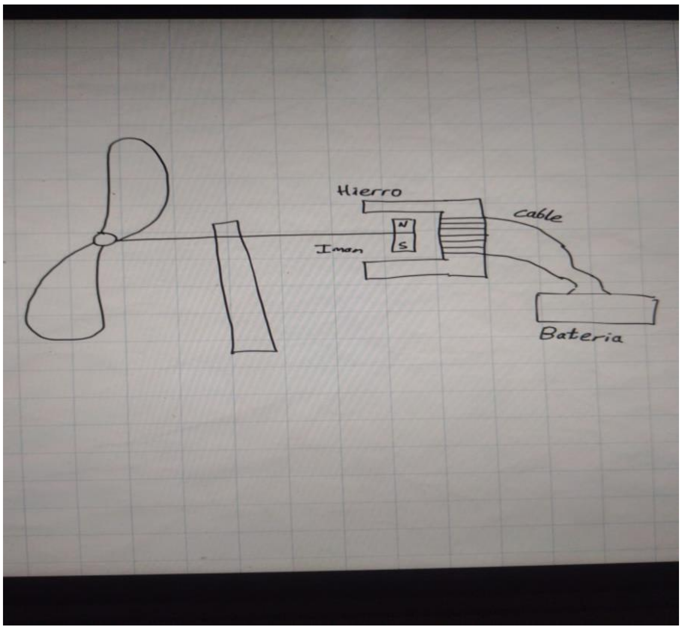
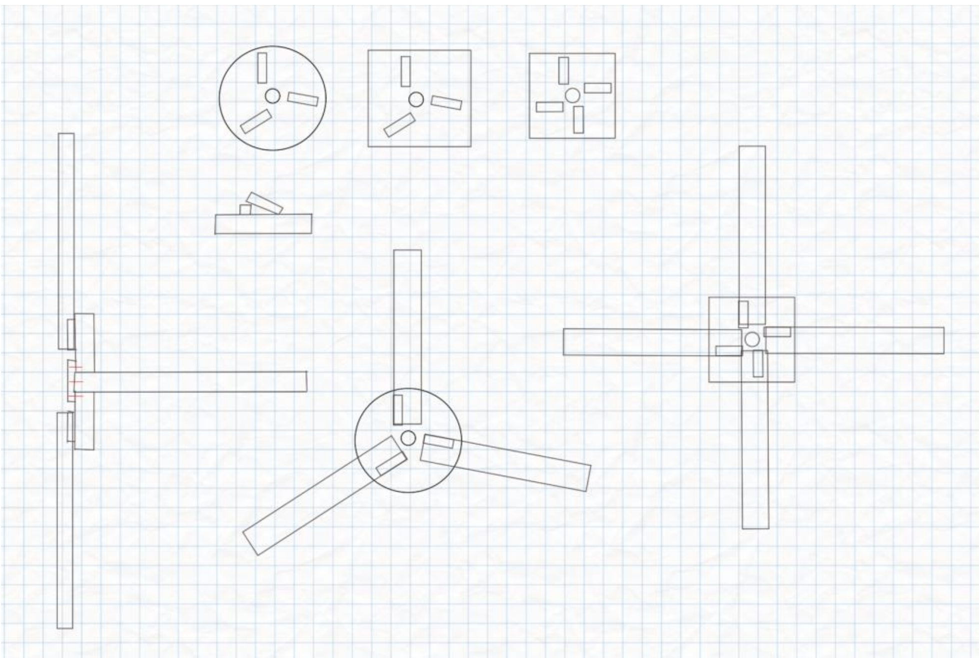
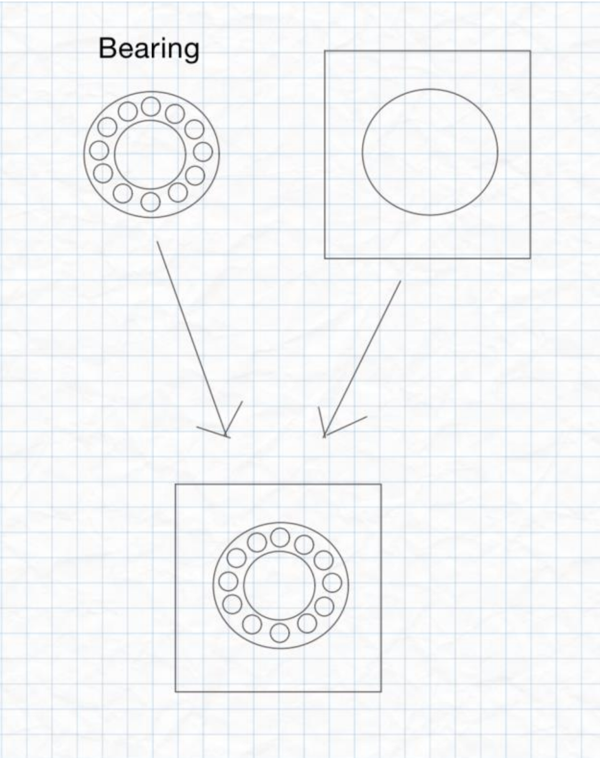
Mechanical Design and Construction of a Small-Scale Windmill



