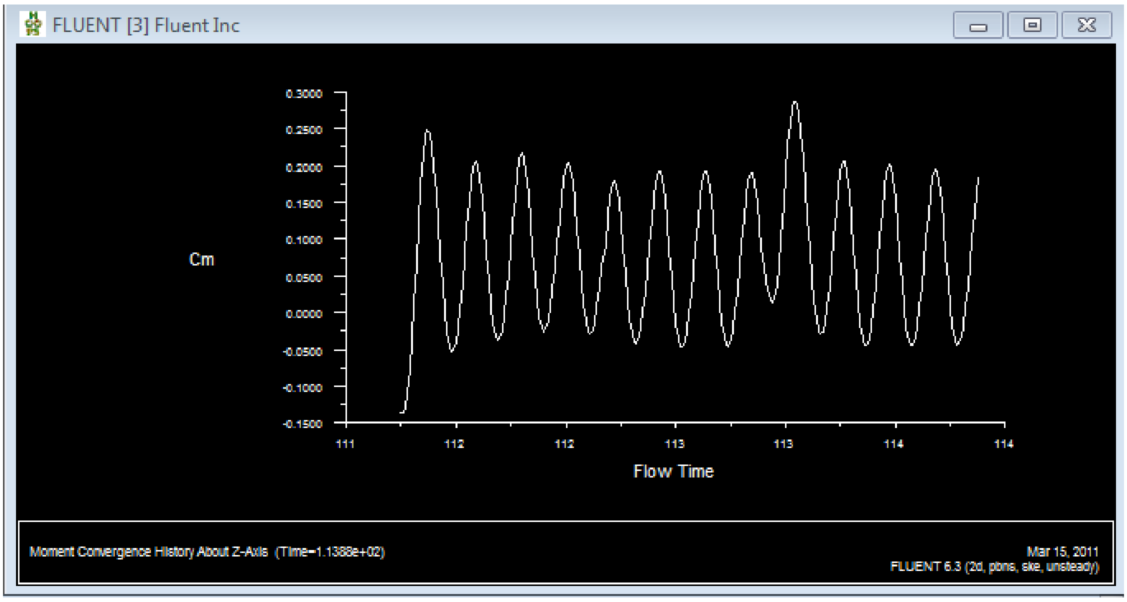

Figure 5.3.

Moment coefficient of NACA 0020

These graphs are oscillating due to rotation of the blades. Each maximum and minimum appears when the airfoils are in the same position that other airfoil.

5.2.2. Results in Excel

To can analyze the results obtained in Fluent is necessary open the text files created by Fluent in Excel.

Once I have opened it in Excel I have done the graph shown below to know what NACA is better. In this graph I have represented only three oscillations because they represent one full circle of the rotor of the vertical axis wind turbine. Fluent gives you the values of the moment coefficient but I need know the values of the power coefficient of the 2D models so I have to apply the equation which relates the power coefficient with the moment coefficient of the rotor how I have explained before:

$$\lambda = \frac{wR}{U} \qquad [3.5.]$$

Where w = 10 rad/s

R = 2 m

U = 10 m/s

So the tip speed ratio of these three 2D models is:

$$\lambda = \frac{wR}{U} = \frac{10 * 2}{10} = 2$$

The tip speed ratio of these three 2D models is 2, it means the velocity of the airfoils is double of the velocity of the wind. So I have to multiply all values of the moment coefficient by 2 to know the values of the power coefficient following the below equation:

$$Ct = \frac{Cp}{\lambda} \qquad [\mathbf{3.7.}]$$

After this, I have calculated the average value of each line to know exactly the value of the power coefficient of each 2D model. The result obtained for each 2D model is:

- NACA 0012: C_p = 0.037

- NACA 0015: C_p = 0.117

-NACA 0020: C_p = 0.079

Finally I have chosen the NACA 0015 to my final design because in my study these NACAs have a power coefficient upper than the others NACAs.

