Wind Turbine Project

Design Engineering 2

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INDEX

This report presents the design and engineering of wind turbines. The objective of the project is to come up with three turbine blades that will give maximum performance. This is achieved by researching existing airfoil profiles, a selection of best performing materials and use of appropriate manufacturing technology.

1. INTRODUCTION

This project aims to cover practical aspects of engineering design with a special emphasis on sustainability. The team formed for this assignment set out a project plan in which the different tasks were given allocated times within the deadlines given. The purpose was to produce two sets of blades using two different manufacturing methods, one by laser cutting sections which would later be assembled and wrapped and the other by using the CNC router to produce an airfoil from a digital file. The project involved a good amount of research to find an airfoil profile with a good tip speed and lift-to-drag coefficient, evaluating material properties and thorough calculations to enhance the performance of the designed blades. These were then tested with variable wind speed and angle of attack to glean results that would then be compared with calculated outcomes.

2. CALCULATIONS

During the testing of our blades, we used a tachometer to measure the actual RPM of our turbine blades. In order to ensure results were fair we took an average from the readings to account for any anomalies. We found that our measured result of 1116.13 RPM was within an acceptable range of our calculated RPM of 1282.74 taking into account the tolerance of our hand-made blades which was much larger than if we had used the CNC router.

It was important that our tip speed was high, as it was one of our initial design parameters. We calculated that the tip speed of our blade which was 26.87m/s proved to be a sufficient for the scale we were working to.

Revolutions Per Minute

RPM= TSR x 60 x Vwind / π x D

RPM= 5 x 60 x 6 / 3.142 x 0.557

RPM= <u>971.42rpm</u>

Speed

Tip and Base Speed= RPM x π x D / 60

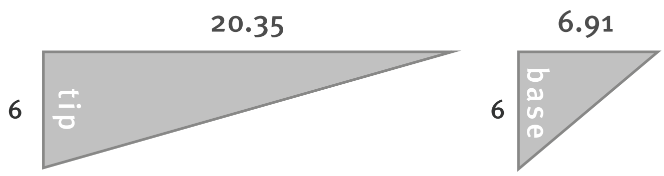
Tip Speed= 971.42 x π x 0.41 / 60

Tip Speed= <u>20.35m/s</u>

Base Speed= 971.42 x π x 0.147 / 60

Base Speed= <u>6.91m/s</u>

Next we took a look at the angle of twist along support rod of the turbine blade; we were able to calculate how much rotation was needed to augment the airfoil sections correctly along the length of the blade dividing the amount between the nine airfoil sections along the length of the blade.



Tan=O/A
Tan6/20.35=0.29

Tan-1=<u>16.42°(Tip)</u>

Tan=O/A
Tan6/6.61=0.86

Tan-1=<u>40.96°(Base)</u>

Angle of Twist= 40.96 – 16.42
= <u>24.54°</u>

Through our initial research we knew that the Reynolds number for the Wortman airfoil would be low. However, initial calculations came out high but this was because the equation for Reynold's number calculation employs Kinematic viscosity except with airfoils which use 'dynamic viscosity' which takes into account air density at sea level. Upon discovery of this fact we used dynamic viscosity to help calculate a Reynold's number of 63 530. This means that we do not have severe pressure gradients and that maximum lift will be restricted.

The force of lift acting on our blade was calculated at 31.34 Newtons. This was deemed to be a substantial amount for the scale of our blade and proved to be key in our testing as the blades adhered to one of our design parameters of a high life-to-drag ratio.

Reynolds Number

$Re = (\rho \ V \ l)/\mu$

$Re = \underline{63\ 530}$

Force of Lift

$Fl = \frac{1}{2} \rho A V^2 Cl$

$Fl = \frac{1}{2} \times 1.293 \times 0.903 \times 6^2 \times 1.491$

$Fl = \underline{31.34N}$

The target energy production for our turbine blades was 3 Watts provided by a current and voltage of 0.5A and 6V respectively. Whilst testing we ran our turbine blade at the desired wind speed and angle of attack and measured the voltage and current output using DMM (Digital multi meters). We managed to surpass our goal and produced 3.582 Watts from 0.535 Amps and 6.72 Volts.