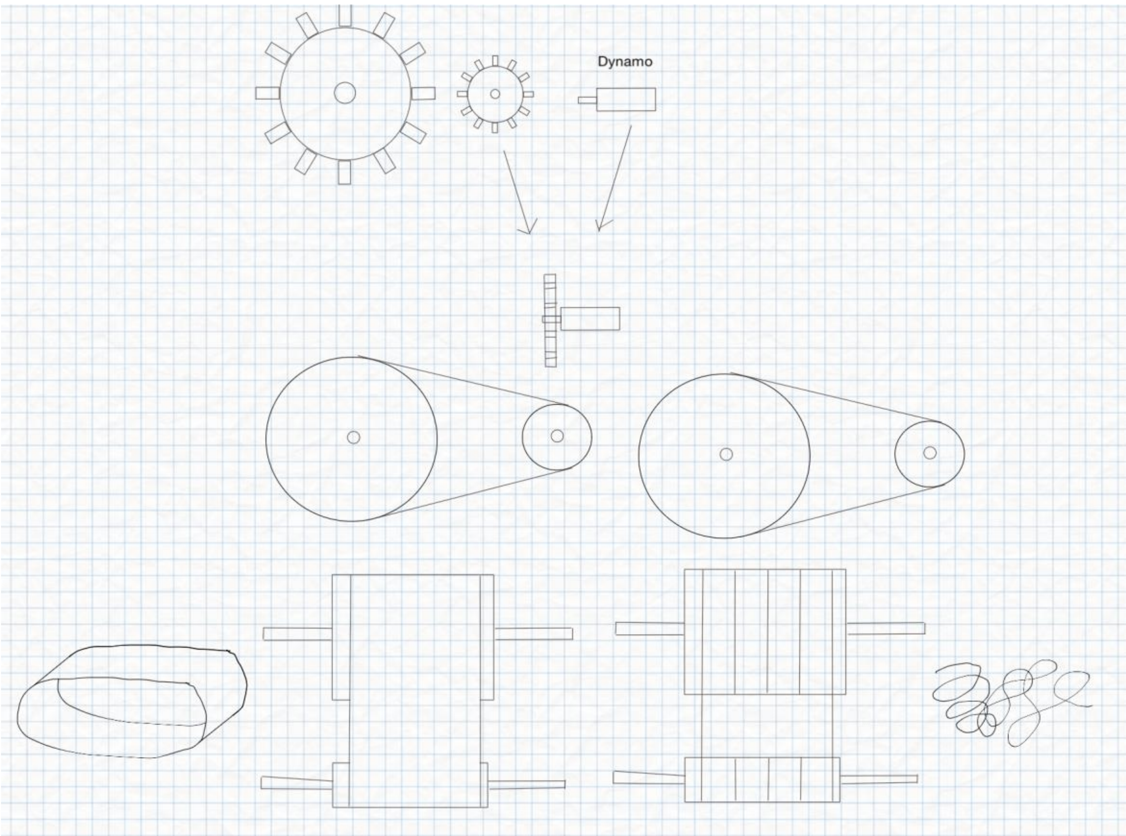
The inspiration for this project came after watching *The Boy Who Harnessed the Wind*. It highlighted how the potential for energy production is all around us. This motivated me to explore building my own windmill, starting with a simple sketch. My first drawing featured blades rotating a rotor with a magnet, spinning inside an iron core connected directly to a battery. While this initial idea was overly simplified (since a battery cannot be charged with AC), it served as the starting point of the project and marked the transition from an idea into a reality.



