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Design of a Savonius Wind Turbine

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Abstract

The objective of this report is to study and manufacture a wind turbine of vertical axis, Savonius type. In particular, what will be studied is which geometrical design of the wings of the wind turbine is the most efficient, while taking into account the cost, the elegance, the simplicity, the feasibility and the durability.

Firstly a research took place on the existing bibliography, so every member of the team would be up to date about the so far theoretical and technological development of this kind of wind turbine. After this briefing the team was at the position to exclude some geometrical designs and conclude to the most efficient. Thereafter, based on our means and tools we performed a research for the final decision of the kind of Savonius wind turbine we would manufacture. Later on, we divided the tasks that had to be done into categories and distributed them to the team members depending on their individual skills and knowledge to achieve the best possible result. These tasks included the analysis of the materials' durability, what mechanical elements were needed, various software simulation tests and the electrical installment of the wind turbine.

After the analysis was over, the next step was the manufactural, which followed in detail and precision the design that had been preceded. Finally, a compatibility check was performed of the theoretical sizes compared to the ones that the final construction showed.

Contents

1.0 Introduction

While the environmental pollution keeps going on, there is a last try at a worldwide scale, which will render the production of renewable energy more accessible and more efficient.

Within this project the goals have been set by the European Community; the most recent of them is “20-20-20”, which aims to a 20% reduction of the greenhouse gases, 20% increase of the power efficiency and 20% penetration of the renewable sources of power in the energy community until 2020. For these goals to be achieved, various ways and the technological means with which even an individual with limited financial resources can contribute to this twist to the renewable forms of energy have been developed.

Typical examples are the installation of photovoltaic system and small size wind turbines. More specifically, this paper aims to study and manufacture a wind turbine of vertical axis, Savonius type.

2.0 Project Data

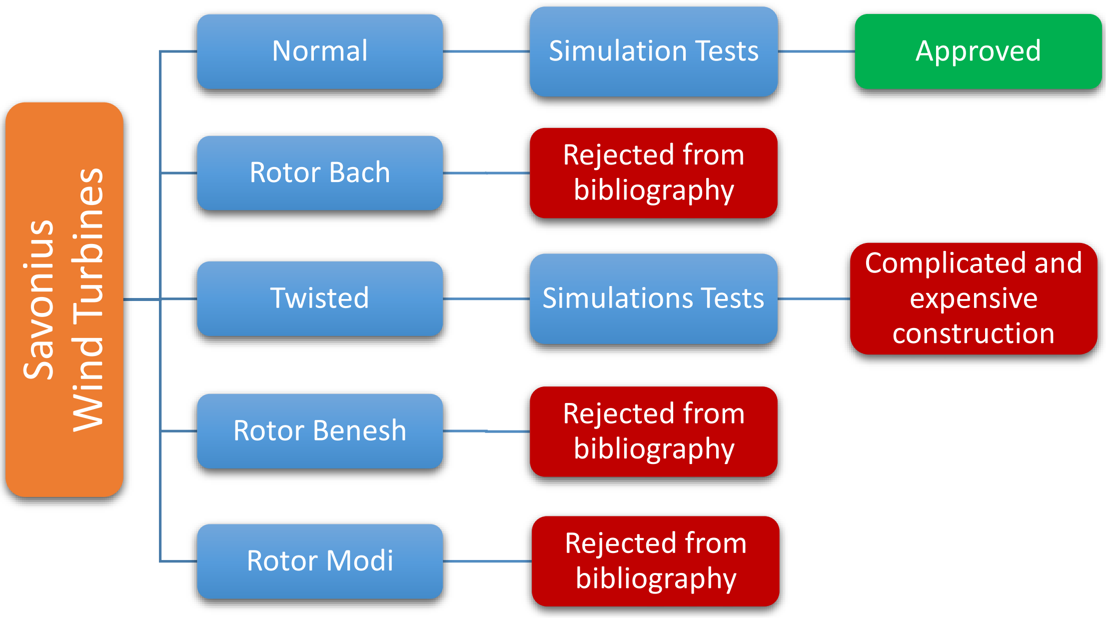
1. Problem/Need: Most wind turbines are big sized, expensive and hard for individual use. It is not easy for normal use by common citizens.
2. Intended users and uses:
   i. Home owners with enough open space to accommodate a small sized wind turbine to generate energy for personal profit.
   ii. To produce electricity to traffic and street lights and electric street signs.
3. Project limitations:
   i. The cost needs to be affordable for common civilians.
   ii. The design should be elegant for inside the town use.
   iii. Innovation and fresh ideas would be appreciated.
   iv. The solidity of the construction was necessary.
4. Project objectives: Manufacture a vertical axis wind turbine to reduce the energy consumption, increase the use of renewable sources, spending a reasonable amount of money, while keeping a modern, sleek design.

3.0 Solution and Process principles

First thing after starting with the project was to define a timetable that concluded to strict steps of progress and a specific timeline. The timetable was defined according to the bibliography that many companies use in these kinds of projects. That was:

1. Decision of constructing a Savonius wind turbine.
2. Definition of: Budget, Technological equipment, Construction size, Project needs, Time limits.
3. Brainstorming for the different ways of construction.
4. Disquisition based on the thought of the previous step.
5. Construction of the wind turbine based on the disquisition of the previous step.
6. Inspection of the construction.
7. Match of the real data with the theoretical ones.
8. Possible modification.

The flowchart below shows a presentation of the Savonius wind turbines and the selection process.



Flowchart 1: Comparison between the Savonius kinds of wind turbines.

4.0 Flow simulation analysis

In this part of the project the wind turbine will be tested under the maximum wind force (blast of wind 27 m/s). The forces that result are regardless of the dimensions and the mass of the machine elements, so the test can take place in the beginning.

The objectives that have been set were to:

i) Calculate the maximum pressure on the construction as a whole.
ii) Calculate the maximum speed the wind develops as it passes through the blades, in the entrance and in the exit.
iii) Calculate the resultant force developed by the distributed load all over the surface of the structure created by the wind, and the position in which it is applied.
iv) Analyze the forces received by the wind turbine from the wind in three resultants (x, y, z)
v) Calculate the bending moment and the torque.

"GG" refers to the general analysis of the entire construction and "SG" refers to the analysis that has been carried out exclusively for the blades. The "positive" blade marked with the number "1" and "negative" blade with the number "2". The combinations are shown in Table 1.

Note: The “positive” blade refers to the active blade that helps the rotation of the turbine. The “negative” blade refers to the inactive, the one that obstructs the rotation.

Goal Name	Unit	Value
GG Force 1	[N]	172,6613141
SG Force 1	[N]	140,3797957
SG Force 2	[N]	85,7649137
GG Force (X) 1	[N]	-34,197354
SG Force (X) 1	[N]	9,681329968
SG Force (X) 2	[N]	-53,13208037
GG Force (Y) 1	[N]	5,068891883
SG Force (Y) 1	[N]	-0,001759382
SG Force (Y) 2	[N]	0,006415934
GG Force (Z) 1	[N]	169,1649394
SG Force (Z) 1	[N]	140,0455601
SG Force (Z) 2	[N]	67,32460484
GG Torque (X) 1	[N*m]	60,55278714
SG Torque (X) 1	[N*m]	51,05747308
SG Torque (X) 2	[N*m]	24,30901068
GG Torque (Y) 1	[N*m]	-8,681791874
SG Torque (Y) 1	[N*m]	-9,764532432
SG Torque (Y) 2	[N*m]	4,597953706

Table 1: Forces and torques developed at various points.

Results for the "positive" blade (Tables 2 and 3)

Parameter	Minimum	Maximum	Average	Surface Area [m^2]
Pressure [Pa]	101290,094	102401,96	102285,297	0,217431092
Shear Stress [Pa]	0	4,91229115	0,932252374	0,217431092
Relative Pressure [Pa]	-34,9059345	1076,9597	960,297307	0,217431092

Table 2: Pressures and Stresses for the “positive” blade.

Parameter	Value	X-component	Y-component	Z-component	Surface Area [m^2]
Normal Force [N]	140,525998	9,72122408	0,000233997	140,18935	0,217431092
Friction Force [N]	0,14923532	-0,039894115	-0,001993379	-0,143790357	0,217431092
Force [N]	140,379796	9,68132997	-0,001759382	140,04556	0,217431092
Torque [N*m]	52,0858925	51,0574731	-9,76453243	-3,27544654	0,217431092
Surface Area [m^2]	0,217431092	-3E-06	-4,12226E-06	-0,138599999	0,217431092
Torque of Normal Force [N*m]	52,1376262	51,1085921	-9,76845589	-3,28955035	0,217431092
Torque of Friction Force [N*m]	0,053173958	-0,051119064	0,003923458	0,014103813	0,217431092

Table 3: Forces and Torques for the “positive” blade.