Maximum Power Output

Power = Current x Voltage

$P = IV$

$P = 0.535A \times 6.72V$

$P = \underline{3.582W}$

Coefficient of Power

$Cp = P/(0.5 \rho A V^3)$

$Cp = 34.94/72.97$

$Cp = \underline{0.47}$

Power

$P = 1/2 \times \rho \times A \times V^3 \times Cp$

$P = 1/2 \times 1.293 \times 0.903 \times 6^3 \times 0.47$

$P = \underline{59.26W}$

Measured Power Output

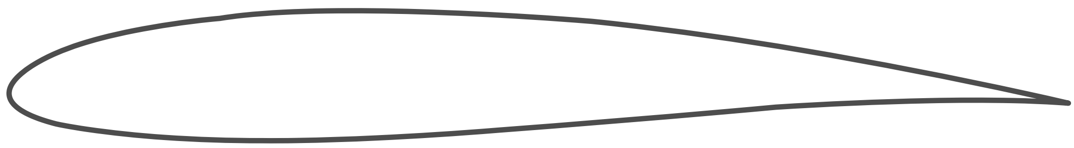
$P = IV = 0.535 \times 6.72 = \underline{3.582W}$

We needed to calculate the chord of the tip of our blade in order to give us the size of our tip. We did this by deriving the formula for the force of the lift in order to achieve this. However, the chord tip that was calculated was not able to be produced as such a small chord at the tip of our turbine blade would not be able to attach to the main support rod.

3. DESIGN

The main factors considered when deciding on a final design were the following: Airfoil profile, angle of twist, overall length and surface production.

After extensive research into airfoil profiles, we found that the most effective wind turbine blades had two main contributing factors that determined their efficiency: the tip speed of the blades and the lift-to-drag ratio. In order for maximum efficiency, the blade should have both a high tip speed and a high lift-to-drag ratio. After establishing these parameters, an airfoil profile that met our constraints had to be found. The research was mainly done online through the databases at The World Of Krauss and NACA. The chosen airfoil profile was the Wortman FX-60-126 because it fulfilled what criteria we were looking for in a blade and would prove to be the most effective and efficient blade to manufacture. The Wortman FX-60-126 had a very high lift-to-drag ratio of 170.4 and a high tip speed of 18.4m/s, which proved a perfect match for what we were looking for in an airfoil.