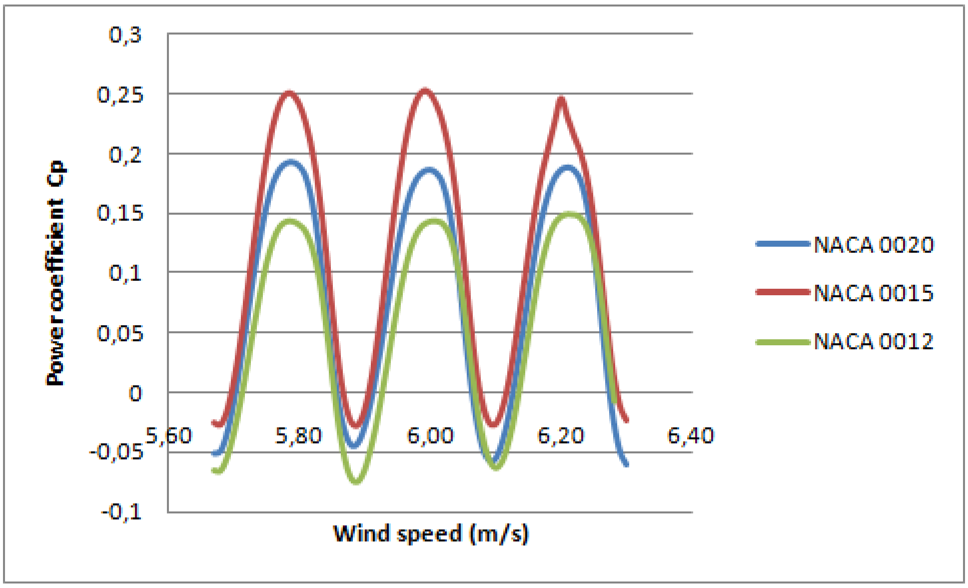

Figure 5.4.

Power coefficients of 2D models

5.3. Choice of the best prototype

5.3.1. Criteria on the prototypes

Effects of solidity on performance

Solidity is one of the main parameters dictating the rotational velocity at which the turbine reaches its maximum performance coefficient. Higher solidity usually dictates lower tip-speed ratio and lower efficiency. At low tip-speed ratios, the rotor blades do not interact as strongly with much of the air flow passing through the volume swept out by the proceeding blades, but at high tip-speed ratios, rotor blades begin to interact with the wakes strongly from upstream blades.

The equation to calculate the solidity of each prototype is the following:

$$S = \frac{N * c}{D} \qquad [5.1.]$$

Where S = solidity

N = number of blades

c = chord length (m)

D = diameter (m)

For each one of the three prototypes the solidity will be:

$$S_1 = \frac{N * c}{D} = \frac{3 * 0.4}{2} = 0.6$$

$$S_2 = \frac{N * c}{D} = \frac{3 * 0.2}{2} = 0.3$$

$$S_3 = \frac{N * c}{D} = \frac{3 * 0.15}{1.5} = 0.3$$

Effects of swept area

The swept area of a Giromill wind turbine is given by the length of the blades multiplied for the rotor diameter:

$$A = L * D \qquad [5.2.]$$

Where A = swept area (m^2)

L = blades lenght (m)

D = diameter (m)

For each one of the three prototypes the swept area will be:

$$A_1 = L * D = 3 * 2 = 6\, m^2$$

$$A_2 = L * D = 2 * 2 = 4\, m^2$$

$$A_3 = L * D = 2 * 1.5 = 3\, m^2$$

Effects of chord length

The chord line is a straight line connecting the leading and trailing edges of the airfoil, at the ends of the mean camber line. And the chord is the length of the chord line and is the characteristic dimension of the airfoil section.