Results for the "negative" blade (Tables 4 and 5)

Parameter	Minimum	Maximum	Average	Surface Area [m^2]
Pressure [Pa]	100918,029	102420,979	101754,948	0,219472219
Shear Stress [Pa]	0	4,37230897	1,65447539	0,219472219
Relative Pressure [Pa]	-406,971018	1095,97853	429,948479	0,219472219

Table 4: Pressures and Stresses for the "negative" blade.

Parameter	Value	X-component	Y-component	Z-component	Surface Area [m^2]
Normal Force [N]	85,5479339	-53,0066522	-0,001491976	67,1471803	0,219472219
Friction Force [N]	0,217426372	-0,125428184	0,00790791	0,177424527	0,219472219
Force [N]	85,7649137	-53,1320804	0,006415934	67,3246048	0,219472219
Torque [N*m]	31,4393216	24,3090107	4,59795371	19,4000455	0,219472219
Surface Area [m^2]	0,219472219	-5,5752E-07	2,70923E-08	-0,140004448	0,219472219
Torque of Normal Force [N*m]	31,3578531	24,2452614	4,57225528	19,3539848	0,219472219
Torque of Friction Force [N*m]	0,082740298	0,063749237	0,025698428	0,04606064	0,219472219

Table 5: Forces and Torques for the "negative" blade.

5.0 Calculations of the machine elements

Before beginning the construction, we had to select materials with the appropriate dimensions. This would give to our wind turbine reliability, solidity, low cost and elegance. To achieve all these we made theoretical and computerized calculations and simulations (figure 1).

The conditions that have been set were: Blast of wind at 27 m/s. Steady wind direction. Steady wind velocity. Temperature 293.2 K. Pressure 101 325 Pa.

All the materials that have been used are presented below with their mechanical characteristics.

	Mechanical Characteristics	**Parts of Use**
Steel C45	Tensile Strength: 600-800 MPa	Axis
	Yield Strength: 340-400 MPa	Support rings
	Shear Stress: 450-600 MPa	Supporters of the base
	Tensile Modulus: 190-210 GPa	Side to side cylinder
	Poisson's Ratio: 0.27-0.30	Bases

	Mechanical Characteristics	**Parts of Use**
Aluminum Alloy 3105	Tensile Strength: 150 MPa	Blades
	Yield Strength: 130 MPa	Top cap
	Shear Stress: 97 MPa	Bottom cap
	Tensile Modulus: 70- 80 GPa	Thin joints (wires)
	Poisson's Ratio: 0.33	Base cover

	Mechanical Characteristics	**Parts of Use**
Metal Sheets Steel 304	Tensile Strength: 515 MPa	Base
	Yield Strength: 205 MPa	
	-	
	Tensile Modulus: 193-200 GPa	
	Poisson's Ratio: 0.29	

Metal Sheets Steel 316	**Mechanical Characteristics**	**Parts of Use**
	Tensile Strength: 515 MPa	Base
	Yield Strength: 205 MPa	
	-	
	Tensile Modulus: 193-200 GPa	
	Poisson's Ratio: 0.29	

Metal Sheets Steel 410	**Mechanical Characteristics**	**Parts of Use**
	Tensile Strength: 755 MPa	Base
	Yield Strength: 575 MPa	
	-	
	Tensile Modulus: 200 GPa	
	Poisson's Ratio: 0.29	

Table 6: Mechanical characteristics of the used materials.

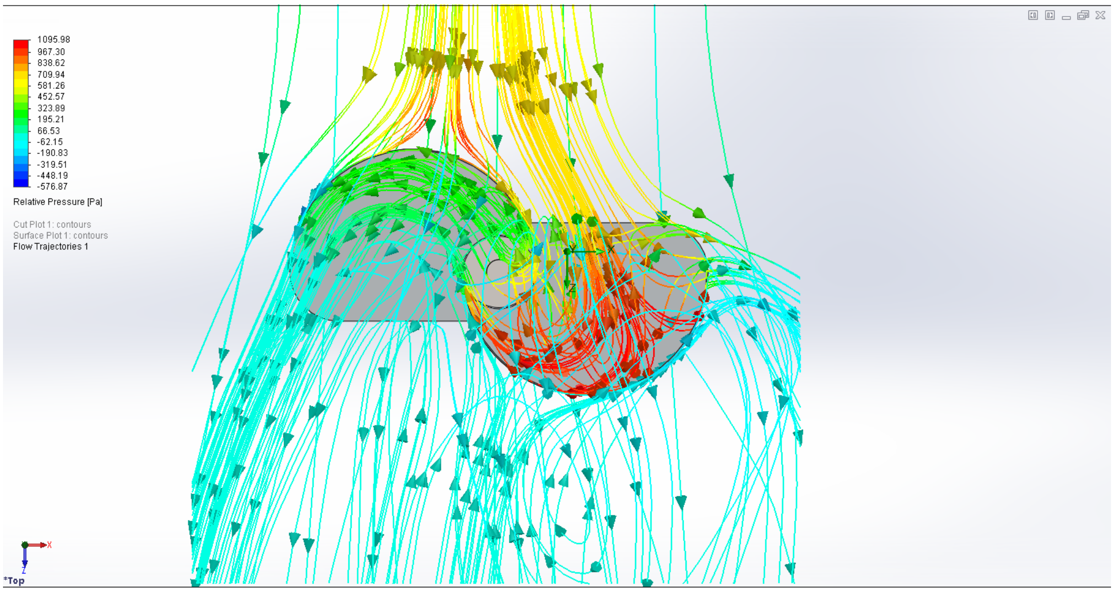


Figure 1: Top view of a section of the wind turbine and the effort of the air to rotate it around its axis.

5.1 Main axis

Firstly, the diameter of the axis had to be calculated. The main parameters to study that, were:

i. the equivalent stress at the most severely stressed point of the axis to not exceed the allowable stress of the material

ii. zero deformation of the axis on the maximum blast of the wind that can accept during operation.

According to the simulations, a blast of wind of 27 m/s equals to a shear force of 169.1 N (figure 2). This force is evenly distributed among the surface of the blades so we can represent it as the resultant force. The first bearing has been placed 10mm at the end of the blades. So the bending moment is calculated as follows: $M = 169{,}1\ N * (\ 0.35m + 0.01m) = 169.1N * 0.36m = \mathbf{60.8\ Nm}$

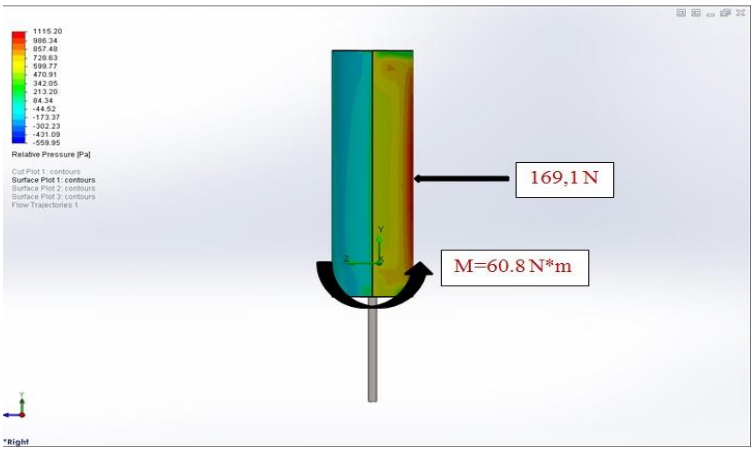


Figure 2: **S**hear force and bending moment on the axis.