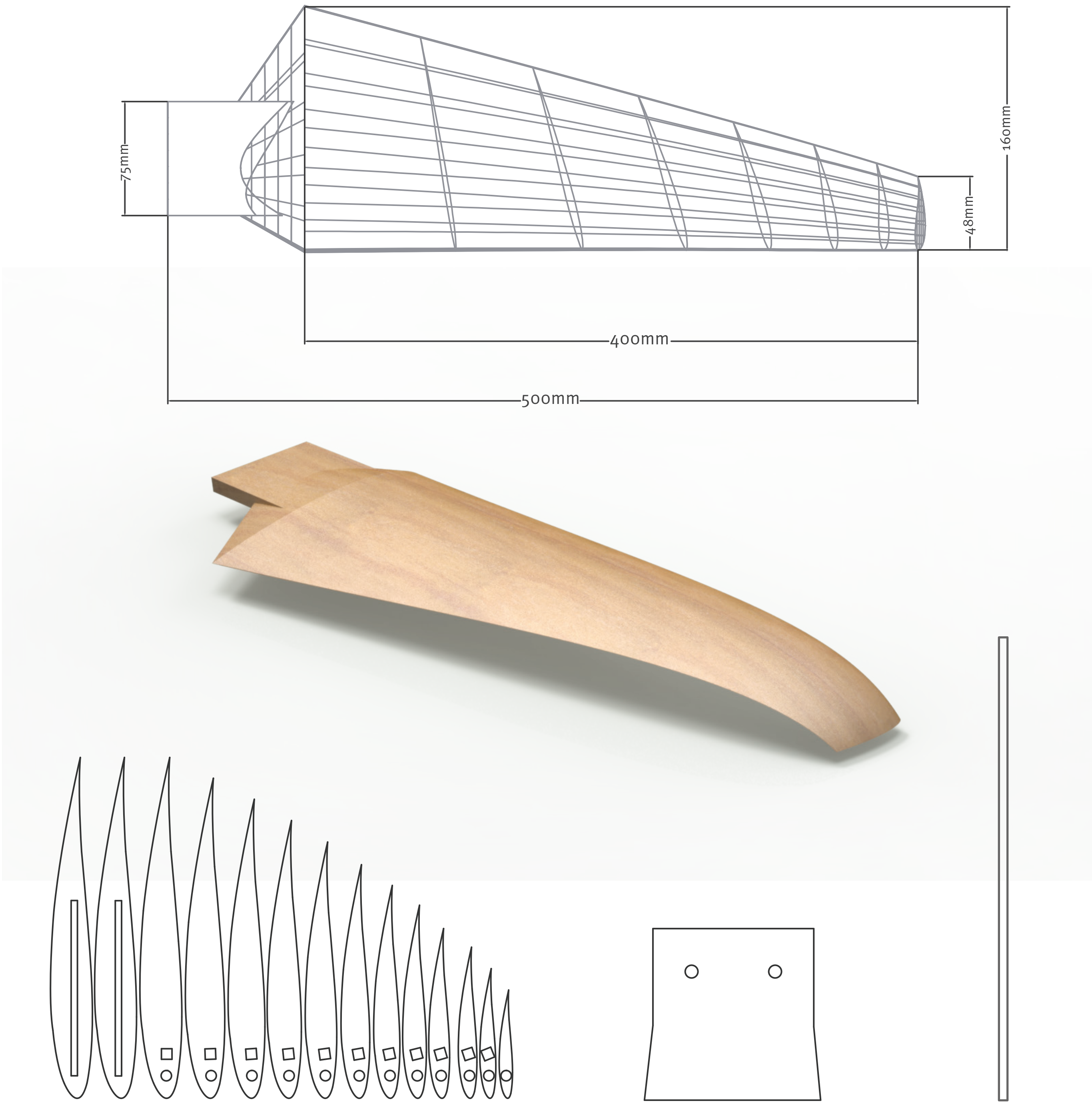
Wortman FX-60-126

The blade was initially designed using Autodesk Alias Design in order to export the model as an stl file that would be used by CNC milling machine.

However, a second design was produced with the intention of using a different technology. The airfoil profile was gradually scaled down along nine stations to be laser cut as sections of the blade. These sections were then augmented about and connected by a square dowel intersecting the profiles at different angles, with the intention of obtaining the desired overall angle of twist through the length of the blade. Another piece that had to be designed was the connecting substrate between the blade and dynamo hub. These were also laser cut and slotted into the sections located at the base of the blade.

The turbine blade was designed to taper in order to achieve maximum efficiency and predicted to be capable of a high tip speed and have a high lift-to-drag ratio. The formula ($F_d = 1/2\ \rho\ A\ V^2\ C_l$) indicates that the force of the drag is relative to the frontal area of the turbine blade facing the wind, therefore by reducing the size and chord of the airfoil profile at the tip will reduce the size of the force of drag at the tip. Furthermore, from the formula (Tip Speed= RPM x Pi x D / 60) we deduced that the speed of the tip is relative to the length of the blade, thus by reducing the length of the blade, it will help increase the tip speed and help achieve maximum efficiency. In conclusion, tapering the blade and shortening the overall length of it, maximum efficiency can be achieved to help generate its largest theoretical force of lift.

