Horizontal Axis Wind Turbine Blade Design for the Urban Areas in Puerto Rico

Author: Angel L. Castanon Pereira
Advisor: Jose R. Pertierra Garcia, MBA
Mechanical Engineering Department

Abstract

Horizontal Axis Wind Turbines are the preferred and most common method for power extraction from wind. In this study, the researcher will test three different airfoils to design a blade that optimizes wind energy generation, given the specific challenges that the Puerto Rican urban landscapes present. The researcher will use Blade Element Momentum Theory to analyze the performance of each of the airfoils given the specific variables present and choose a design that maximizes the power output of the wind turbine. The researcher will focus on the aerodynamic aspect of the design, focusing on the optimal geometry for generation. The SD7062 was found to be the optimal airfoil with an estimated power of approximately 700 W at the designated parameters.

Introduction

Wind power is one of the fastest growing sources of new electricity supply and the largest source of new renewable power generation added in the United States since 2000. Wind power is clean, sustainable, and dependable making it a good candidate for countries looking to phase out fossil fuels as a mean of power generation. It is not only great in the large scale for countries but can also be implemented successfully at the small scale, bringing power generation to those who need it.

Background

The theory behind the generation of power from wind comes from Momentum Theory. Energy is extracted from the wind as it is transferred from the molecules in the air to the blades of the turbine.

In Figure 1 the researcher can see a representation of wind flowing through a turbine and the different section of velocity and pressure. The fluid loses velocity before and after close to the turbine, where the energy transfer happens. Also, a difference in pressure is created.