And the torsion torque is ***T = 8.68 Nm.*** Now that we calculated the shear torque and the torsion torque we can find the diameter of the axis: $d \geq \sqrt[3]{\frac{32N}{\pi Sy}\sqrt{M^2+\frac{3}{4}T^2}}$

And using safety factor N=3: $d \geq \sqrt[3]{\frac{32*3}{3.14*340*10^6}\sqrt{60.8^2+\frac{3}{4}8.68^2}} \Leftrightarrow \boldsymbol{d} \geq 0.017m \ = 17mm$

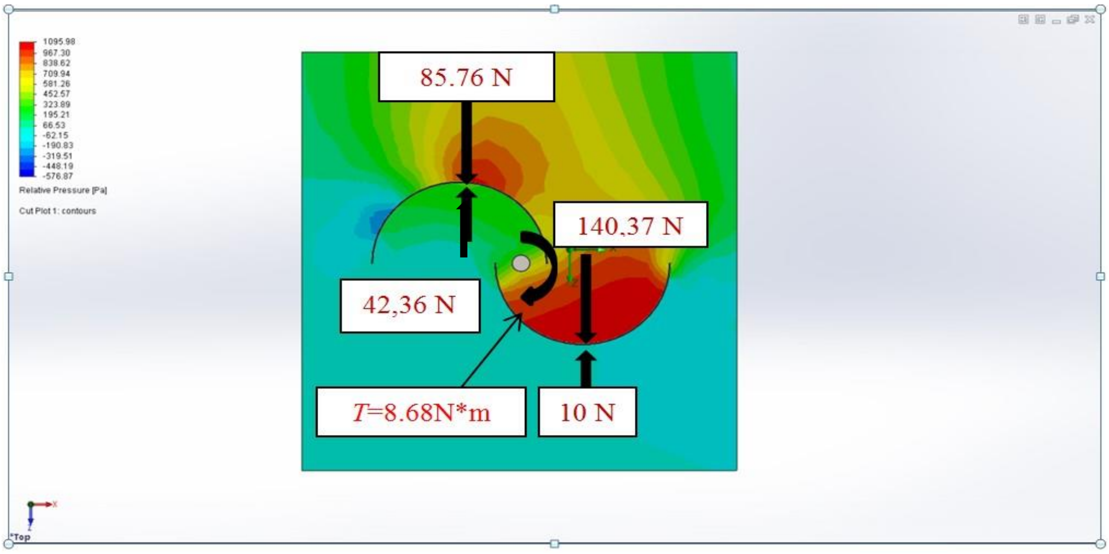
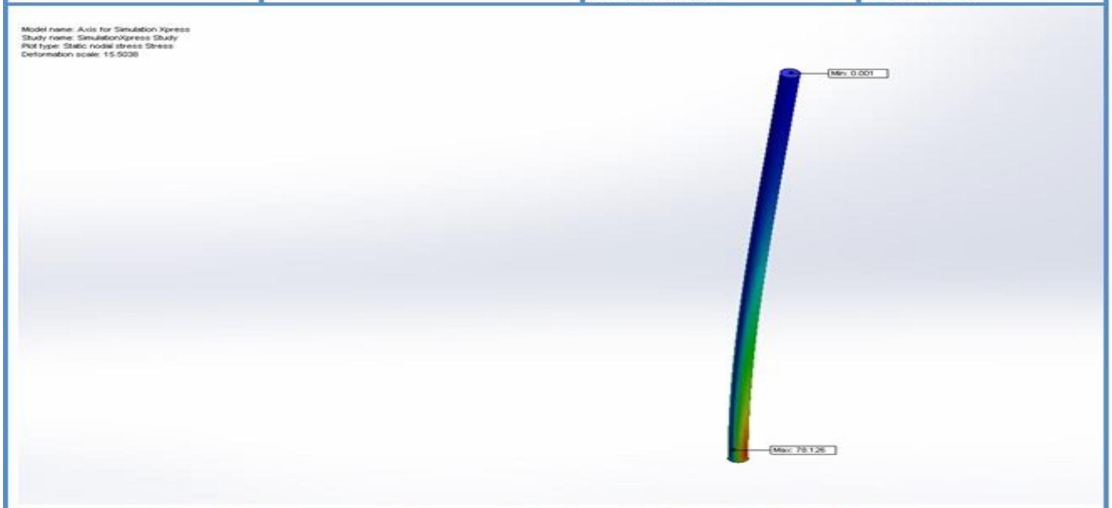


Figure 3: Torque on the axis.

Because of the future mechanical working and the stiffness the axis needs, the next standard diameter of 20mm is selected. After simulations ran with Simulation Xpress, it was concluded that the total mechanical stress according to Von Misses theory is above the Yield number of the material. This means that the axis works in safety. Also, as it is shown in Figure 4, the deformation (the max was 4.5mm) is between the limits that allow the wind turbine to perform without any problems. Finally, the safety factor in the part where the highest force is, is N=7.2.

Name	Type	Min	Max
Stress	VON: von Mises Stress	0.000983438 N/mm^2 (MPa) Node: 3604	78.1257 N/mm^2 (MPa) Node: 947



Axis for Simulation Xpress-SimulationXpress Study-Stress-Stress

Figure 4: Deformation of the axis.

5.2 Blades' Strength

There are two kinds of wind load that the wings receive. The first is at the concave side where the wind contributes to the rotation of the turbine and the second is at the convex side where the wind moves against the rotation. To find out what kind of support the fan needs, the deformation under high loads the blades will have and how safe its operation is (using the Von Mises theory), we will once again use SimulationXpress by SolidWorks.

Notes: The blades are stabilized at the top and the bottom. The material of the blades is aluminum alloy 3105.

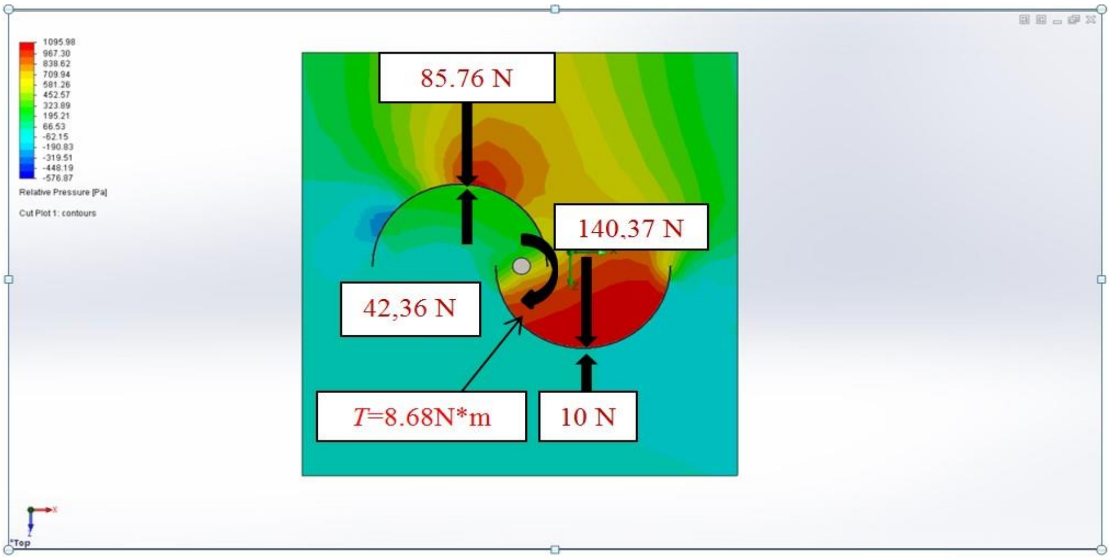


Figure 5: Top view of the shear forces on the blades.

Figure 6 and 7 below show how the "positive" and the "negative" blades can be deformed in case of very high wind powers.

Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm Node: 1	0.079101 mm Node: 104

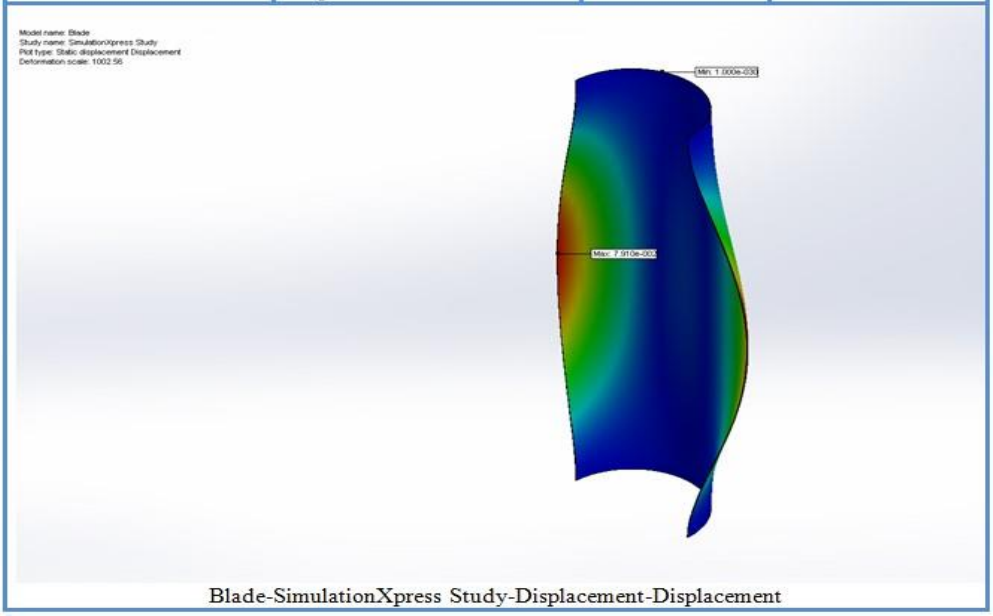


Figure 6: Deformation of the "positive" blade.