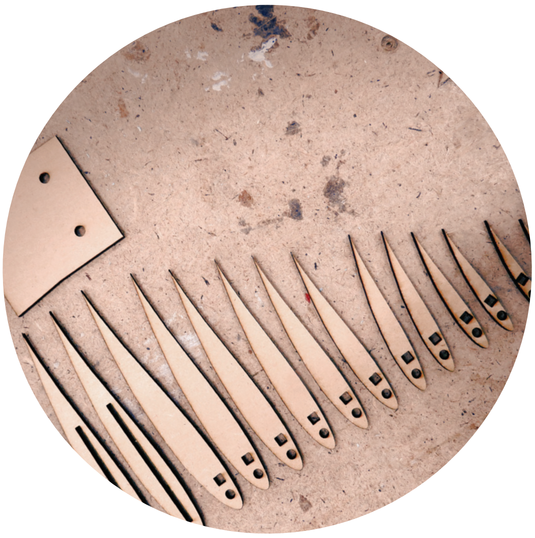
In order to enhance the performance of the blades further, the ideal material for wrapping the internal structure had to be chosen. The turbine blade had to be wrapped because the force of the drag is relative to the surface texture of an object; therefore having a smooth surface on our blade would mean reducing the drag and helping the blade to move through the air more freely. The right material would be lightweight and easy to wrap around the MDF sections. Stemming from our research into model airplane manufacturing, we found that light tissue like paper would be ideal. However, due to time constraints and budget baking paper was chosen as it fulfilled both of these considerations.



4. MATERIALS AND MANUFACTURE

We initially wanted to manufacture our blades in the CNC routing machine out of plywood; this would have been done by creating a 3D CAD model of the turbine blade in Autodesk Alias and exporting the file in a stl format to the CNC machine. We then discovered that as the CNC would not of been able to cut both the top and bottom of the blade in one go, we had to split the blade through the x-axis into two pieces so that the CNC could cut the top of the blade first, then the material would be turned over manually so that the bottom of the blade could be cut. We found that each of the two surfaces took approximately 2 hours to complete, which would of meant a total production time just to produce the blades and without finishing and assembly of around 12 hours. As a group we decided that with the time we had, we would not have been able to cut, assemble and finish all three blades, this would also have meant abandoning the project plan we had set in place at the beginning of this assignment.

The alternative method was to laser cut a number of the airfoil profile sections and assemble them with a dowel. The file for the laser cut was initially drawn in Adobe Illustrator, which was then exported as a 2004 dwg file to AutoCAD. The file in AutoCAD was then adjusted by changing the line colour to red and the line thickness to 0.05mm which were the generic constraints for the laser cut to recognize the cut lines. The file was then exported to the Denford laser cut program to check if the file was compatible.



Initially the file was damaged and the drawn profiles were skewed so the files were then taken back into AutoCAD where they were exploded, Cleaned up for any duplicate lines and then flattened. This process was found to have solved the issue. The profiles were then laser cut from 3mm thick MDF.

The way in which the blade was assembled was by spacing the laser cut profiles out along a dowel that would support and keep them together. We also used this square dowel to achieve our angle of twist, we calculated our wing to have a 23.26° twist, we laser cut 9 profiles out and therefore rotated the square that the dowel would go through by 2.58° on each profile, so that as each part of the profile was put on, the whole blade would twist and achieve our angle of twist to a very accurate scale.



Struts had to be fixed in between each airfoil profile in order to stop the blade from flexing and to give the blade more strength and structural rigidity, once the glue dried and the struts were fixed, the blade proved to be stronger and more rigid.

After the blades were all assembled, they were then wrapped in an initial layer of baking paper, glued using a mix of PVA glue and water, strips of paper were glued to the front and the back of the blade in order to give the blade more rigidity. Once dried, a second layer of baking paper was applied to the blade, to give it more strength and rigidity. Baking paper was used because it proved easy to work with and mould around tight corners; we also chose baking paper because it was recommended to us by a model airplane expert. Our preliminary tests proved this to be sound advice.

In order to achieve our design constraints of having a high tip speed, we wanted to curve the tip of our turbine blade in order to achieve a higher tip speed. This would of only of been possible when manufacturing our blade in the CNC machine, but when we opted to change our manufacture method; we had to sacrifice this addition to our design because it would not have been possible using the laser cut machine.

5. TESTING

After our blades were manufactured, we took them to be tested within a lab located in the Borough Road Building. The test equipment was comprised of the following items: Shimano 6v 3W dynamo hub, Wind generator, Lighting Rig with 3W bulb, Digital multi meter (DMM) and a tachograph.