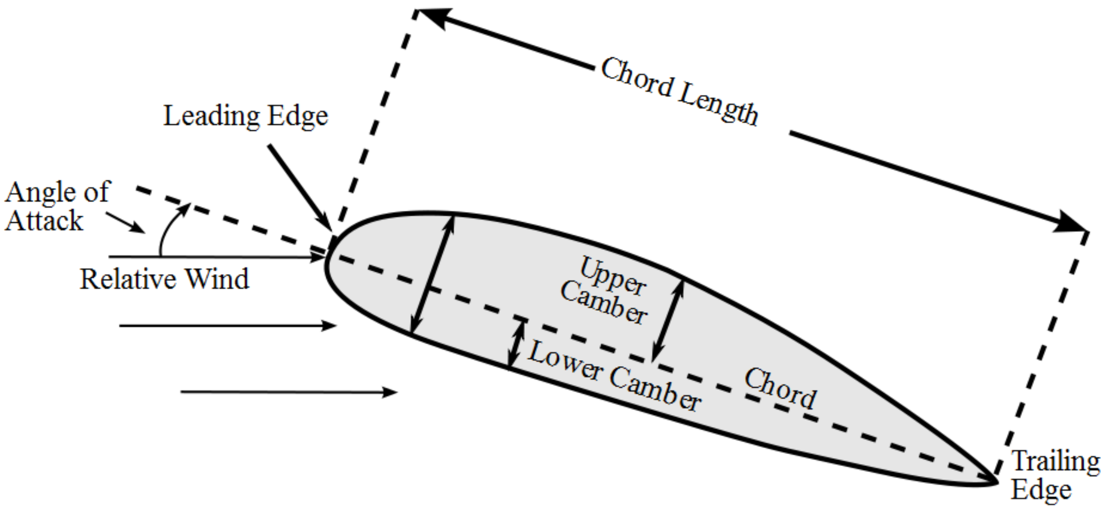

Figure 5.5.

Characteristics of airfoils

The chord lengths of the blades in each prototype are:

- Prototype 1: c = 0.4 m
- Prototype 2: c = 0.2 m
- Prototype 3: c = 0.15 m

5.3.2. Analysis in Fluent

The three prototypes have been analyzed in the same conditions of working to be compared and knowing the results obtained I have could chose the best prototype of them. These operating conditions are:

- Operating pressure: 101325 Pa
- Velocity inlet: 10 m/s
- Rotational speed: -12.5 rad/s

The rotational speed of the rotor is negative due to the direction of working of it, how I have explained when I was analyzing the 2D models.

To check the correct working of the rotor in the figure shown below we can see the direction of the movement of the wind and the direction of rotation of the blades, through pathlines option:

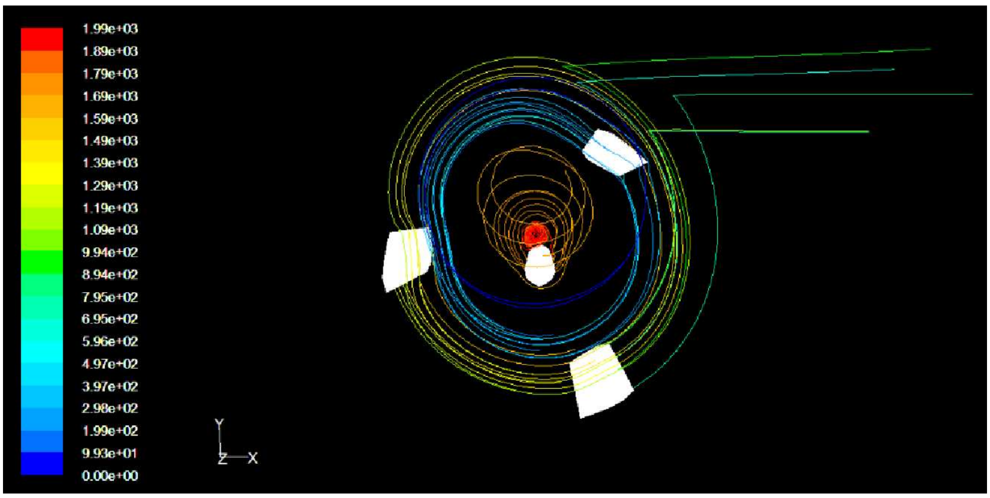

Figure 5.6.