The conclusion for the first figure (the "positive" blade) is that the composite stress in the blade is very far off the yield strength of the used material and this results to very high safety factors. Furthermore, the most important output of this analysis is the little deformation at the middle of the blade in case of very high wind powers. This deformation is about 0.079mm and it is not of the magnitude that the images show since the figures are plasmatic and they only explain the kind of deformation. Conclusively, the safety factor at the worst point and without extra support, at the middle of the blades, is N=48.4.

Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm Node: 1	0.0323608 mm Node: 2046

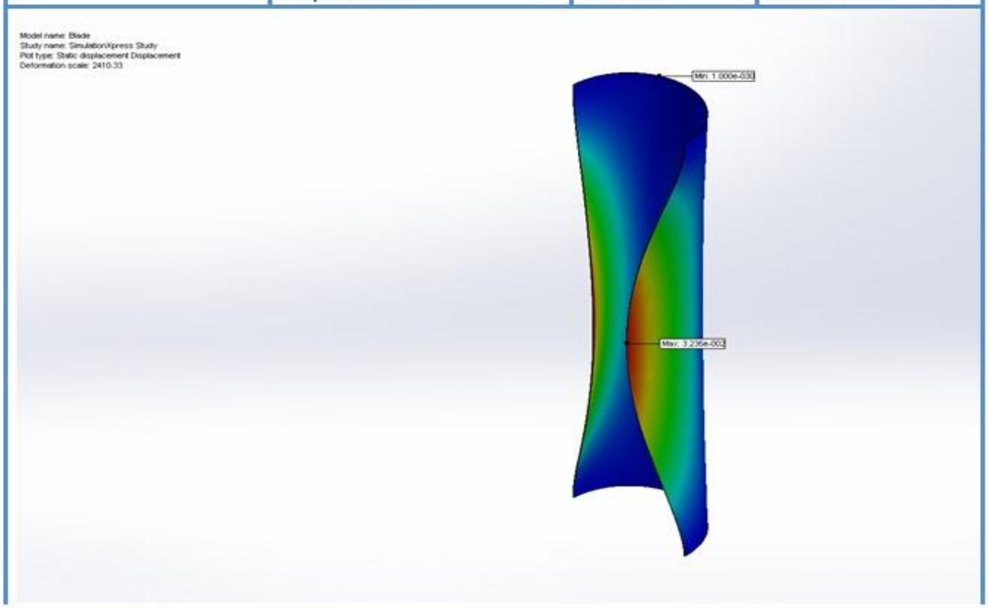


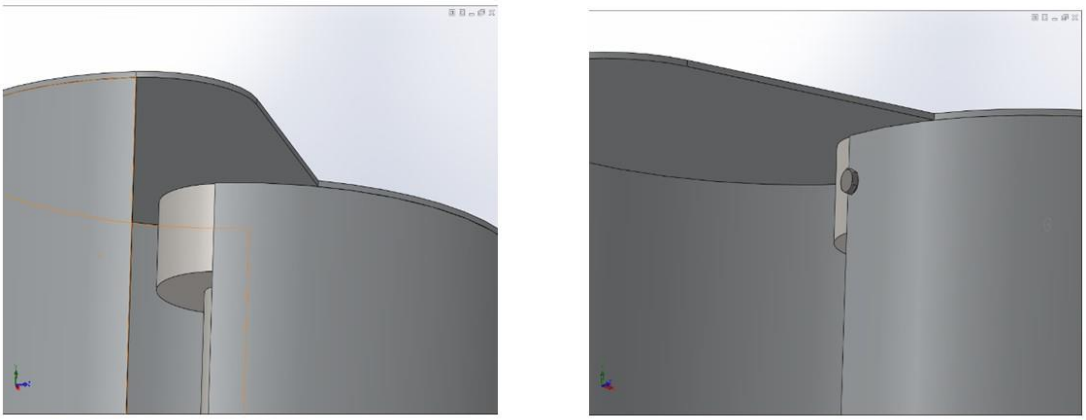
Figure 7: Deformation of the "negative" blade.

Regarding the negative blade, the deformation is even less in the case of high loads, so no further support or change is required.

5.3 Bolts between the axis and blades

To connect the blades with the axis, a link of a 60mm diameter will be used. It also needs to have a bore of a 20mm diameter in the middle through where the axis will be placed. This item will be a ring with two little bores, one opposite of the other in a way that two screws can be applied and hold it. Figure 8 shows this connection illustratively. The load that the bolts will receive will arise only from the movement of the blades. At this point it should be noted that the blades will not only be held by the bolts but they will also be welded with the top and bottom bases and they will be supported from a thin wire at their middle height.

After detailed calculations, considering the velocity of the wind, the mass of the blade, the fact that we will use 2 screws which means the load is divided by two and the Von Mises theory, the bolt that was decided was the most appropriate is the metric thread bolt with diameter d=2.9mm. Considering this, the next standard diameter is the M3. The calculations have been made for a safety factor of N=3. The images below show the blades before and after the link with the bolts.



Before After

Figure 8: Before and after the application of the screw that holds together the axis and the blades.

5.4 Bearings

To select the appropriate bearings we had to do an analysis of the mechanical stresses they undergo and combining this with the desirable hours of operation we could calculate their final size.

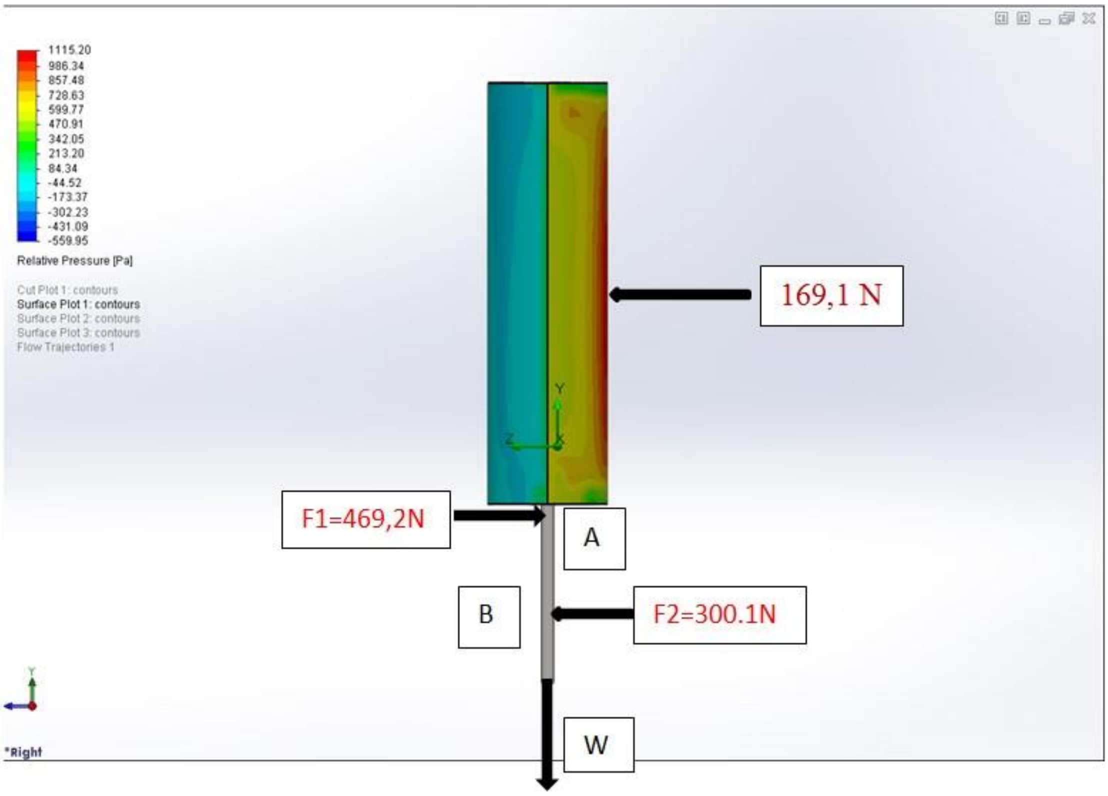


Figure 9: Radial and Axial forces on the bearings.