The first thing we did was set up the controls for our testing; speed of the wind at the front edge of the turbine blades was measured at 6m/s. The wind generator was set 2 meters away from the turbine setup. For better testing efficiencies the aperture of the wind generator was raised to align with the center of the dynamo hub.

For our preliminary tests, the lighting rig was not working, so we made a group decision to test the blades and take direct readings directly from the DMM. We measured high amounts of volts as there was no extra resistance imparted by the lighting rig. The rig adds an electrical resistance to the dynamo hub which limits the output readings to 6V, 0.5A and 3W output.

This preliminary testing did prove useful in the fact that it helped us to establish our optimum angle of attack which resulted at 77.5°, with 0° being the point at which the blade is perpendicular to the direction of the wind. It also helped us to establish our stall angle which was at 80°, so it made the second round of testing a lot quicker to set up and establish.

Table of generated power at different angles of attack:

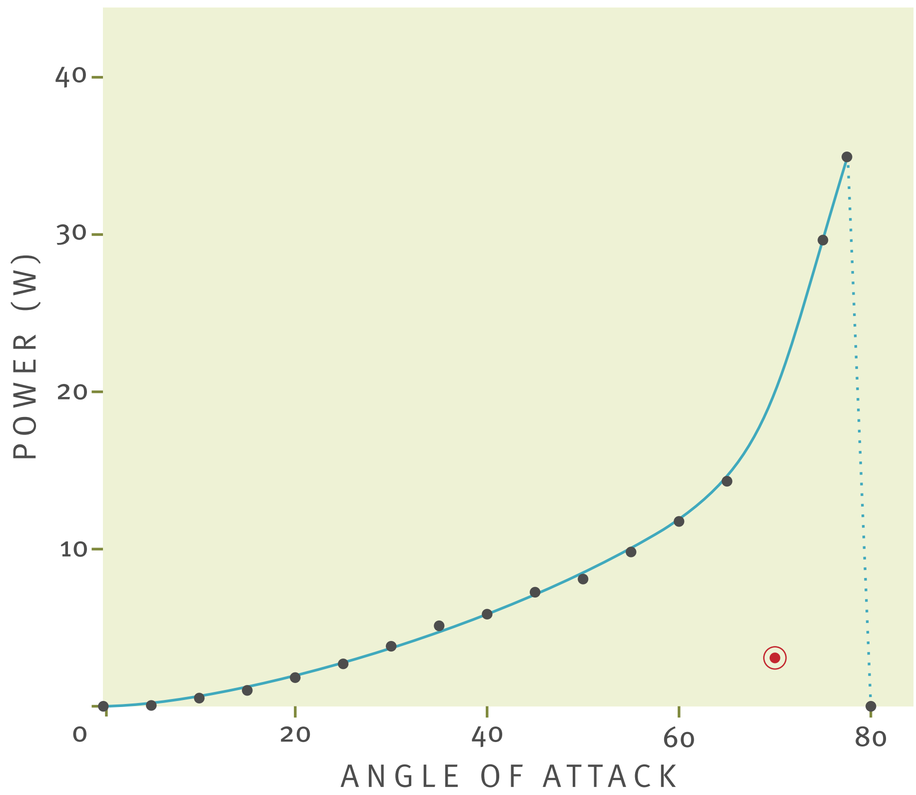
Angle of Attack (α°)	Voltage (V)	Current (Amps)	Power IV (Watts)
0	0.01	.01	$1x10^{-4}$
5	1.80	.03	0.054
10	2.90	.18	0.522
15	4.60	.22	1.012
20	5.70	.32	1.1824
25	7.10	.38	2.698
30	**8.30**	**.46**	**3.818**
35	10.20	.502	5.120
40	11.60	.505	5.858
45	13.74	.528	7.254
50	15.50	.522	7.254
55	18.80	.522	8.091
60	22.61	.520	9.813
65	27.00	.530	11.757
70	38.02	.081	14.310
75	55.21	.537	3.079
77.5	**65.31**	**.535**	**29.647**
80	Stall	Stall	34.94

N.B.

The blue highlighted set of results represents just over the target output of 3W we were required to achieve via a voltage of 6 and a current of 0.5A. At an angle of attack of 30°, we were able to output slightly above this and produce 3.818watts.