Movement of the wind

After doing the iterations, in the following picture, the velocity vectors coloured by velocity magnitude (m/s) of the fluid close to the blades is shown:

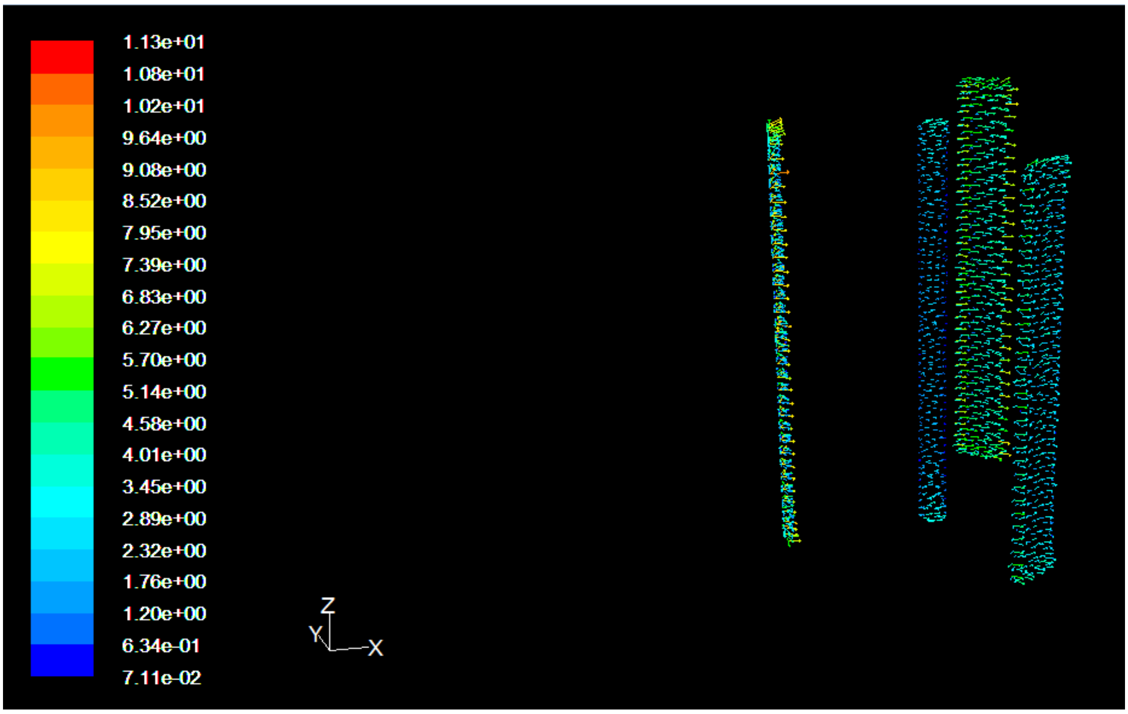

Figure 5.7

Velocity vectors coloured by velocity magnitude (m/s)

5.3.3. Results in Excel

To can analyze the results obtained in Fluent is necessary open the text files created by Fluent in Excel. The process of analysis is similar to the 2D models.

Once I have opened it in Excel I have done the graph shown below to know what prototype is better. Fluent gives you the values of the moment coefficient but I need know the values of the power coefficient of the three prototypes so I have to apply the equation which relates the power coefficient with the moment coefficient of the rotor how I have explained before:

$$\lambda = \frac{wR}{U} \qquad [3.5.]$$

Where w = 12.5 rad/s

$R_1 = R_2 = 1$ m

$R_3 = 0.75$ m

U = 10 m/s

So the tip speed ratios of these three prototypes are:

$$\lambda_1 = \frac{w * R_1}{U} = \frac{12.5 * 1}{10} = 1.25$$

$$\lambda_2 = \frac{w * R_2}{U} = \frac{12.5 * 1}{10} = 1.25$$

$$\lambda_3 = \frac{w * R_3}{U} = \frac{12.5 * 0.75}{10} = 0.9375$$

So I have to multiply all values of the moment coefficient of each prototype by its tip speed ratio respectively to know the values of the power coefficient of each prototypes following the below equation like in the analysis of 2D models:

$$Ct = \frac{Cp}{\lambda} \quad [3.7.]$$

After this, I have calculated in Excel the average value of each line to know exactly the value of the power coefficient of each prototype. The result obtained for each prototype is:

- Prototype 1: $C_p = 0.077$

- Prototype 2: $C_p = 0.047$

-Prototype 3: $C_p = 0.01$

Finally I have chosen the proportions of the prototype 1 to my final design because in my study this prototype has its power coefficient upper than the others two prototypes.