Initially, I planned to make the blades flat for simplicity and angle them by lifting one side with a small piece of wood. Although I didn't end up using this design fully, the process gave me valuable insight into how to connect the blades to the shaft. I also decided to use an even number of blades, both for ease of construction and to maintain balance, reducing the risk of vibrations.



I decided to use two bearings inside a wooden block to support the rotor shaft and secure it to the frame, the construction process involved extensive sanding to ensure the bearing fit tightly within the wood.



I explored three different designs for transferring the rotational energy from the shaft to the dynamo:

1) Gear system

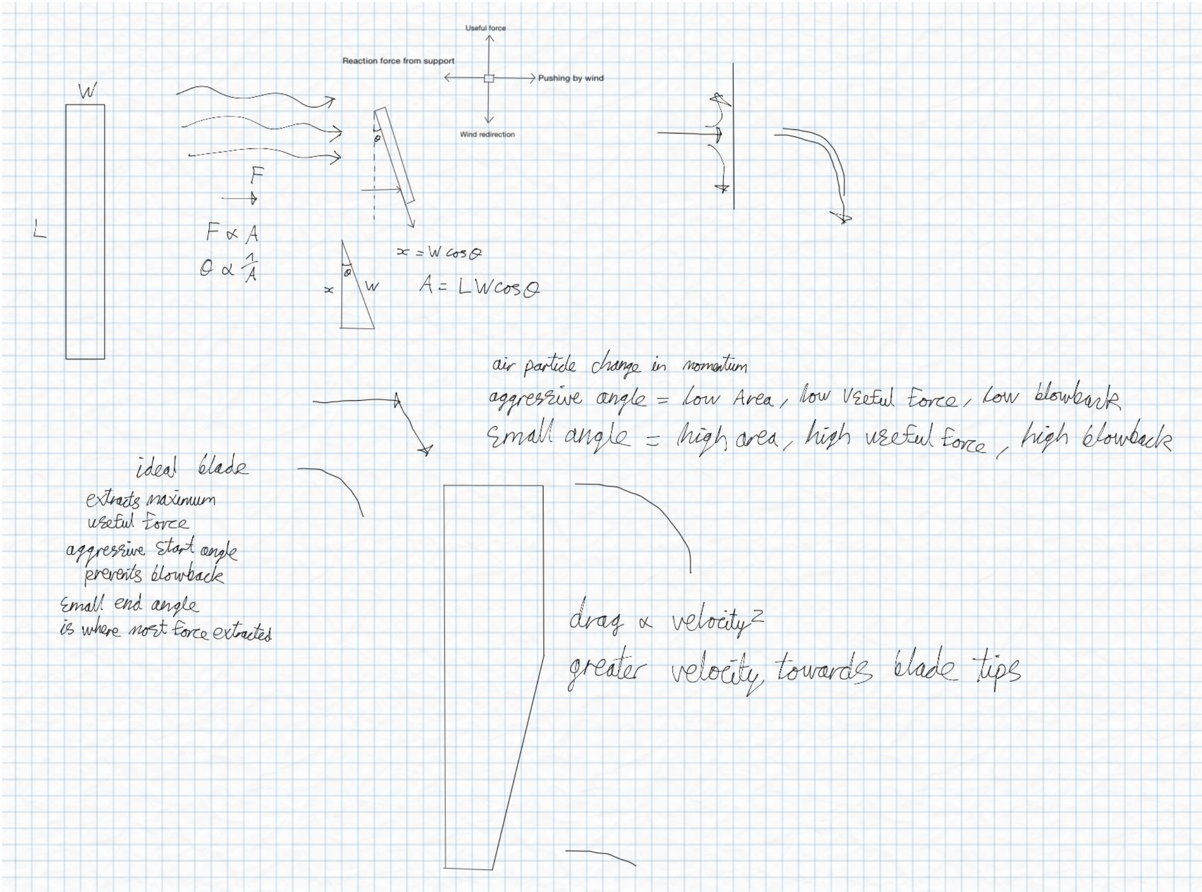
A large gear on the shaft driving a smaller gear on the dynamo would increase the dynamo's speed, making effective use of the torque from the blades. This would improve output, since induced EMF is proportional to the rate of change of magnetic flux. However, manufacturing precise gears from wood would have been extremely difficult, and the teeth could easily break under sudden gusts of wind.