The first bearing is distanced 10mm from the bottom of the blades and the other is distanced 200mm from the first bearing. This distance was decided after tests and according to the limitations the base had. The equation to calculate the force shown on Figure 9 was:

$$\Sigma Fx = 0 => -169.1 + F1 - F2 = 0 \ (1)$$

$$\Sigma M_B = 0 => 169{,}1N * 0{,}555m - F1 * 0.2m = 0 => F1 = 469.2N$$
$$(1) : F2 = 300.1N$$

The *F1* and *F2* forces are the radial forces of the bearings in the A and B points. Also, the bearings undergo to axial force because of the weight. The weight is *W*=5.1 kg that equals to 51 N of force. So the radial load the bearings undergo during their operation is:

$$P = \max[(X\ V\ F_r + Y\ F_a), V\ F_r] \quad \Leftrightarrow \quad P = \max[(X * 469.2 + Y * 51), 469.2]$$

V = 1 when the internal ring of the bearing is moving and *V* = 1.2 when the external ring of the bearing is moving. In our case V = 1.

According to the bibliography the life time of a low power electric motor is between 8000 and 10000 hours. So: $L_h = \frac{10^6}{60n}\left(\frac{C}{P}\right)^p$

The angular velocity for wind speed of 27 m/s is 1512 rpm. We have a ball bearing so, *p* = 3. For the life time we used the upper limit. So: $10000 = \frac{10^6}{60*1512}\left(\frac{C}{P}\right)^3 => \frac{C}{P} = \sqrt[3]{907.2} => \frac{C}{P} = 9.6 => \quad \frac{C}{X*469.2+Y*51} = 9.6$

X and *Y* factors are calculated like this: If *Fa/Fr* <=e → X=1 & Y=0 otherwise *X*=0.56 & *Y*=2.

Figure 10 presents the appropriate bearing for our case:

Principal dimensions			Basic load ratings		Speed ratings		Designation
			dynamic	static	Reference speed	Limiting speed	
d	D	B	C	C_0			* SKF Explorer bearing
mm			kN		r/min		-
20	42	8	7,28	4,05	38000	24000	**16004** *

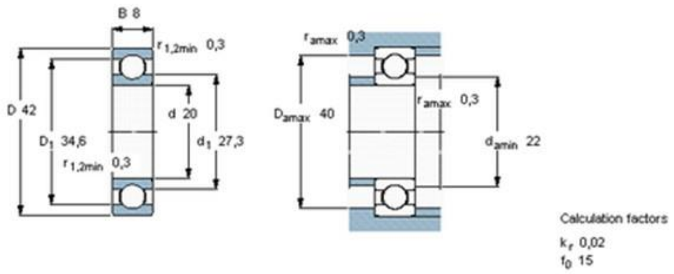


Figure 10: Selection of the bearing.

5.5 Side to Side cylinder for bearings and axis

The side to side cylinder is made of Steel C45, identical with the previous material characteristics.

The cylinder will undergo stress at the points where the bearings are located as the figures 9 and 11 show. This means that we will also have bending moment. The stress at the bearings is calculated only in the bearing with the highest mechanical stress. So: $\sigma_b = \frac{P}{A} = \frac{469.2}{0.008*0.042} = 1.42\ MPa$

It appears that the stress at the bearings we calculated is much lower of the acceptable yield strength of the material we will use.

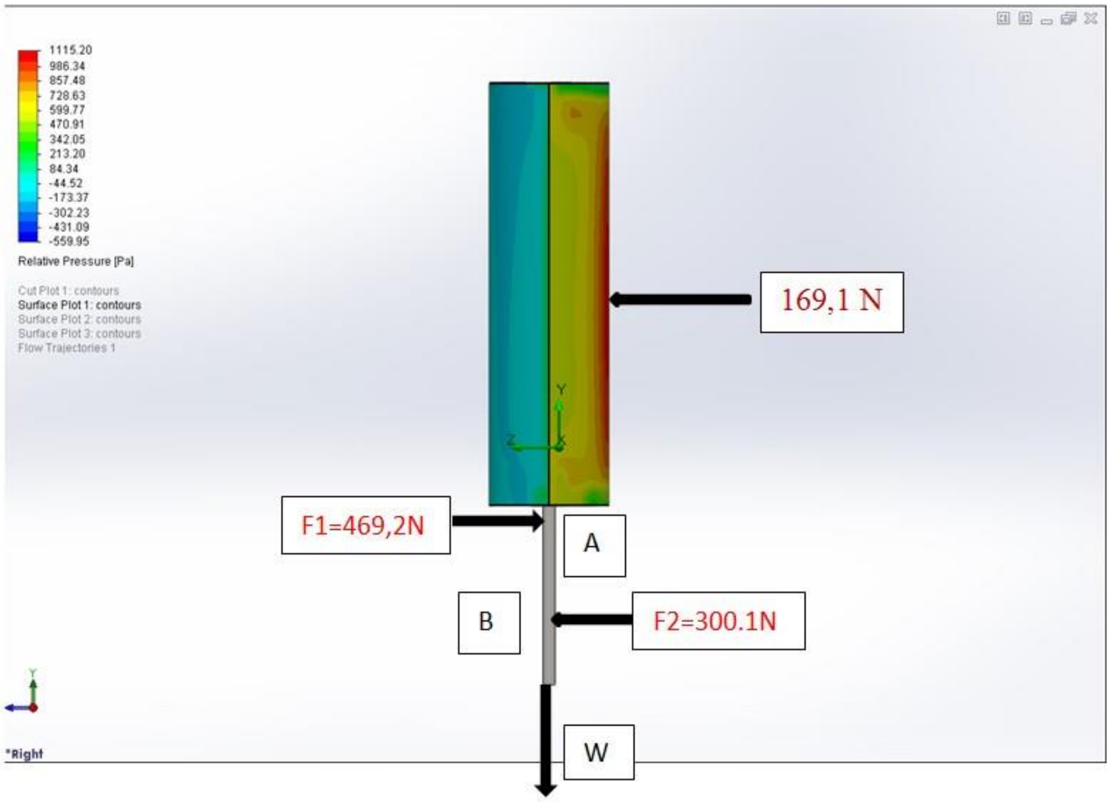


Figure 11: Radial and Axial forces on the Side to Side cylinder.

5.6 Support bases

Considering the total weight of the so far construction which is 5.1kg (figure 12) and the desirable design of the wind turbine three support bases will be used. The first is situated on the bottom and supports the motor while the two others above it support the side to side cylinder. These three levels are connected and supported by four equal axes, which form a square. The material we used for the bases was metal sheet of S235JRG4 according to EN 1025 (Yield Strength: 275 MPa and Tensile Strength: 450 MPa). The analysis will be applied on the one of the three bases, the one that is on the top and undergoes the highest forces. The weight of the wind turbine develops shear stress on the base. According to "Machinery Handbook" when the shear stress of a material does not exist is approximately calculated: 0.5*(Tensile Strength). So, in our case τ = 0.5*450 MPa= 225 MPa. The stress at the bearings is: $\sigma_b = \frac{469,2}{t*0.062} => 275 * 10^6 = \frac{469,2}{t*0.062} => t = 26.81 * 10^{-6} m$

The shear stress of the weight is: $\tau = \frac{P}{A} => 225 * 10^6 = \frac{51}{t*0.062} => t = 3.65 * 10^{-6} m$

According to the simulations we can use a very thin metal sheet, but it needs to be standardized according to the metal sheets of the market. So a metal sheet of 2.5mm width will be used.