In this graph I have represented only three oscillations because they represent one full circle of the rotor of the vertical axis wind turbine like in the analysis of 2D models:

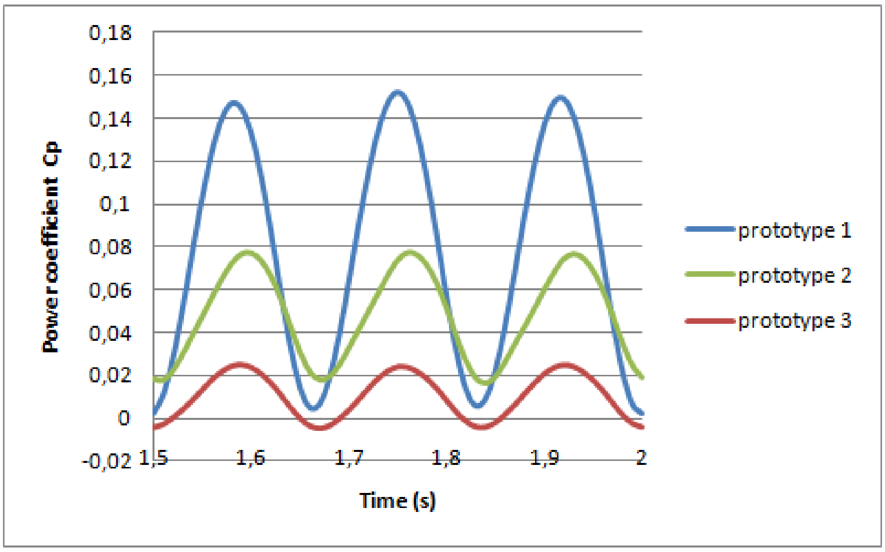

Figure 5.8.

Power coefficients of prototypes

In conclusion, I show the below figure which shows the characteristics of each prototype and its power coeffient (C_p):

Parameters	Prototype 1	Prototype 2	Prototype 3
Chord length (m)	0.4	0.2	0.15
Blades length (m)	3	3	2
Diameter (m)	2	2	1.5
Solidity	0.6	0.3	0.3
Cp	0.077	0.047	0.01

Figure 5.9.

Characteristics of prototypes

5.4. Analysis of T.S.R.

5.4.1. Introduction

Once determined the proportions of the final design of the rotor, the next step is determine the best T.S.R. of operation of the wind turbine. The letters T.S.R. are the acronym of Tip Speed Ratio (λ) which is the relationship between the velocity of blades and the velocity of wind, how I have explained before. We can see the power coefficient of the rotor depends of its tip speed ratio. So to design the final rotor firstly it is necessary know what Tip Speed Ratio give to the rotor the largest power coefficient.

5.4.2. Analysis in Fluent

To know what T.S.R. is the best, I have carried out one study in which I have applied to the rotor one wind of 5 m/s and I have done rotate to the wind turbine with different rotational speeds in Fluent. So I have forced to the rotor to work with different Tip Speed Ratios. How we can see in the graph shown below, exactly I have studied the rotor working with five different Tip Speed Ratios: 0.5, 1, 1.5, 2 and 2.5. Being 101325Pa the operating pressure.

Knowing the wind velocity, the ratio of the rotor, and the Tip Speed Ratios which I want to analyze the wind turbine, it is necessary apply the equation of the Tip Speed Ratio (λ) to determinate the rotational velocity of the blades. So I have to realize the following calculations:

$$\lambda = \frac{wR}{U} = \frac{w*1}{5} = 0.5 \longrightarrow w = 0.5*5 = 2.5 \text{ rad/s}$$

$$\lambda = \frac{wR}{U} = \frac{w*1}{5} = 1 \longrightarrow w = 1*5 = 5 \text{ rad/s}$$

$$\lambda = \frac{wR}{U} = \frac{w*1}{5} = 1.5 \longrightarrow w = 1.5*5 = 7.5 \text{ rad/s}$$

$$\lambda = \frac{wR}{U} = \frac{w*1}{5} = 2 \longrightarrow w = 2*5 = 10 \text{ rad/s}$$

$$\lambda = \frac{wR}{U} = \frac{w*1}{5} = 2.5 \longrightarrow w = 2.5*5 = 12.5 \text{ rad/s}$$

