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Manufacture of a Wind Turbine Blade

Advanced Processes & Materials ACMA6000

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1 Abstract

This report presents the preliminary design and assessment of a small-scale wind turbine blade intended to contribute towards the annual electricity requirements of an electric vehicle. The study considers aerodynamic design, material selection, manufacturing, cost and structural performance to identify a suitable blade solution. A 1.44 m blade was designed using the NACA 4412 airfoil, with a target power coefficient of 0.4. Furthermore, the blade geometry was developed across five radial sections, which allowed the chord and twist to vary along its length to improve aerodynamic performance. A weighted decision matrix was then used to compare different materials, GFRP, CFRP, aluminium alloy and alumina. These were assessed against tensile strength, fatigue resistance, density, manufacturability, cost and sustainability for best suitability for the proposed blade. CFRP achieved the highest overall score, providing the most favourable balance of mechanical performance and low density. Different manufacturing methods of producing the blade were considered, with vacuum infusion being the preferred method. This was due to its suitability for producing the complex tapered and twisted profile, while remaining appropriate for small to medium production volumes. Cost analysis showed that CFRP has a higher estimated cost than aluminium, but its improved mechanical performance justified the additional expense and was therefore chosen for the proposed blade. Preliminary structural analysis of the blade produced a maximum bending stress of approximately 13 MPa and a factor of safety of 33.9 against the assumed CFRP compressive strength. Overall, vacuum-infused CFRP is recommended, although further FEA and fatigue testing are required to validate the blade under variable real-world loading.

2 Introduction

The increasing use of Electric Vehicles (EVs) has resulted in greater demands for electrical energy to power them (Hoyos, 2026). While the use of EVs can result in decreased emissions related to transportation, the electricity used to charge such EVs might still originate from sources that are non-renewable. Therefore, the inclusion of renewable electricity generation for domestic EV charging will help in decreasing reliance on electricity from the grid (National Energy System Operator, 2026).

The aim of this report is to develop a small-scale horizontal axis wind turbine blade that will be able to provide enough renewable energy to cover the annual energy requirement for charging of an EV. An energy requirement of 3,000 kWh per year is used as the design objective. The turbine design is carried out from the perspective of a renewable energy engineer working for an automotive company with the intention of producing a commercially viable turbine that could be offered alongside an EV.

The report examines the aerodynamic, structural, and manufacturing considerations of the suggested blade, including selection of an appropriate aerodynamic shape, blade size, operating conditions, material, and production process. As the blade design determines the amount of energy captured, these factors must be considered, alongside overall efficiency and cost-effectiveness.

3 Literature Review

3.1 Wind Turbine Fundamentals

Horizontal-axis wind turbines (HAWTs) are one of the most established forms of wind energy technology, consisting of a rotor, blades, hub, drivetrain and generator (Youssef, 2018). As illustrated in Figure 1, the rotor blades are aligned in the direction of the incoming wind and are thus exposed to aerodynamic forces that cause rotation of the blades (Electrical Academia, 2016). This mechanical kinetic energy is passed through the drivetrain to the generator which converts it to electrical energy (Electrical Academia, 2016). Blade design is therefore a critical feature of the turbine since its design will determine how effective the aerodynamic forces will create mechanical energy (Radi, et al., 2024). The wind power capacity, however, depends on air density, swept area of the rotor blades and the wind speed (Schubel & Crossley, 2012).

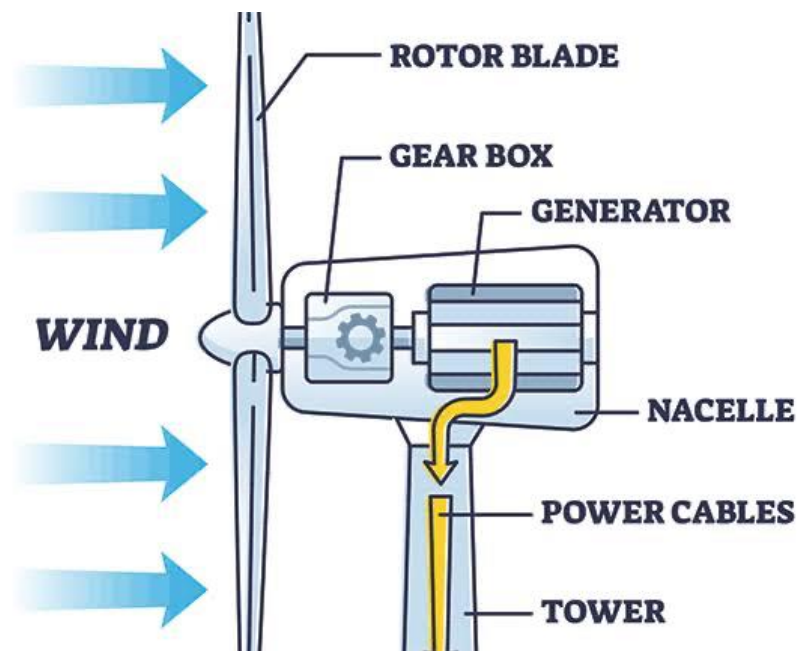


Figure 1- Wind Turbine Diagram (Boythorpe Wind Energy, 2026)