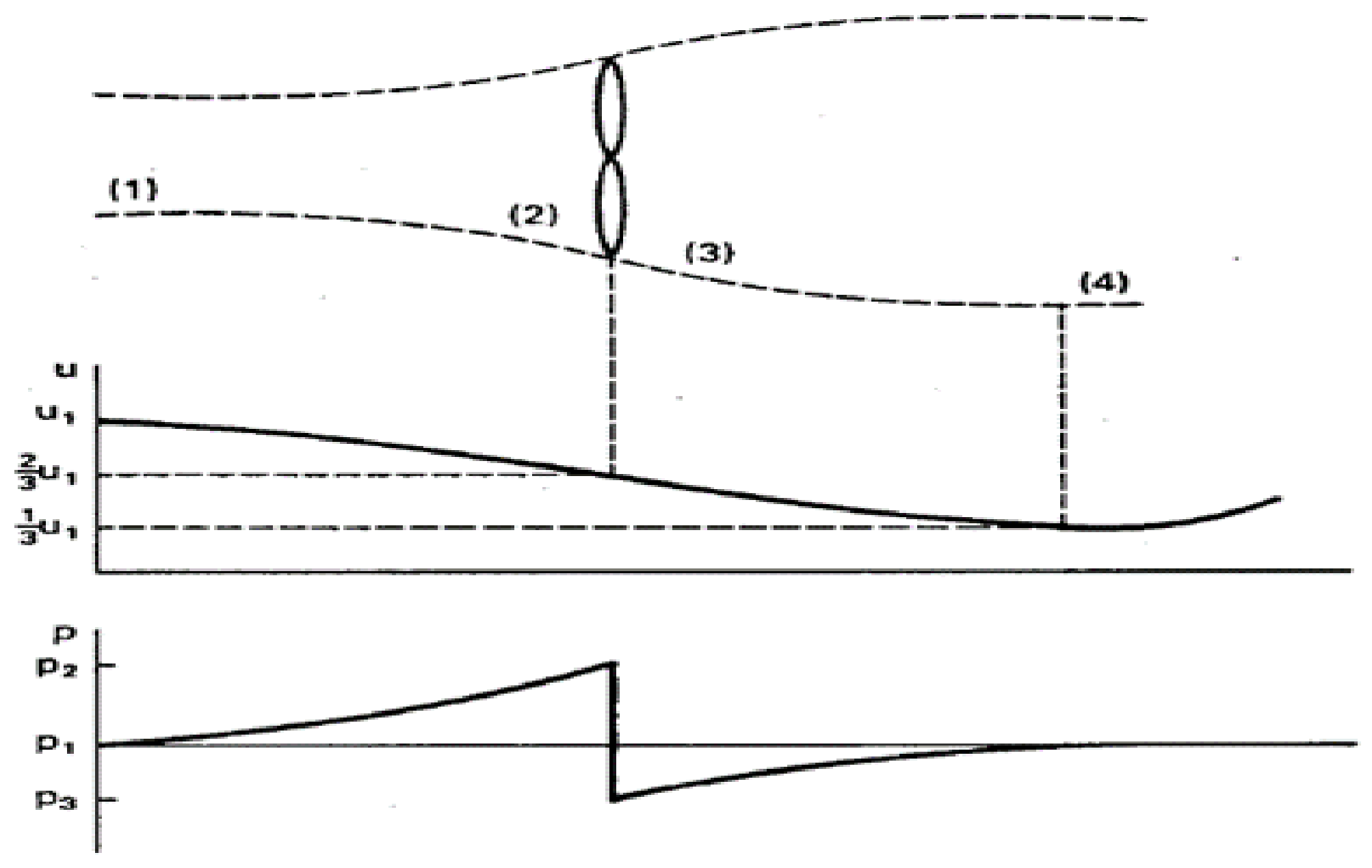


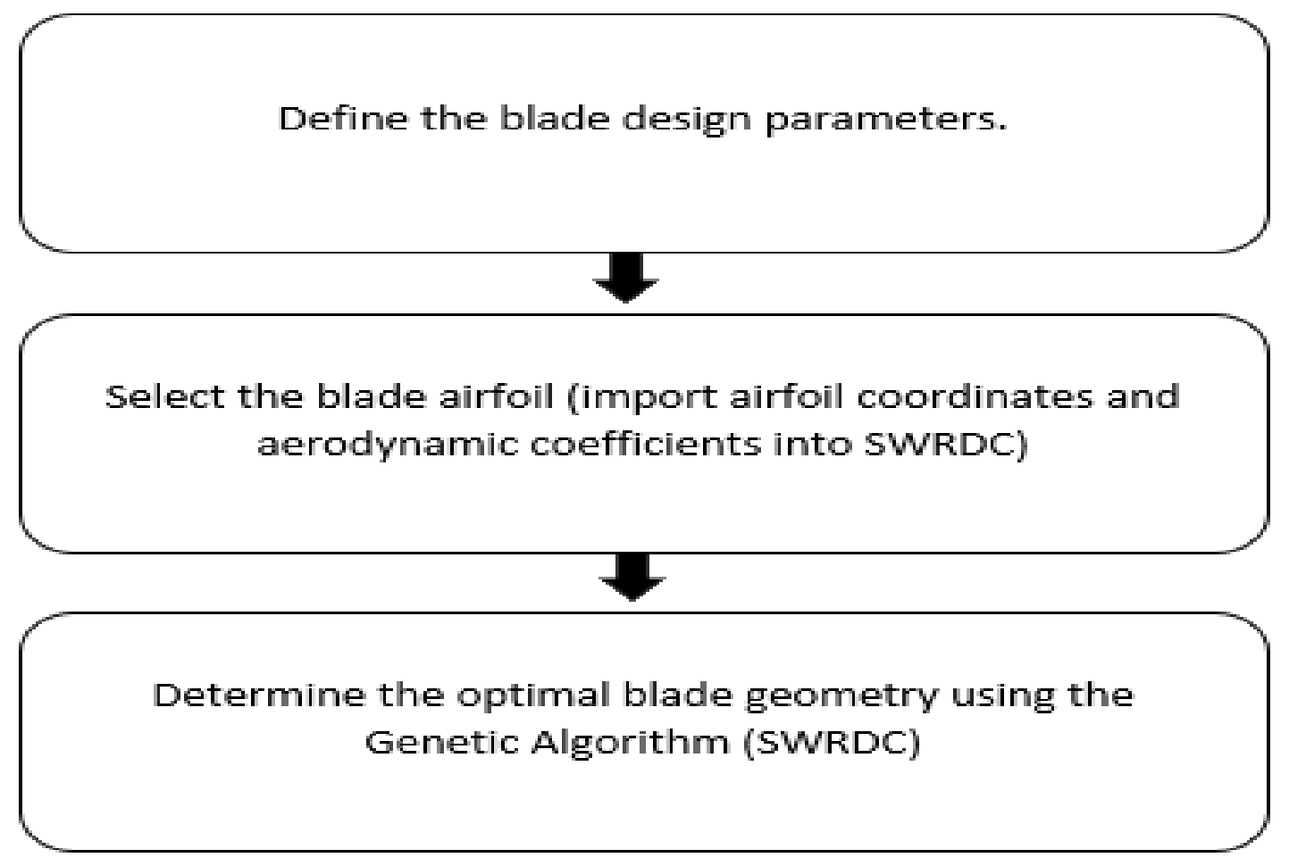
Figure 1 Wind tube flowing through turbine