Fluent gives you the values of the moment coefficient but I need know the values of the power coefficient of the rotor, so I have to apply the equation which relates the power coefficient with the moment coefficient of the rotor how I have explained before:

$$Ct = \frac{Cp}{\lambda} \qquad [3.7.]$$

5.4.3. Analysis in Excel

To can analyze the results obtained in Fluent is necessary open the text files created by Fluent in Excel. After this, I have calculated in Excel the average value of each line to know exactly the value of the power coefficient of the rotor when it is working in each condition. This process is repeated each time that I have to do one analysis of the Fluent results .The result obtained for each conditions of work is shown in the below graph created in Excel where it is proved that the performance due to work of the rotor are when its Tip Speed Rotor is 2:

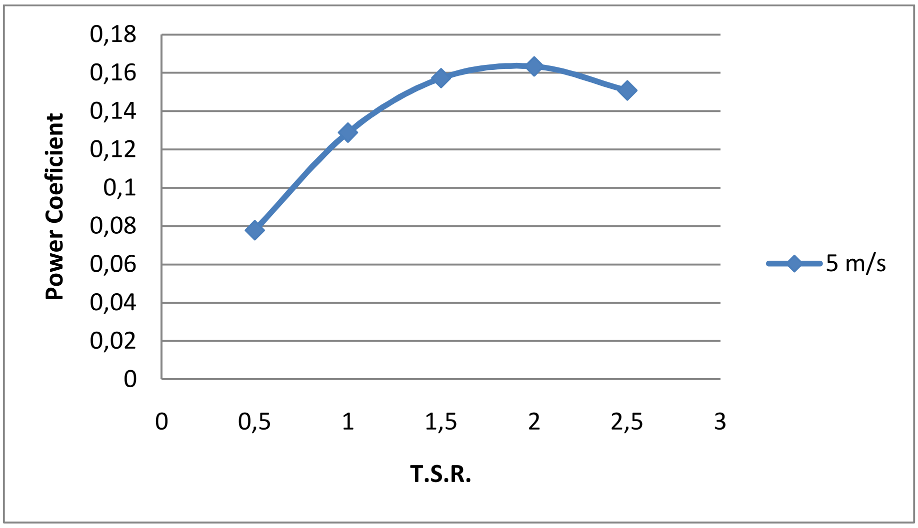

Figure 5.10.

Power coefficient versus T.S.R.

In conclusion, the next analysis will be realized with the rotor working with Tip Speed Ratio 2.

5.5. Find out the power curve of the wind turbine

5.5.1. Introduction

Once the Tip Speed Ratio is known, how I explained before to this rotor the Tip Speed Ratio of work will be 2, it is time of find out the power curve of the wind turbine.

There are many ways to explain what is a power curve of a wind turbine:

- The power curve of a wind turbine is a graph that indicates how large the electrical power output will be for the turbine at different wind speeds.

-Representation of the electric power produced by a wind turbine at different wind speeds.

- Power curve indicates the wind energy captured by a turbine

5.5.2. Analysis in Fluent

To find out the power curve of the wind turbine I have analyzed the behaviour of the wind turbine with different wind speeds, but maintaining constant and equal to 2 its Tip Speed Ratio in Fluent, so the rotational velocity of the wind turbine is different for each velocity following the equation which defines the Tip Speed Ratio:

$$\lambda = \frac{wR}{U} \qquad [3.5.]$$

5.5.3. Analysis in Excel

Like in the others analysis, to can analyze the results obtained in Fluent is necessary open the text files created by Fluent in Excel. After this, I have calculated in Excel the average value of each power coefficient (Cp) line to know exactly the value of the power coefficient of the rotor when it is working in each condition. To define the power curve I have found out the generated power by the wind turbine with 11 different velocities.

How Fluent gives you the values of the moment coefficient but I need know the values of the power coefficient of the rotor, so I have to apply the equation which relates the power coefficient with the moment coefficient of the rotor how I have explained before:

$$Ct = \frac{Cp}{\lambda} \qquad [3.7.]$$

Once I have known the value of the power coefficient (C_p) in each condition, I have had to calculate the generated power using this equation:

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