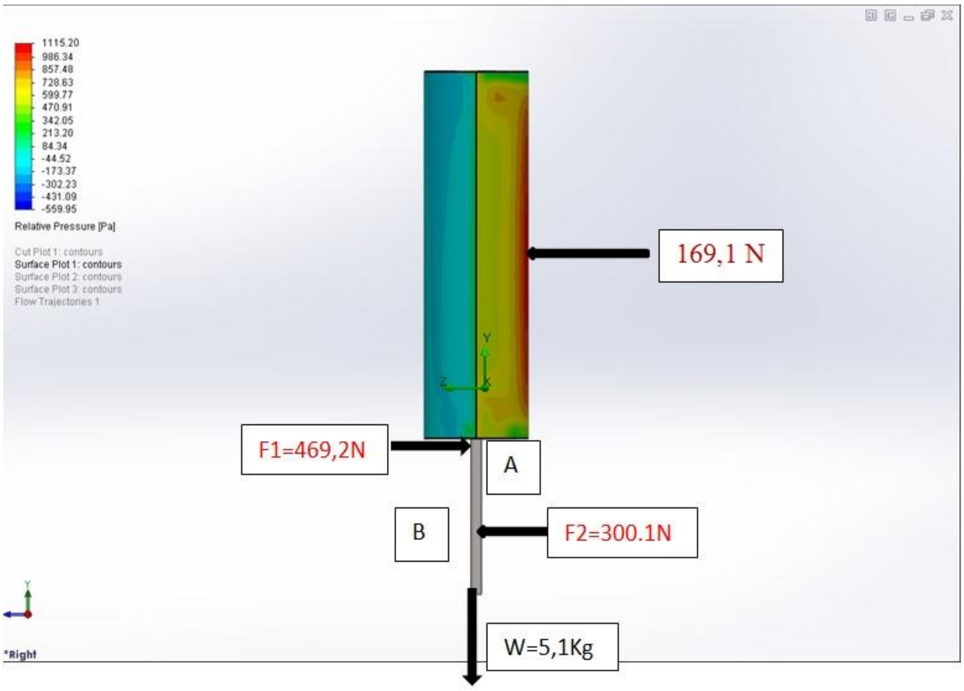


Figure 12: The mass of the turbine parts so far which calculated with a scale.

5.7 Base support axes

The three bases above are connected with four equally and cyclically arranged axes that support the bases. The axes height is 0.35m and the material that has been used was steel C45. They undergo on shear stress because of the bases and also on bending moment. Below is calculated the bending moment at the bottom of the base support axes.

$$\Sigma M_o = 469{,}2 * 0{,}35 - 300{,}1 * 0{,}15 = 119{,}205 N * m$$

The moment of inertia according to the diameter is: $I = \frac{\pi * d^4}{64}$

The yield strength of the material is 340 MPa, so: $\sigma = \frac{M * y_{max}}{I}$, and $y_{max} = d/2$,

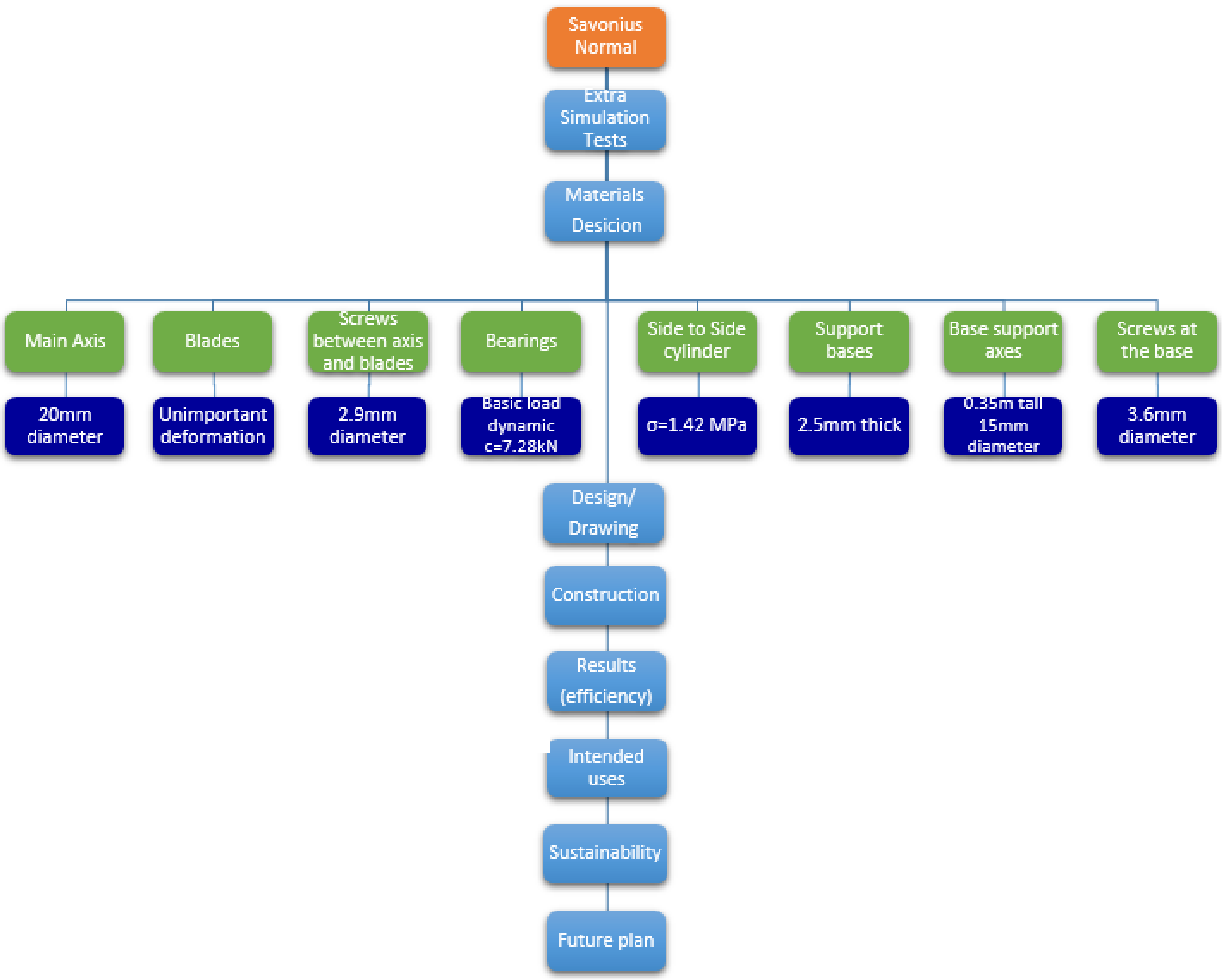
$$340 * 10^6 = \frac{119.2 * \frac{d}{2}}{\frac{3.14 * d^4}{64}} \Rightarrow d = 0.0152m = 15.2mm$$

So the appropriate axis is the one of 15mm diameter. If we consider that we have 4 axes, the loads will be shared. The only problem is that at the bottom of each axis there is a special opening where screws will connect the base with the axis. High stress will be developed there, therefore the diameter of the axes may has to recalculated. But this will be analyzed it in the next chapter where the screws will be calculated.

5.8 Screws at the base

The screws in the base are of high importance. There are four screws, one for each axis. These four screws will support the whole construction. The screws are made of steel, fitted of normal, metrical thread. The screws undergo shear stress and bending moment. The bending moment was calculated above and was 199.2 Nm and the shear stress is 169.1 Nm. The stress on the screw is: $\sigma = \frac{M*c}{I} = \frac{119.2*\frac{d}{2}}{\frac{3.14*d^4}{64}}$ and using the Von Mises theory we have: $\sigma_{eq} = \sqrt{\sigma_{tot}^2 + 3\tau_{tot}^2} \leq \frac{S_y}{N}$ The safety factor is N = 3. So: $\sqrt{\left(\frac{119.2*\frac{d}{2}}{\frac{3.14*d^4}{64}}\right)^2 + 3*\left(\frac{169.1}{\pi*\frac{d^2}{4}}\right)^2} \leq \frac{180*10^6}{3} => d = 0.0036m = 3.6mm$

So according to the standardization four M4 screws will be used. The safety factor is *N*=3. If we want a safer construction we can increase the diameter of the screws. Summarizing this chapter, every important detail of the elements and the rest of the process can be seen at Flowchart 2.



Flowchart 2: The process and basic data after the selection of the Savonius kind.