Problem

There is one major challenge when implementing wind power in Puerto Rico, and that is the local wind speeds. The literature shows that Puerto Rico has an inland estimated wind velocity of 0 to 5.9 m/s, which lands it in the "Poor" Wind Power Density classification. There are select places along the coast and further inland where the velocities are higher, but wind speeds do not surpass the 5.9 m/s readings normally .

Methodology

To design a small wind turbine (50 kW or less rated power), optimizing the blade geometry is fundamental; this way the researcher maximize power generation and energy extraction from the wind.



Define the blade design parameters.

Select the blade airfoil (import airfoil coordinates and aerodynamic coefficients into SWRDC)

Determine the optimal blade geometry using the Genetic Algorithm (SWRDC)

Figure 2 Flowchart for design and analysis of blades

The parameters for the wind turbine in this study are:

- Design Wind Speed = 5 m/s
- Number of blades = 3
- Design tip speed ratio = 7
- Design angle of attack = 0 deg
- Rotor radios = 2.5 m

The researcher will be analyzing 3 different airfoils for this scenario. These airfoils were chosen because of their performance at low wind speeds. The Reynolds numbers in this study range from Re = 100000 to Re = 2000000 for all airfoils to be able to better understand the aerodynamic properties of the airfoils.

After obtaining the polar coordinates the researcher then used the SWRDC code to determine the chord and twist angle distributions for the airfoils. The blades were divided into 30 sections in which the localized chord and twist would be optimized. These distributions are optimized to obtain the highest Cp possible, and this is done with a Genetic Algorithm. The algorithm works by optimizing the criterions (i.e., chord and twist angle) by minimizing or maximizing its objective function.