2) Belt system

This design used a large wooden cylinder on the shaft and a smaller cylinder on the dynamo, connected by a belt. It would have been simpler to construct than gears and provided more grip than rope. However, carving large cylinders from wood would be wasteful, and sourcing a suitable belt was not practical with the materials available.

3) Rope system

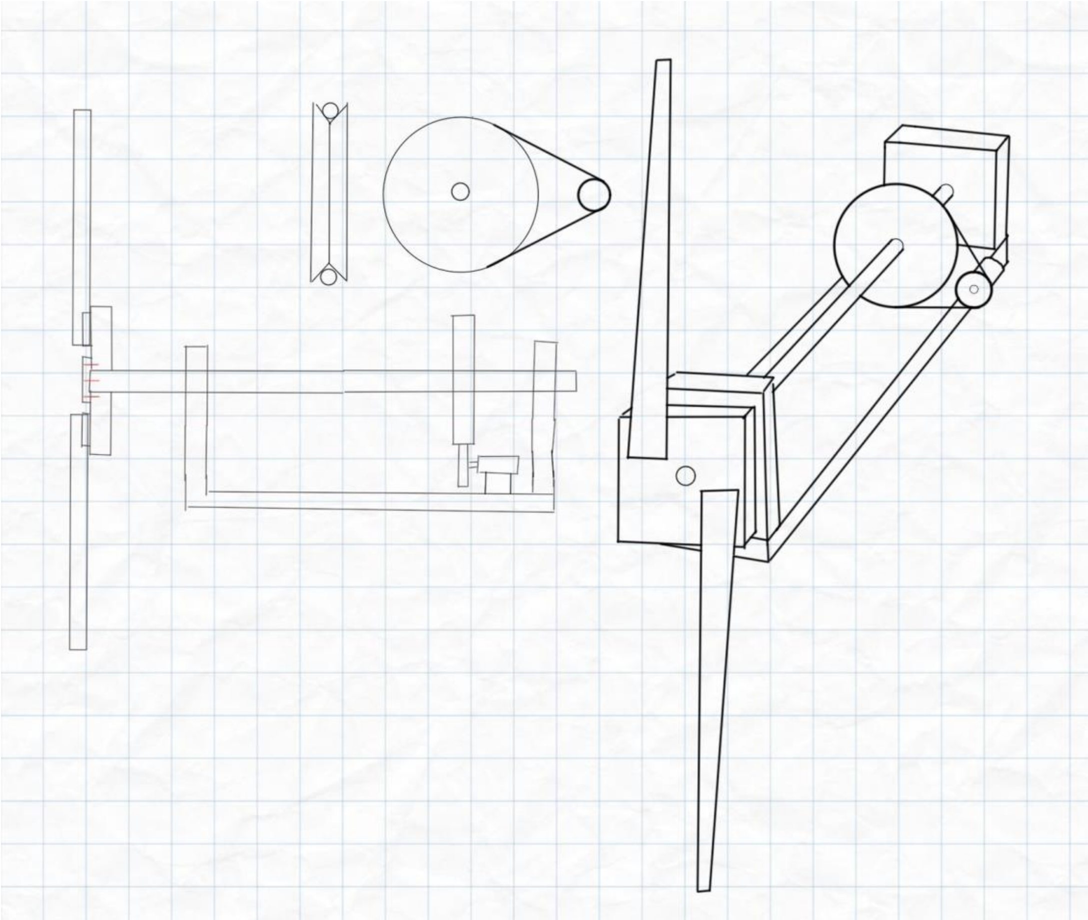
This approach was similar to the belt system, but used a thinner wooden wheel and rope in place of a belt. Rope was readily available, simple to install, and much easier to work with than gears or belts. Although rope provides less grip, this did not cause noticeable problems during operation.



My next task was designing the blades for the windmill. Initially, I considered keeping the blades flat and simply angling them. To explore this idea, I defined a function for the blade's cross-sectional area as a function of its angle, intending to use calculus to optimise performance. The reasoning was that a larger cross-sectional area would capture more wind, while the blade angle controlled the torque generated. Balancing these two factors proved challenging, and this approach was ultimately discarded.