6.0 Electrical layout

The electrical installment that will be used consists of the following items:

-Motor DC 12V
-Diode 6A
-Terminals + and –
-Wires 1,5mm, red and white

Figure 13 shows the entire electrical layout:

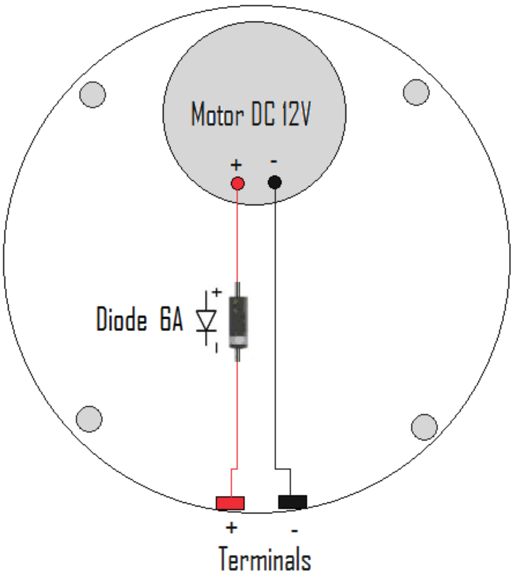


Figure 13: Electrical installment

In figure 14 it is shown the entire layout of the wind turbine which consists of:

-Motor DC 12V
-Charge controller
-Inverter (DC to AC)
-Terminals + and -

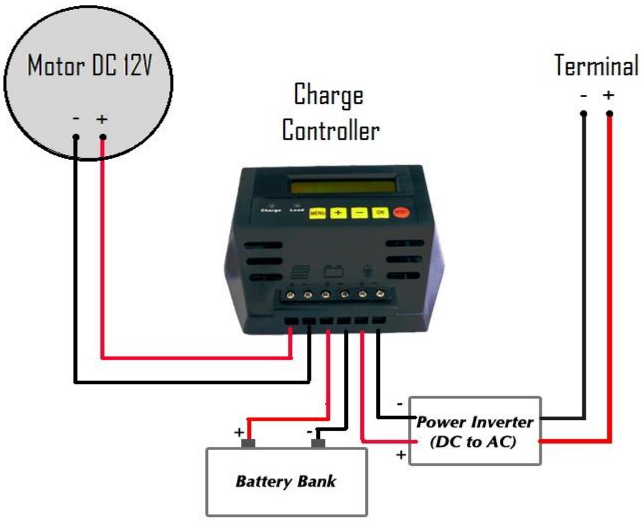


Figure 14: Entire electrical layout.

7.0 Cost calculation

According to the limits and the restrictions of the budget, which was set by the supervisor, the aim was to spend the least amount of money that was possible. Certainly, the team tried to keep the quality of the construction at high standards, trying to find a balance between the cost of the items and their reliability.

Conclusively, considering the quality, the cost of the construction and the energy saving, this wind turbine system turns to be an efficient solution for individual and small scale solutions.

In table 7 is presented the cost of every material that has been used and also the rest of the costs.

Description	Pieces	Cost
Rings	3	7.00 €
Axis	1	3.00 €
Black metal sheets for the base	3	18.00 €
Bearings	2	6.00 €
Support Beams	4	2.40 €
Protection of the Base	1	10.00 €
Side to side cylinder	1	4.50 €
Support metal sheets of the base	4	3.50 €
Gears	2	5.00 €
Screws, Safeties	-	0.50 €
Work	2 working days	90.00 €
Paints	-	12.00 €
Hinges		2.50 €
Aluminum + Cutting	1,2 kilos	5.00 €
Motor 12V (Second hand)		5.00 €
Stickers		10.00 €
	Total:	**184,40 €**

Table 7: Cost of the materials.

8.0 Efficiency calculations

After the analysis of the necessary data that are required for the design of the electrical material, the next step is the calculations. The data of the wind turbine can be found in Table 8. It must be noted that the Tip-Speed Ratio will be used for the calculations, with λ equal to 1. For the vertical axis wind turbines λ varies from 0.9 to 1.1. The units of measurement will follow the International System (S.I.)

Data	
Tip-Speed Ratio λ	1
Blade height	0,7 m
Rotor Diameter *D*	0,34 m
Blade Diameter *d*	0,2 m
Distance *e*	0,06 m
Axis Diameter d(axis)	0,02 m
Surface that wind covers	0,238 m^2

Table 8: Basic wind turbine data.

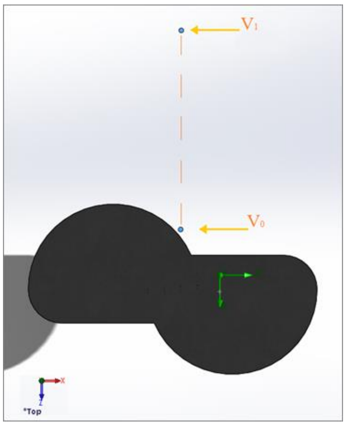


Figure 15: Points of velocity measurements.

Apart from the above date, we will need to find the velocities V_1 and V_0 using the Flow Simulation software by DSS.

At Figure 15, in the top view, are shown the spots that the measurements will take place. These velocities are necessary to calculate the power factor or the aerodynamic efficiency factor C_p. The results of the measurements of the two velocities can be found in Table 9. The last column shows the actual power of the wind turbine.

Wind Velocity u	Velocities V_1, V_0	Coefficient $\alpha = (V_1 - V_0) / V_1$	Coefficient C_p	Actual Power $P = 0,5 * A * Cp * \rho * u^3$
4 m/s	V_1 = 4 m/s V_0 = 1,032 m/s	0,742	0,197	1,84 Watt
6 m/s	V_1 = 6 m/s V_0 = 1,506 m/s	0,749	0,188	5,80 Watt
8 m/s	V_1 = 8 m/s V_0 = 1,980 m/s	0,752	0,185	13,86 Watt
10 m/s	V_1 = 10 m/s V_0 = 2,412 m/s	0,758	0,177	25,90 Watt
12 m/s	V_1 = 12 m/s V_0 = 2,884 m/s	0,759	0,176	44,51 Watt
14 m/s	V_1 = 14 m/s V_0 = 3,395 m/s	0,757	0,178	71,49 Watt
16 m/s	V_1 = 16 m/s V_0 = 3,894 m/s	0,755	0,181	108,51 Watt

Table 9: Test results.

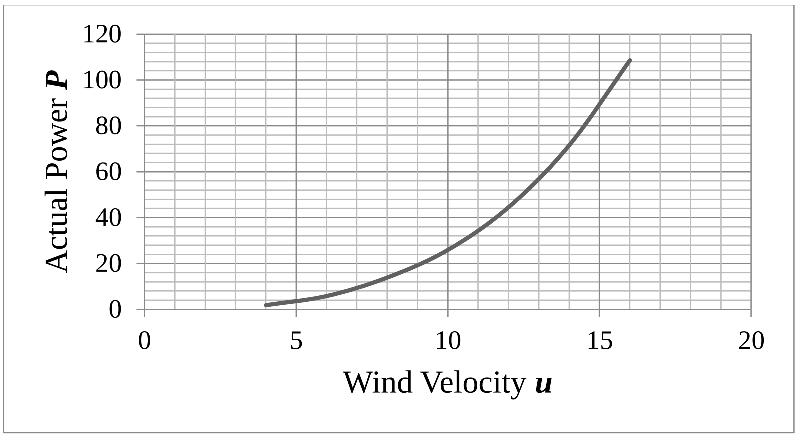


Chart 1: Actual Power according to the Wind Velocity.

Chart 1 shows the relation between the wind velocity and the actual power of the wind turbine. The conclusion is that for double wind velocity the power becomes 8 times more.

Another very important value is the Rotational Speed of the turbine depending on the wind velocity which is shown to the next table and chart.

Wind Velocity u	Rotational Speed n
4 m/s	224 rpm
6 m/s	337 rpm
8 m/s	449 rpm
10 m/s	561 rpm
12 m/s	674 rpm
14 m/s	786 rpm
16 m/s	898 rpm

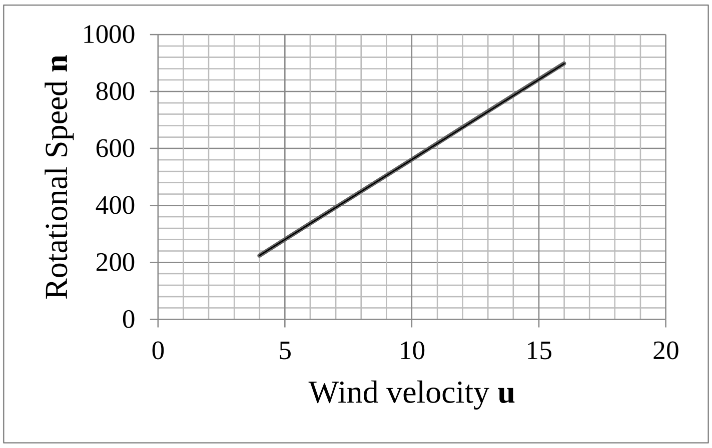


Table 10: Rotational speed for every Wind velocity. | **Chart 2:** Rotational speed according to Wind velocity.