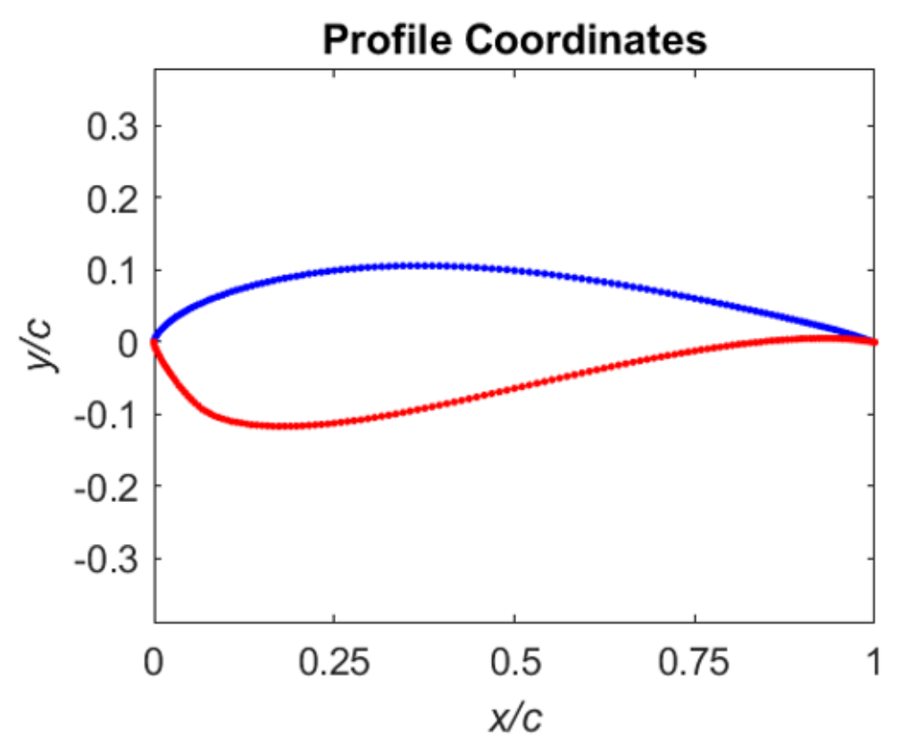


Figure 3 S823 Profile

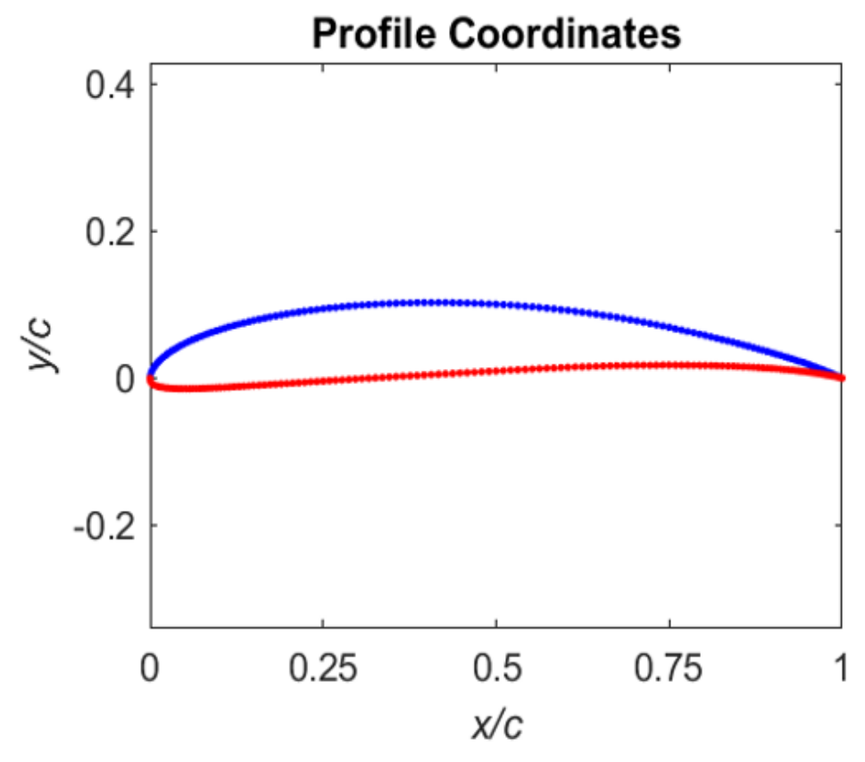


Figure 4 SG6043 Profile

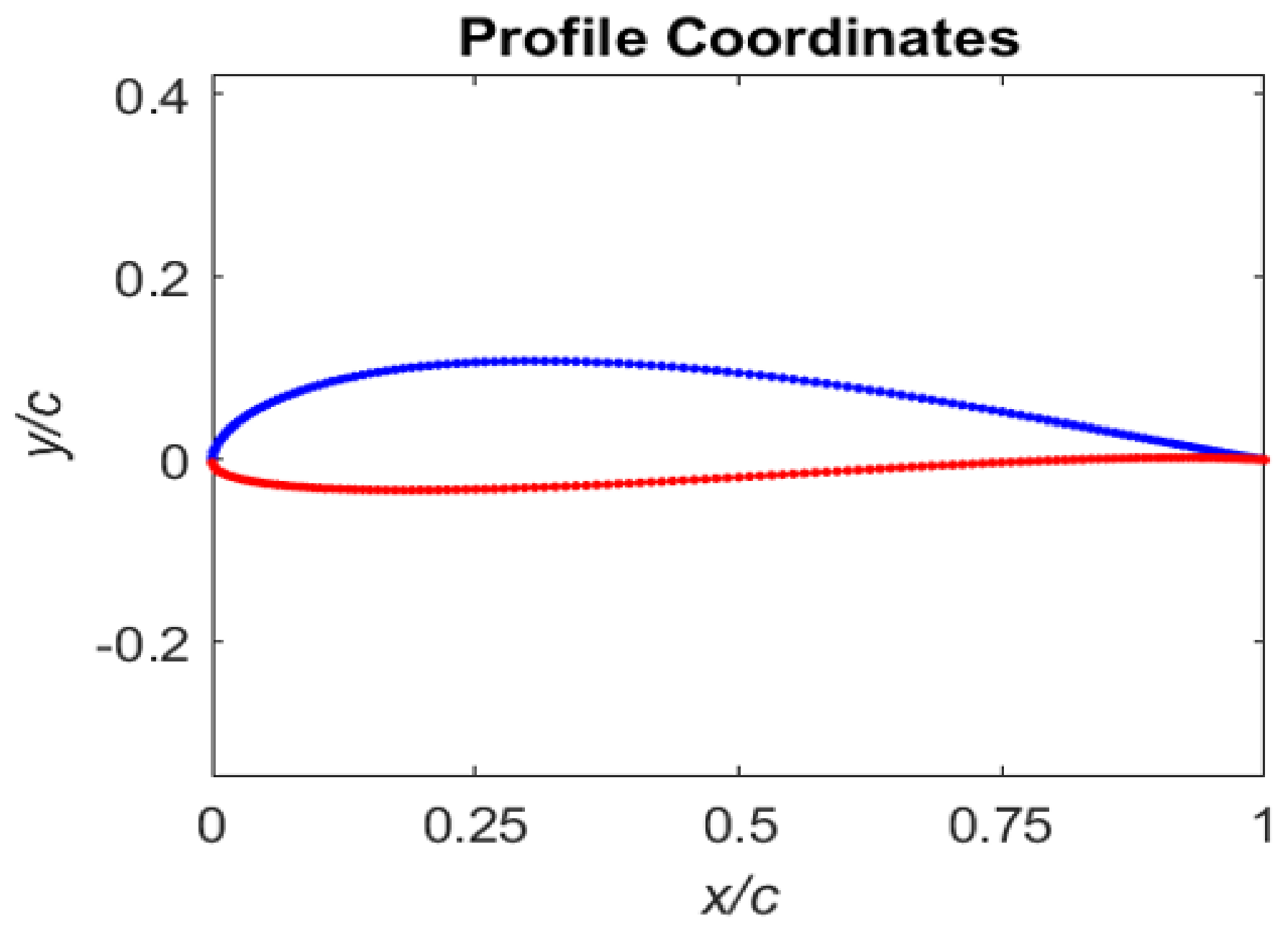


Figure 5 SD7062 Profile

Results and Discussion

After running SWRDC for all three airfoils, using the previously presented parameters, the researcher obtained the different optimized chord and twist distributions.

Looking at the performance results, a relation between the different parameters can be noticed. It is shown that as the Power Coefficient increases the Power, Torque, and Thrust also increases.

The S823 airfoil had the largest twist angle of the three at 29.35 degrees. It was also the one with the narrowest chord of 0.4872 at the beginning of the airfoil. The airfoil performed very well with a Cp of 0.4146, giving it a power of 623.25 W. But as the TSR increased past the optimal value, it is shown that it had a substantial decrease in power, even though torque and thrust kept increasing.

The SD7062 is the all-around best performing airfoil of the three. It had a maximum twist angle of 27.35 degrees and a maximum chord of 0.5021 m. With a Cp of 0.4641 and a power of 697.77 W it outperformed both other airfoils. Although after the optimal TSR the Cp starts decreasing, it is not as steep as the other two airfoils.

The SG6043 is by far the lowest performer of the three airfoils, with a Cp of 0.2394 and a power of 359.85 W. For this airfoil optimal TSR was around 4 or 5 and after that power, torque and thrust rapidly decrease. After a TSR of 8 the airfoil stopped producing power. This maybe because the blades were going so fast that they were running into turbulent air from the previous blade, thus reducing the generated power.

