Designing Micro Wind Turbines for Portable Power Generation

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Introduction

The objective of this research project is to design a small wind turbine with the capability of charging the batteries of portable devices such as cellular phones. **Why should we use wind turbines when we have power supplies?** These micro turbines would be in use developing countries where they possess cellular phones but no power supply to recharge them.

Cellular phone energy consumption

Typical battery: Li-Ion
Capacity: 1170 mAh
Voltage: 3,7V

To recharge a battery in three hours, we would need a power source of approximately **1.5 Watts.**

Rotor dimensions

In 1919, the German physicist Albert Betz proved that the conversion of wind power into mechanical energy has a theoretical limit efficiency of 59,3% using simple fluid dynamics equations. In practice, most current wind turbines operate at an efficiency close to 40%.

The kinetic power of wind within a certain area can be expressed as:

$$P_{kinetic}=(1/2)\rho A v^3$$

After the wind to mechanical conversion and the mechanical to electric conversion losses, we are left with the equation :

$$P_{output}=(1/2)\ \eta_m\ \eta_e\ \rho A v^3$$

Using an air density of 1.23kg/m^3, a power output of 1.5W, a design wind speed of 6m/s and efficiencies of η_e=0.7 and η_m =0.4, we obtain an approximate **diameter of 20-25cm**.

Design specifications

There are many parameters and variables that need to be evaluated and selected prior to the design of a wind turbine rotor.

Number of blades
The number of blades does not have a significant impact on the efficiency of a wind turbine. We have chosen a two blade design because of ease of fabrication in order to keep manufacturing costs low.

Tip Speed Ratio
The Tip Speed Ratio (TSR) can be defined as the speed of the tip of the blade divided by the speed of the wind. This value is crucial as it will influence the design of the blade, the operational RPM and the efficiency. Depending on the number of blades of a rotor, each turbine is designed to operate at a particular TSR to obtain maximum efficiency.

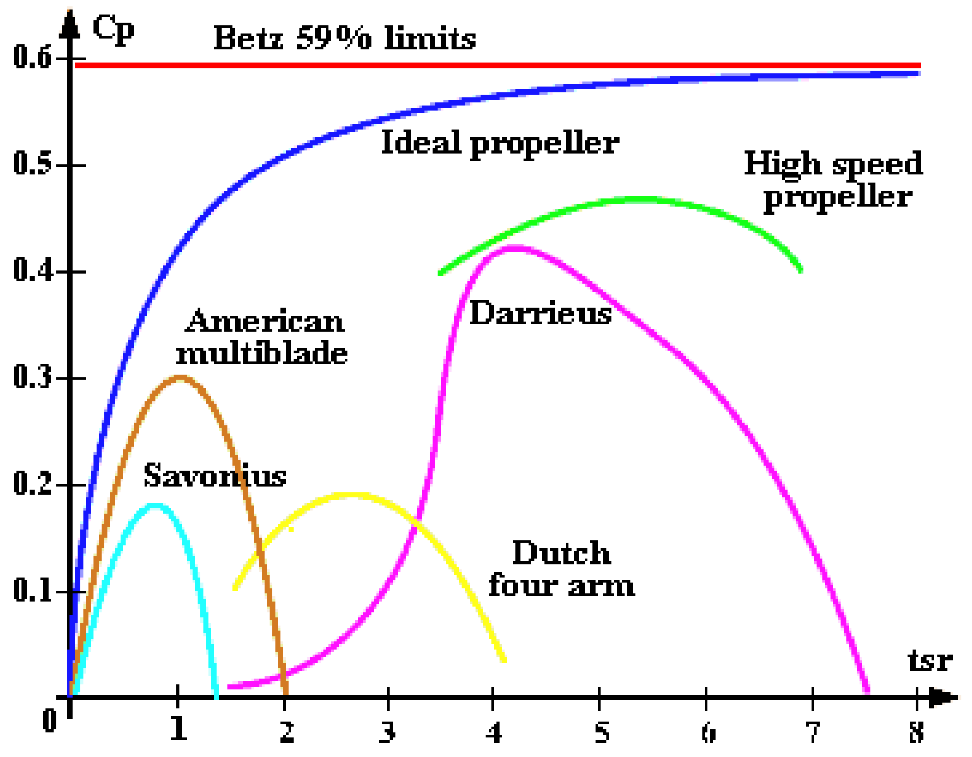


Figure 1: Optimal TSR of popular turbines

Airfoil
The airfoil needs to be optimized in order to have the best Lift/Drag ratio. The Reynolds number is an indicator of the wind speed and the dimensions of the blade and is key in choosing the correct airfoil profile. In our case, the Reynolds number is around 25,000. This led to the choice of NACA-0009 for our airfoil.