The green highlighted set of results show which angle of attack our blades would be the most efficient and produce the largest power output. As seen on the table above, at an angle of attack of 77.5° our blade produce a voltage of 65.31V and a current of 0.535A, therefore produced a power output of 34.94watts

Graph of results of generated power at different angles of attack:



After we obtained the preliminary set of test results, we went back to test our blades for their power output with the use of a working lighting rig, hoping to reach the target of 0.5A, 6V and 3W.

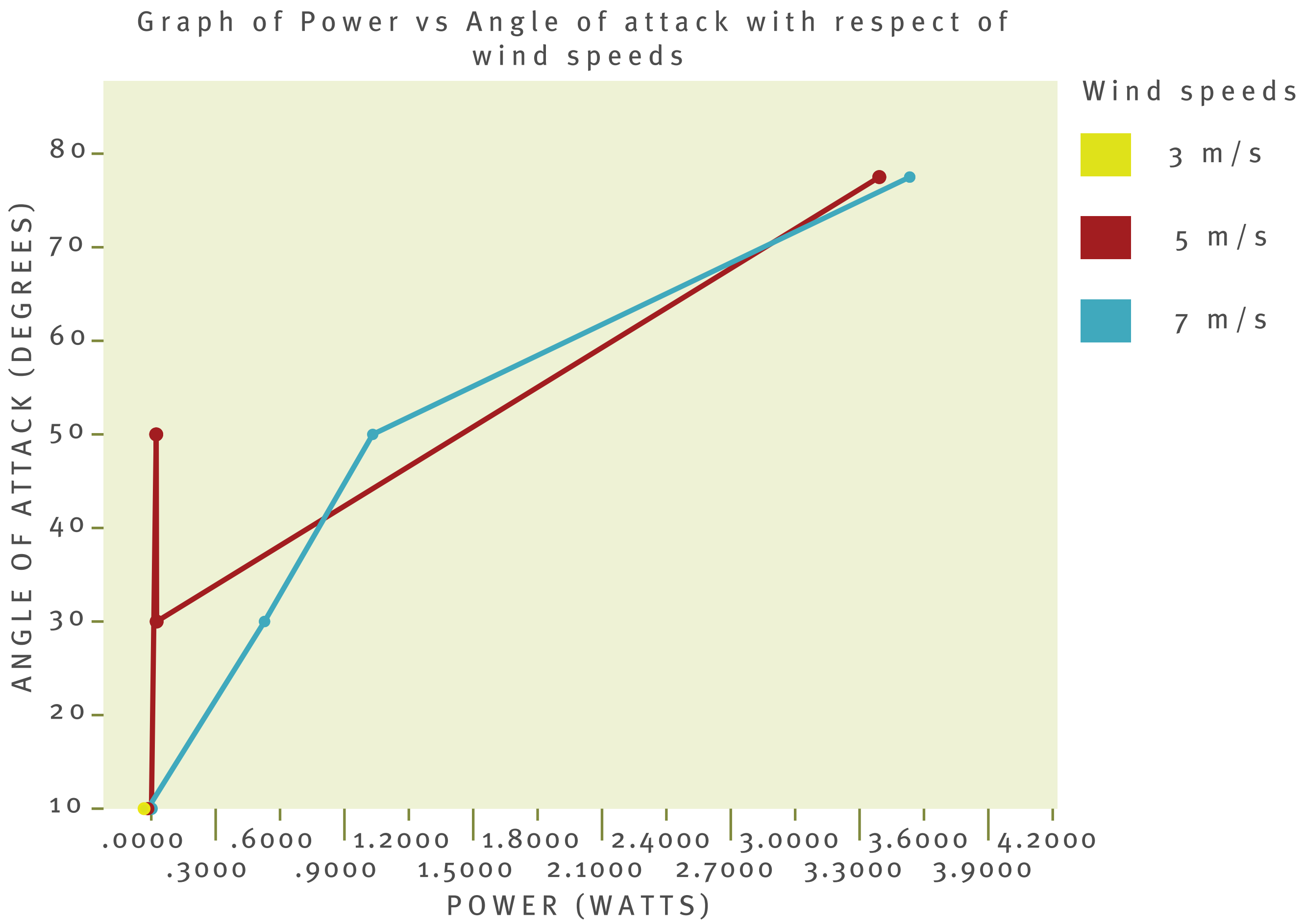
We set out to test for different power outputs at different wind speeds and angle of attacks, the table below shows the results we obtained:

Second table of generated power at different angles of attack (showing different wind speeds:

Vwind (ms^{-1})	Angle of Attack	Current (Amps)	Voltage (Volts)	Power, IV (Watts)
$3ms^{-1}$	10°	0	0	0
$5ms^{-1}$	10°	0.08	0.01	8×10^{-4}
$7ms^{-1}$	10°	0.45	0.07	0.032
$3ms^{-1}$	30°	0	0	0
$5ms^{-1}$	30°	0.126	0.2	0.025
$7ms^{-1}$	30°	0.277	2.08	0.576
$3ms^{-1}$	50°	0	0	0
$5ms^{-1}$	50°	0.162	0.14	0.023
$7ms^{-1}$	50°	0.357	3.03	1.08
$3ms^{-1}$	77.5°	0	0	0
$5ms^{-1}$	77.5°	0.525	6.46	3.392
$7ms^{-1}$	77.5°	0.533	6.72	3.582

The second table of results shows us that we achieved the maximum power output at a wind speed of 7m/s (an extra m/s faster than previous) at an angle of attack of 77.5°. At a very steep angle of 10° we found that the turbine blades would not turn and thus no readings could be taken for results.

During testing we found that the resistance the lighting rig provided to the power output was too much for the turbine to start rotating from static, so we disconnected the bulb and allowed the turbine to gain momentum, we then connected the bulb and let the turbine to settle for around 1 minute before we took readings, to enable us to take strong, accurate readings.



6. CONCLUSION

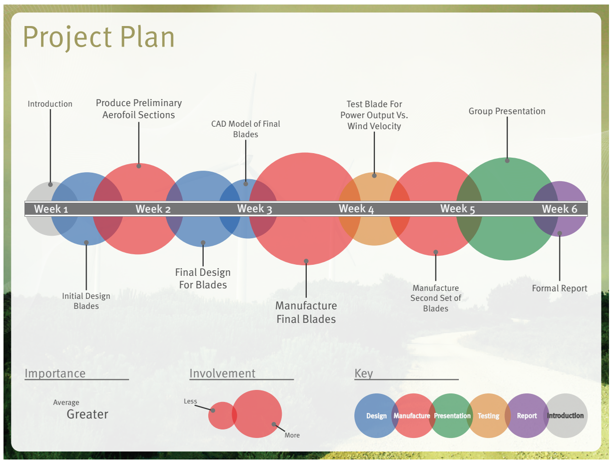
The aim of this project was to design and manufacture wind turbine blades to simulate those of a larger scale wind turbine. We have achieved the aim of this project by producing our own wind turbine blades and testing them to produce a power output data.

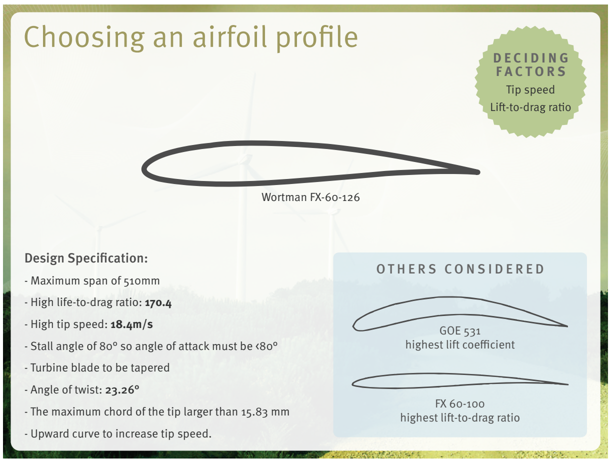
The key points of this project were the design and manufacture of the blades, the testing and the results. We found that the most efficient method of manufacturing the blades was laser cutting and the most suitable material for the skeletal structure to be MDF. Our laser cut and baking paper wrapped turbine blades proved lightweight, strong and efficient during testing and helped us to obtain our results without any major problems.