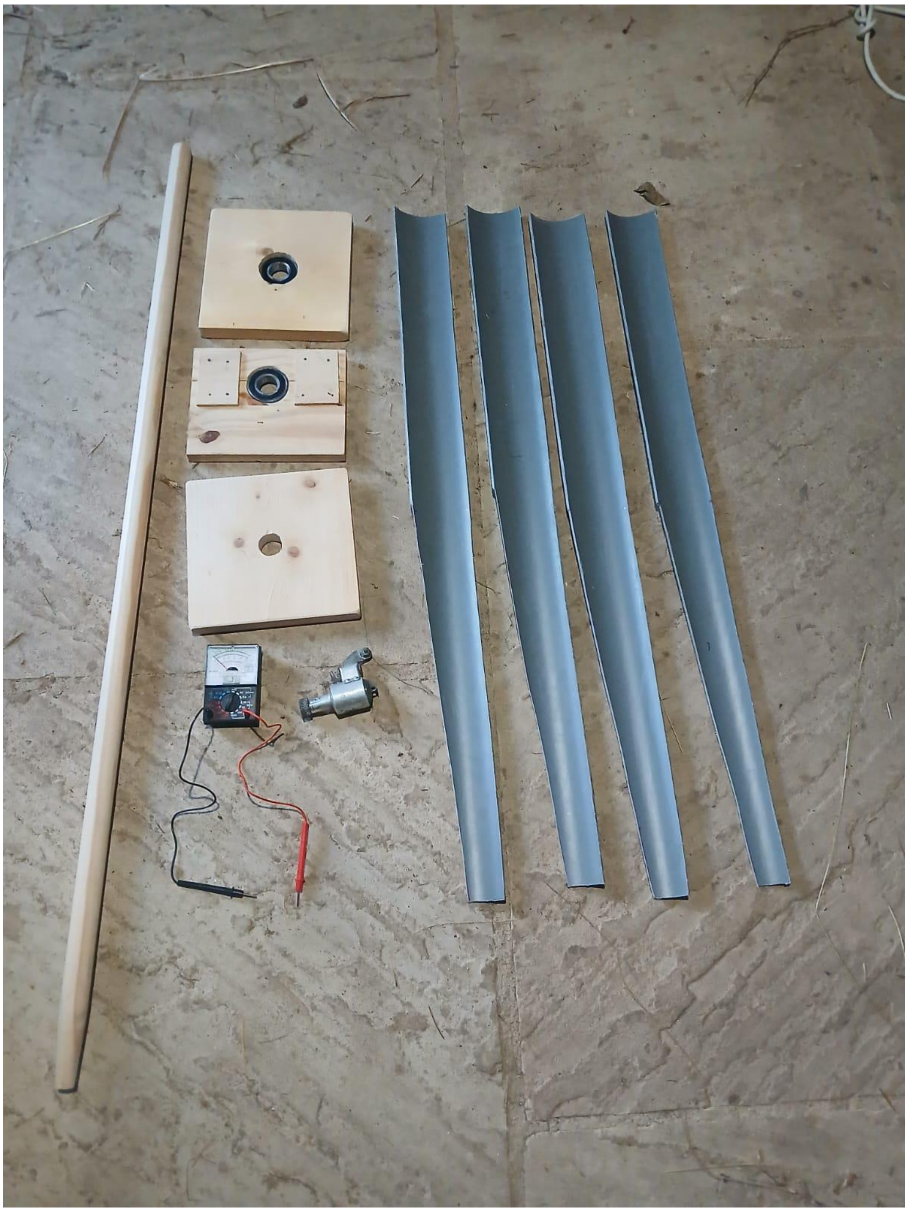
Building on my knowledge of vectors and momentum from A-level physics, I realised that maximum energy extraction occurs when the wind is redirected by 90°. A flat blade could not achieve this, as the airflow would split across both sides, cancelling out much of the force. This led to a curved blade design, starting with a sharp angle to guide the wind and prevent splitting, then flattening towards the tip to redirect airflow by 90° and extract the maximum useful energy.

Finally, I tapered the blades, since the tips move at higher velocity and drag is proportional to the square of velocity. Reducing the cross-sectional area toward the ends helped minimise drag and improve overall efficiency.