Table 1
Performance Results (SWRDC)

Airfoil	Power Coefficient	Power (W)	Torque (N-m)	Thrust (N)
S823	0.414588551	623.2515	44.51796	227.8984
SD7062	0.464156841	697.7675	49.84054	245.4222
SG6043	0.239376681	359.8552	25.70395	116.7018

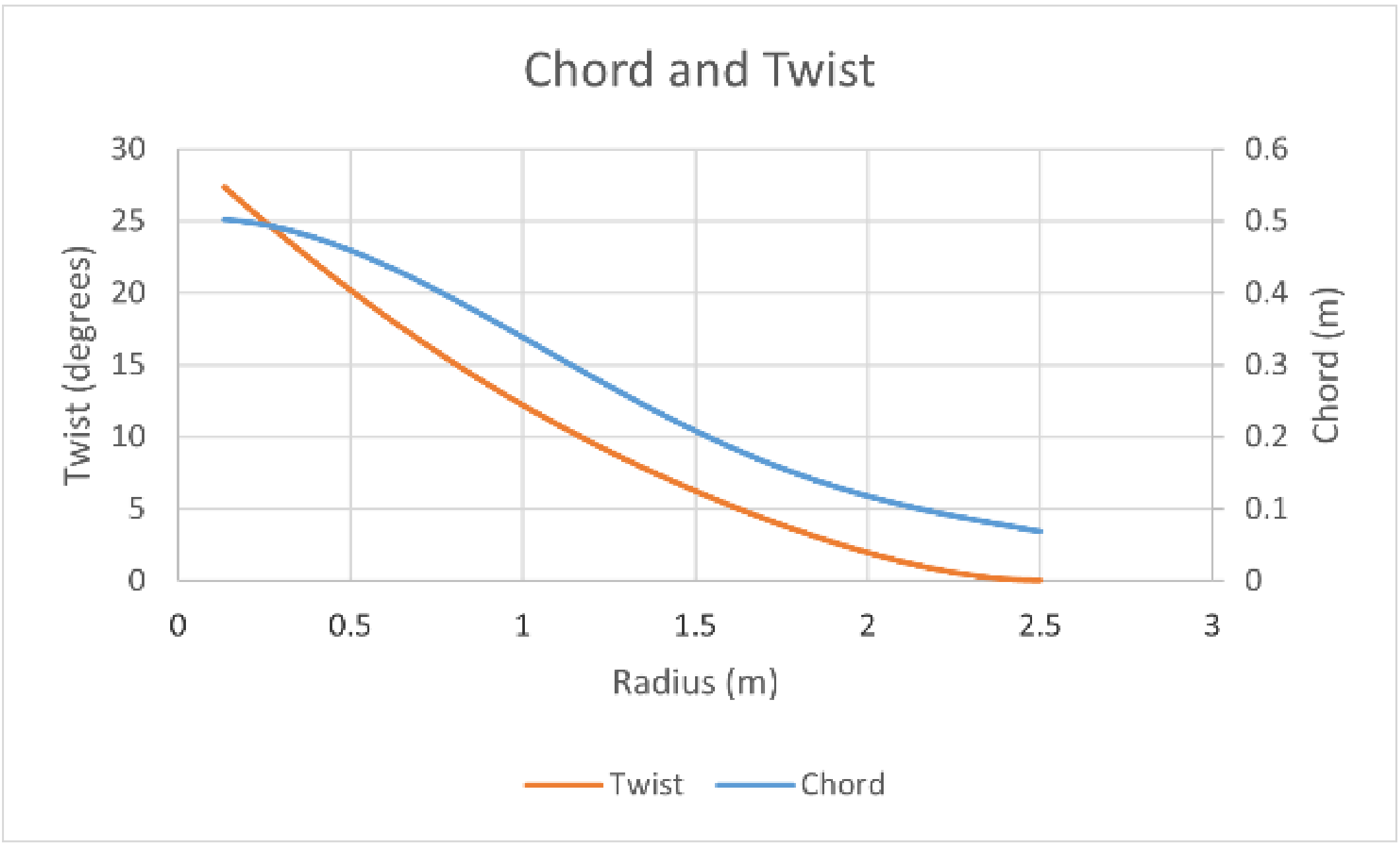


Figure 6 SD7062 Chord and Twist Distribution

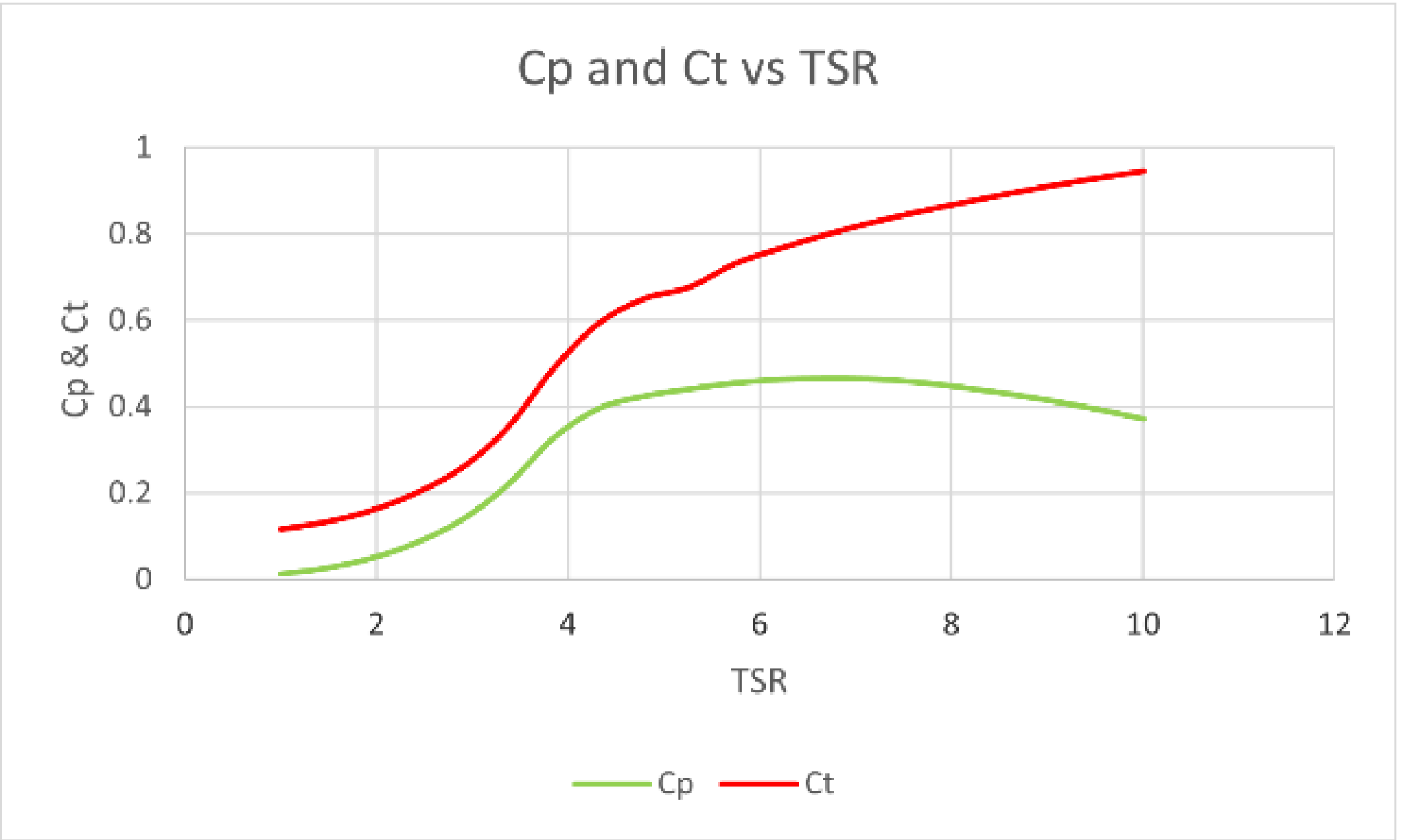


Figure 7 SD7062 Cp and Ct

Conclusions

The best performing airfoil in this study was the SD7062 with and estimated power of 697.77 W at 5 m/s wind velocity, 2.5 m blade radius, 7 TSR and a 0-degree angle of attack.

The purpose of this study was to design a horizontal wind turbine to fit the needs of the urban area in Puerto Rico. This design is a preliminary attempt to reach this goal. With a 2.5 blade radius and a 700 W approximate power generation capability, it is compact enough and scalable enough to fit specific situations in the urban landscape of Puerto Rico.