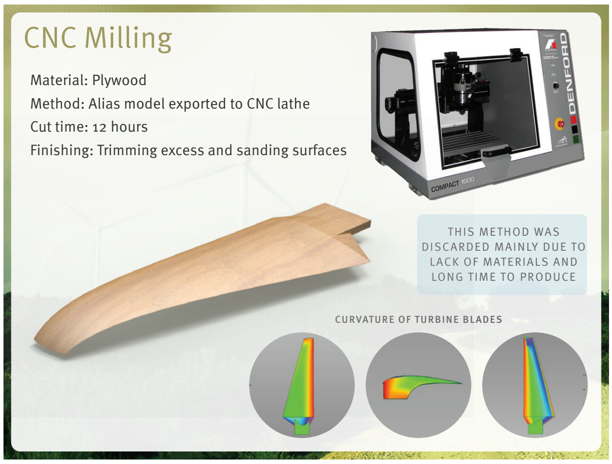
We found that at a wind speed of 6m/s our wind turbine would produce 3.582 Watts of power and each blade turned at 1116.13 revolutions per minute. We also found that our turbine blades would produce a lift force of 31.34 Newtons.

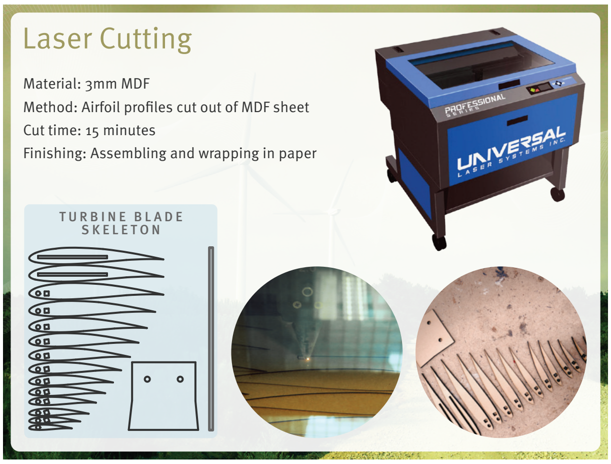
If we were to do the project again, we would try and obtain materials quicker, and try a different method of manufacture akin to our original desire for CNC machining. We would also look at the different variables in this project that have an effect on output results such as characteristic length, and experiment with them

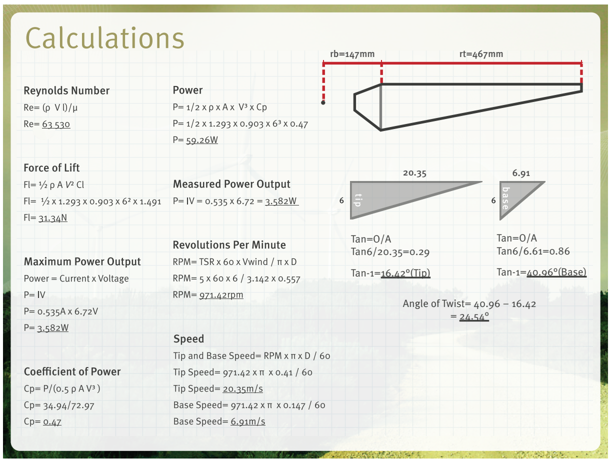
Overall the project went really well for us as a group; we worked efficiently together, organized well and always communicated, which was key. We produced a set of turbine blades and results that we were all very proud of and all gained a lot of knowledge and experience about wind turbines, how they work and their possibilities for energy production.

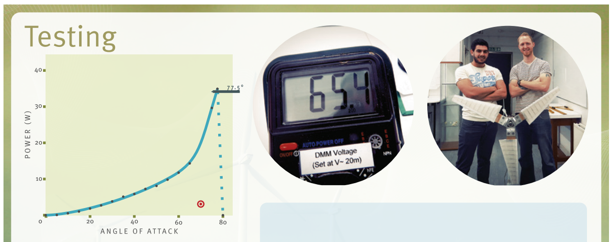












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