9.0 Conclusion

The wind turbine that the team constructed has several advantages and uses. First of all, it can take advantage of every wind direction and begin the rotation under very low wind powers. The noise it produces is very low compared to common wind turbines, especially the horizontal axis one. Furthermore its size and construction is simple and inexpensive with an also very low need of maintenance. These reasons make it suitable to be used by individuals in towns, placed on rooftops, highway lights and electric signs. A significant advantage is that its cost is limited and it can be used by various users with low budgets.

The main idea was to make electric signs at the streets energy self-sufficient, even when being out of direct sun reach. Suitable copies of this wind turbine can be applied above or next to electric signs and provide enough power to keep them lightening during the whole day. An important extension of this idea is to also connect these turbines with the street and traffic lights at areas where the sun or the power cables are difficult to reach. Finally, this could form a wide network of wind turbines that can power electrical signs, street and traffic lights and other devices, regardless other sources of power.

Figure 16 shows a photography the entire finished project of the Savonius wind turbine as well as its main parts.

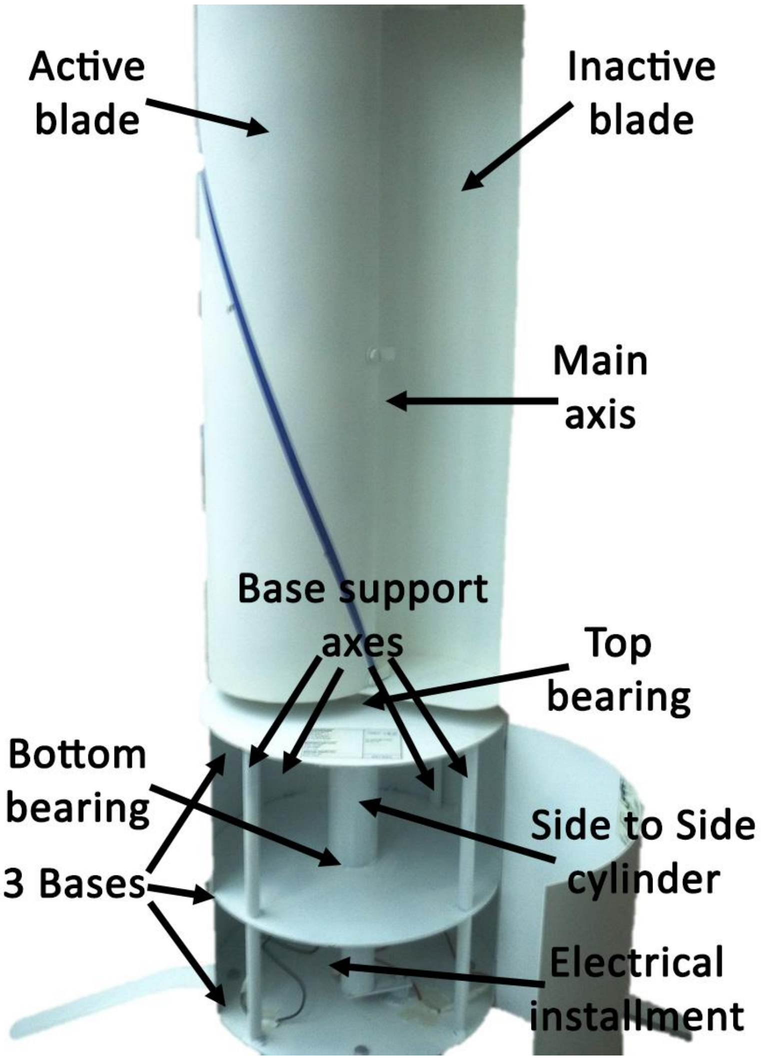


Figure 16: Savonius wind turbine.

10.0 Sustainability

Model name: Savonius	**End of Life**
Weight: 19327.12g	Recycled: 25%
Built to last: 0.167 year	Incinerated: 24%
Duration of use: 7.0 year	Landfill: 51%

10.1 Component Environmental Impact

The greenhouse gases that are released during the lifetime of the product are shown in Figure 17.

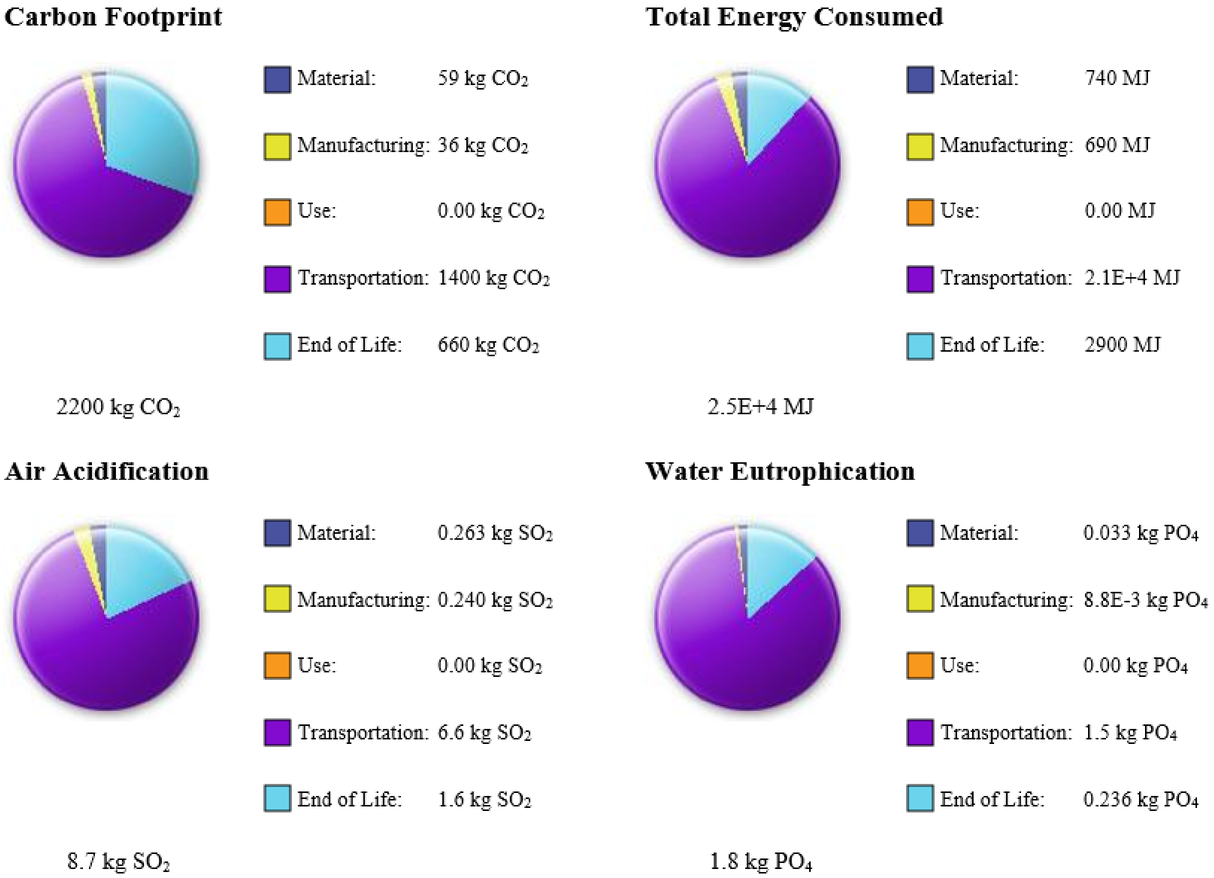


Figure 17: Environmental impact.

Table 11: Top ten components contributing most to the four areas of environmental impact

Component	Carbon	Water	Air	Energy
Side to Side cylinder	14	0.012	0.046	160
Blade	8.9	2.0E-3	0.060	110
Axis	8.7	7.2E-3	0.028	97
Base protector	7.1	2.1E-3	0.023	80
Base supporter	5.6	1.6E-3	0.018	64
Top base supporter	5.4	1.6E-3	0.018	62
Middle base supporter	5.4	1.6E-3	0.017	61
Cap (Top) test	3.4	7.6E-4	0.023	41
Cap (Bottom) test	3.2	7.1E-4	0.021	38
Protective door	2.4	6.8E-4	7.7E-3	27

11.0 References

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