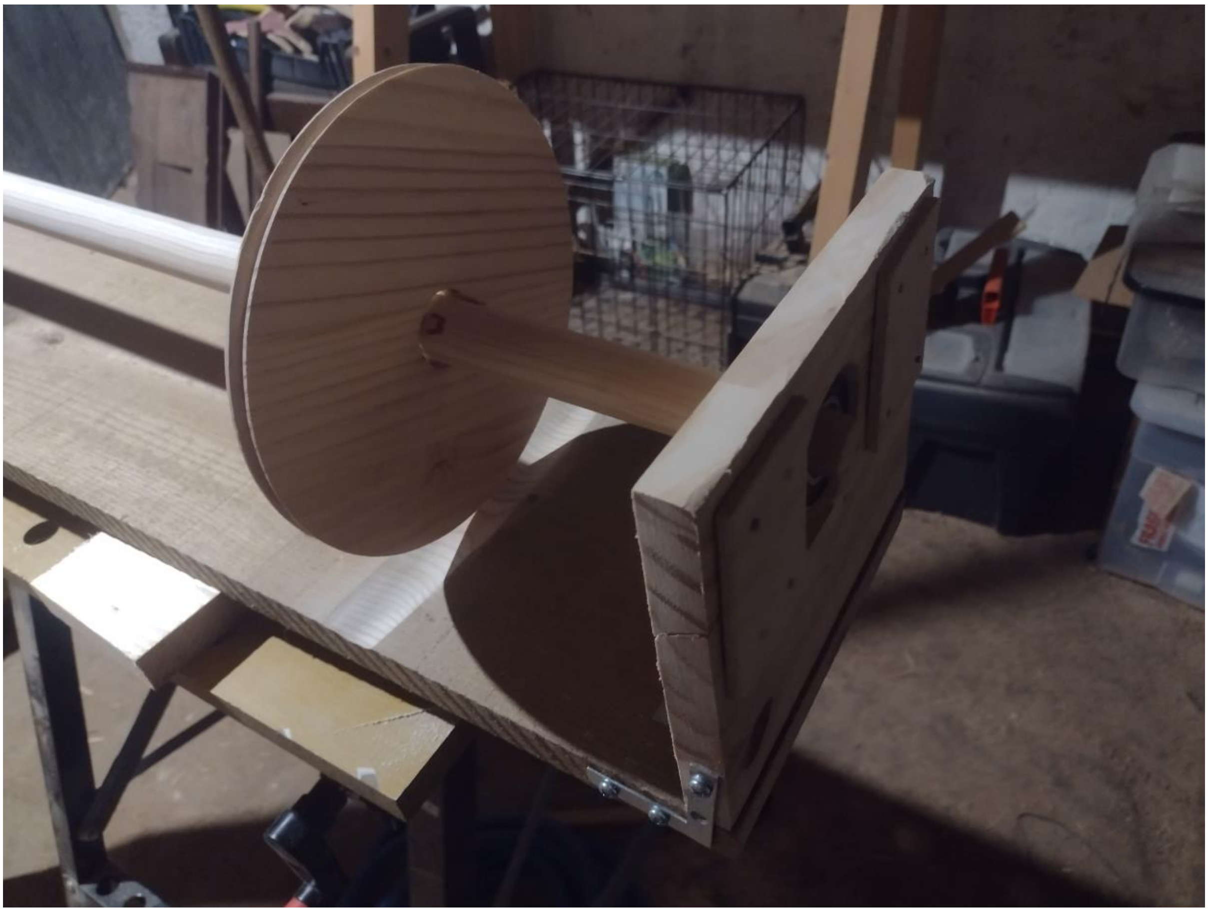


I combined each of my design ideas into the final build. By breaking the windmill into smaller components and tackling them one at a time, the construction process became much more manageable and achievable.

My next task was gathering materials for the windmill. I collected discarded wood from around my village and was kindly given a bicycle dynamo by an elderly couple who no longer needed it. By reusing these materials, I was able to reduce waste in the village while simultaneously creating a small source of renewable energy.



After collecting the materials, I assembled the bearing holders, blades, and the wooden hub that would support the blades.



I connected all the components to a wooden plank using screws and wood glue to ensure stability. For the pulley, I repurposed two wooden pan mats, sanding down their edges to create a groove that securely held the rope in place.

The dynamo’s rotating shaft was too small to grip the rope securely. To overcome this, I designed a custom attachment from wood and epoxy putty, adding a groove to prevent the rope from slipping off during operation.

After a week of work, including both design and construction, the windmill was finally completed. Seeing the project evolve from a passing thought into a working reality was an extremely rewarding experience and reinforced my passion for mechanical engineering, which I plan to pursue at university.

Overall, I was very satisfied with my design. Next summer, I hope to mount the windmill in a permanent location and add a mechanism to allow it to automatically orient itself toward the wind.