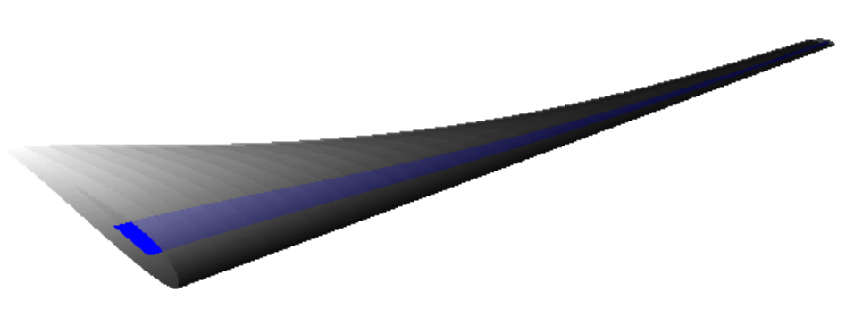


Figure 8 SD7062 3D Render

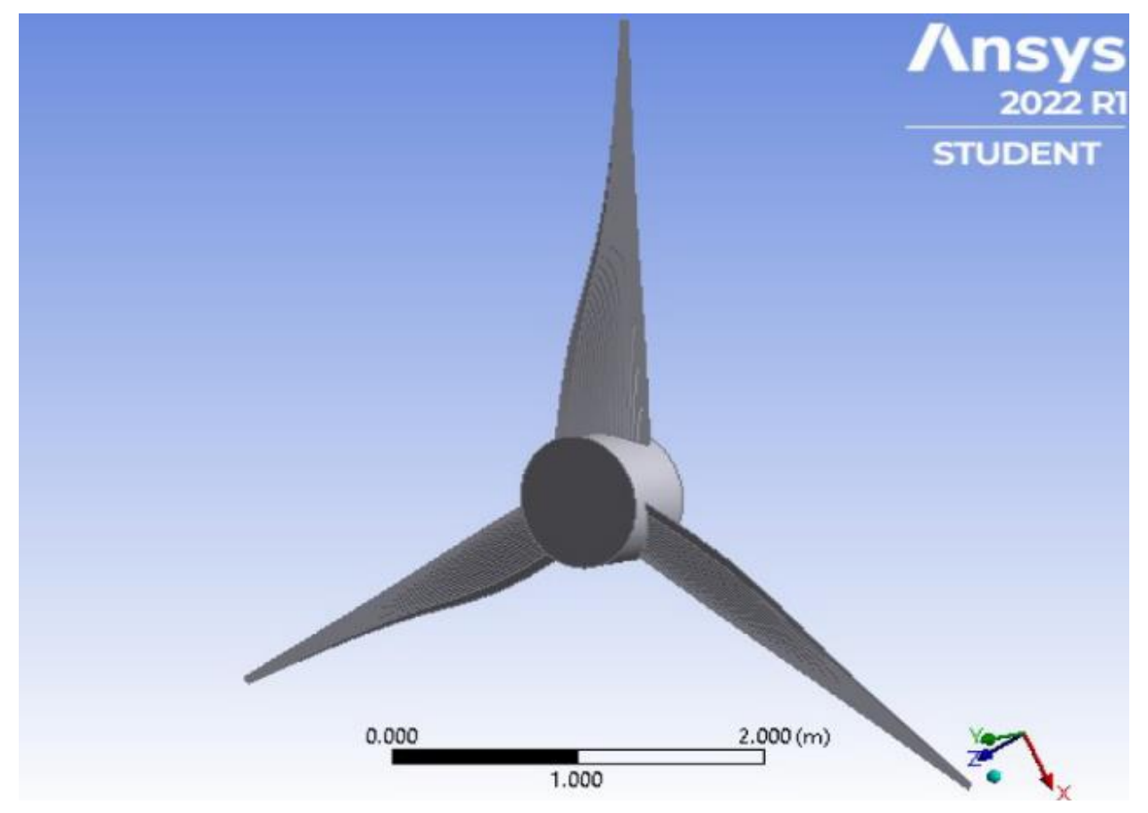


Figure 9 3D Render of SD7062

Future Work

These results were the product of an iterative mathematical solution through different algorithms. A good way to verify this data would be to carry out a CFD simulation of the SD7062 airfoil with the discussed initial parameters. This would add validity and would bring it closer to actual numbers.

One very important limitation to this study was the wind velocity parameter. Puerto Rico does not generally have high speed winds inland. A way to solve this problem could be the implementation of a wind lens to the current turbine design. This technology has been shown to increase efficiency in low-speed horizontal wind turbines and would be an interesting analysis to perform.

Acknowledgements

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