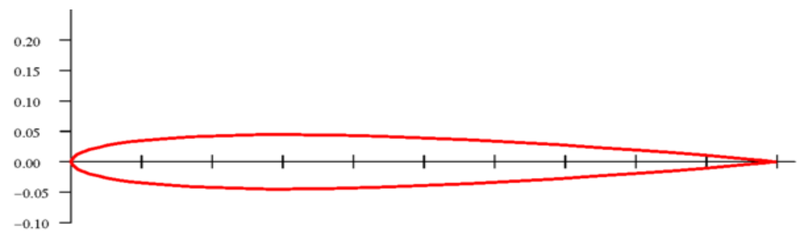


Figure 2: NACA-0009

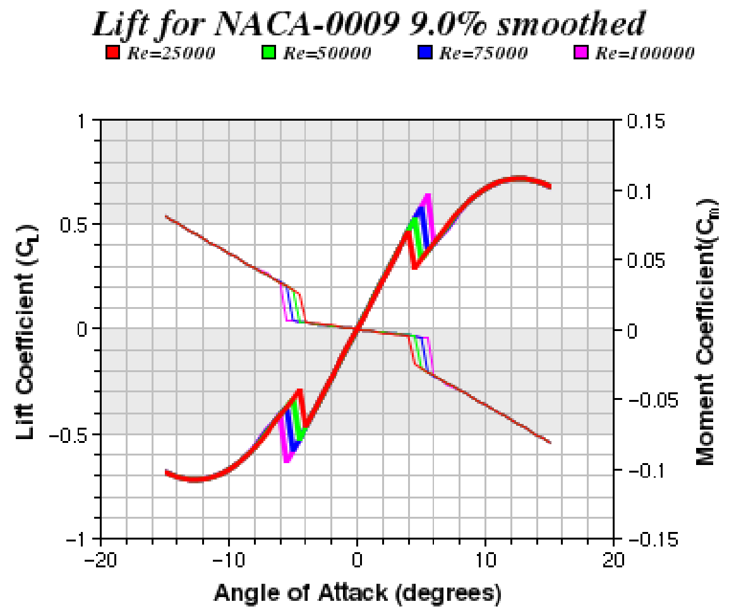


Figure 3: Lift coefficient of NACA-0009

Conclusion

- This two blade micro wind turbine meets the optimal specifications to ensure good efficiency: a high tip speed ratio, an airfoil that behaves well at low Reynolds number and an optimal angle of attack and chord length at every section of the blade.
- The rotor is expected to deliver a theoretical electrical power output of 1,5 watts in winds of 7,5m/s.

Chord and twist

Using simple fluid mechanics, it is possible to demonstrate that the chord length that will optimize lift at each cross-section of the blade is given by:

$$\text{Chord}(r)=\frac{16\pi R^2}{9r\lambda^2 BC_l} \qquad (1)$$

Where:
R=Total Radius
B=Number of blades
λ=Design Tip Speed Ratio
Cl=Lift coefficient

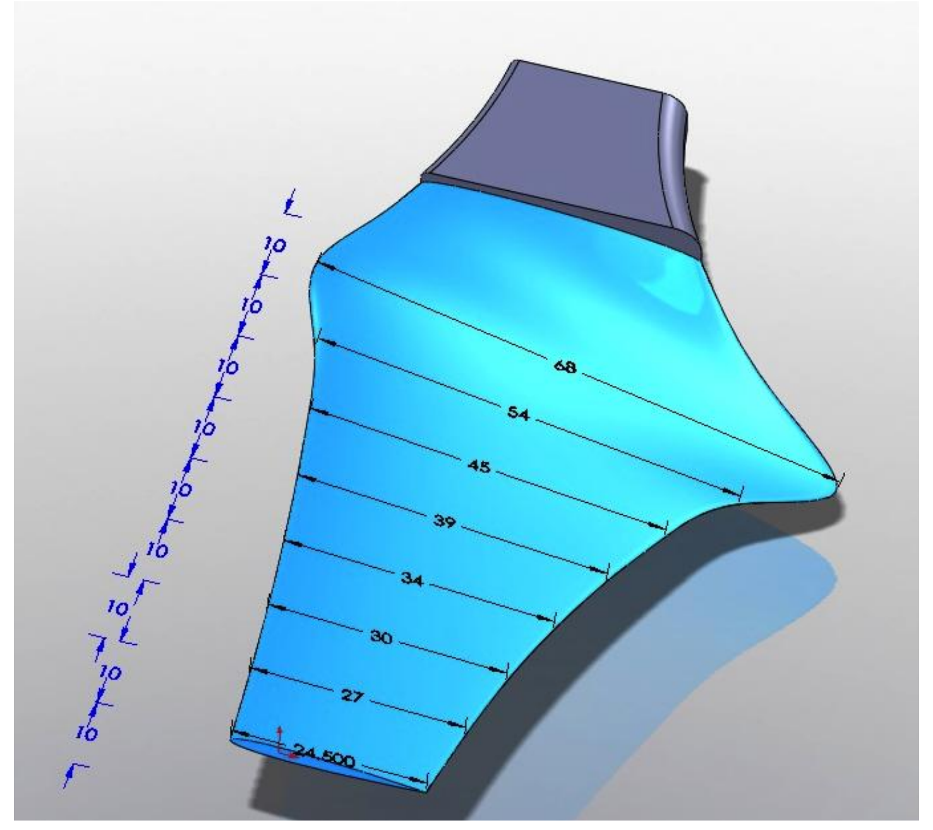
In a similar manner, we can express the optimal twist of the blade at each section of the blade by:

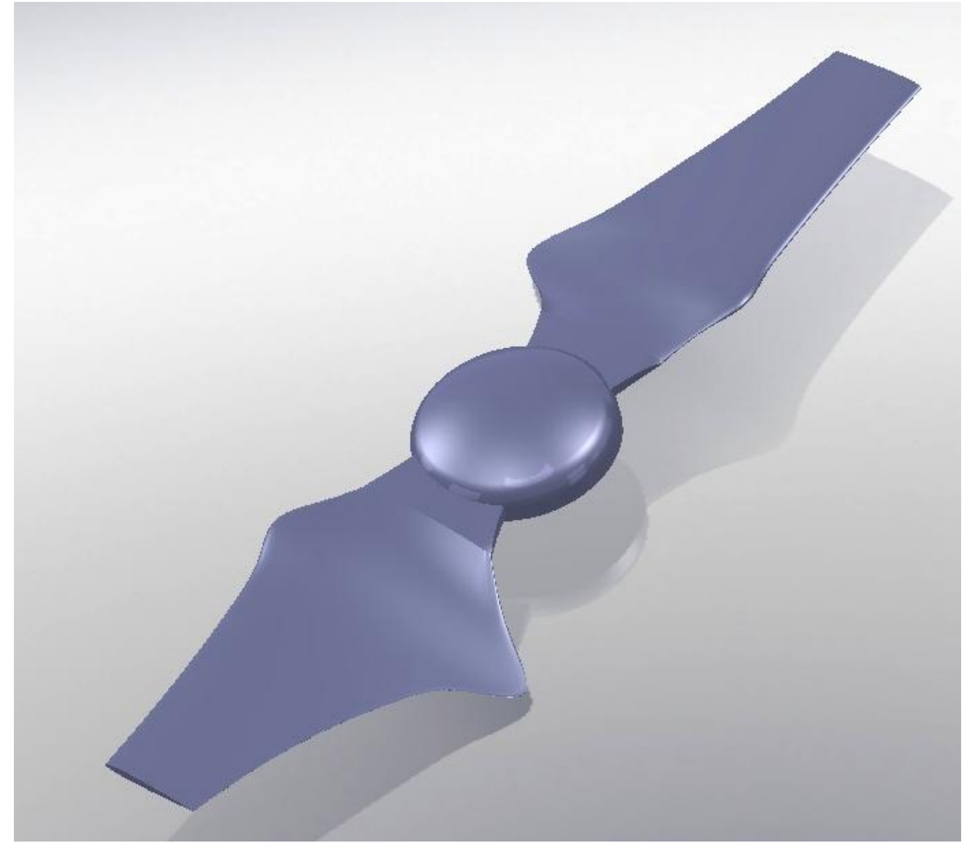
$$\beta(r)=\text{ATAN}\left(\frac{2R}{3r\lambda}\right)-\alpha \qquad (2)$$

Where:
R=Total Radius
λ=Design Tip Speed Ratio
α=Angle of attack

Final design

Once we know the airfoil profile, the chord length and the angle at every section of the blade, it is possible to model a 3-D prototype of the design.





Future efforts

- The rotor design now needs to be prototyped. Once tested in a laboratory and fully characterized, we can then select a generator.
- The electrical output of the rotor should be measured and the experimental output can be compared to the theoretical value.
- As this rotor is designed to be in use in developing countries, it is important that we insure that the large scale manufacturing costs remain low. A further investigation of production costs should be explored.