Whilst efficient power generation is vital, it is important to note that theoretically wind turbines can only extract 59.3% of available wind energy, otherwise known as Betz limit, this is because some wind energy must remain in the air to allow air to continue to flow through the rotor (Schubel & Crossley, 2012). A power coefficient (C_p) value is used to measure the efficiency of wind turbines (Eureka, 2025). Wind turbines

commonly have a C_p of ≤ 0.4 - 0.5 , as shown in Figure 2 below, these values are lower than the theoretical maximum as real turbines experience aerodynamic losses, turbulence or mechanical/electrical losses (Eureka, 2025).

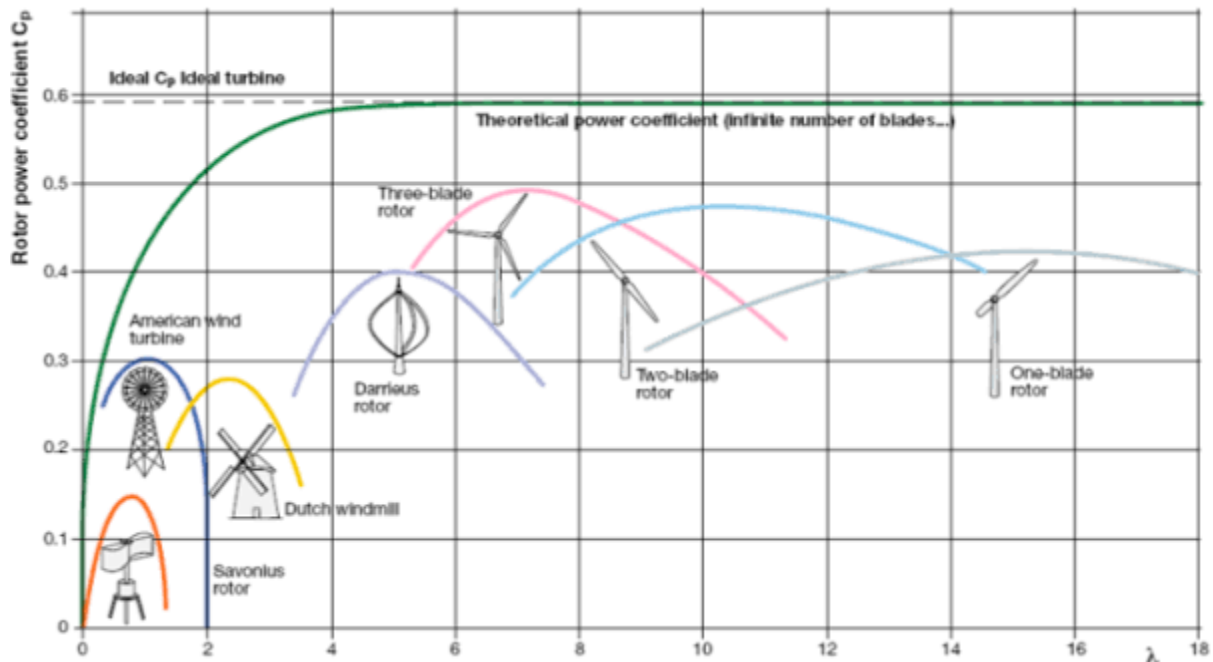


Figure 2 - Average wind turbine power coefficient (C_p) vs. tip speed ratio curves for different blade types (Artal-Sevil, et al., 2022)

3.2 Blade Aerodynamics

Aerodynamics of the blades are crucial for the performance of a turbine, as the blade geometry defines the generation of lift and drag forces that occur when the air flows over its surface (Electrical Academia, 2016). Lift acts perpendicularly to the airflow and creates an aerodynamic force which rotates the rotor, whereas drag opposes the rotor rotation (Electrical Academia, 2016). An airfoil is the cross-section of a turbine blade that is intended to generate these aerodynamic forces in consequence of the flow of air across it (Radi, et al., 2024).

NACA is an organisation that developed standardised airfoil profiles which have been applied in various aerodynamics systems (NASA, 2023). NACA 4-digit series is based on the description of an airfoil profile depending on the camber and thickness of it (Schubel & Crossley, 2012), Figure 3 exhibits an Airfoil profile and its parameters. For NACA 4412, the first digit describes 4% camber; the second states

that the maximum camber is 40% from the airfoil chord and the last two digits represent maximum thickness, which is 12% from the chord.

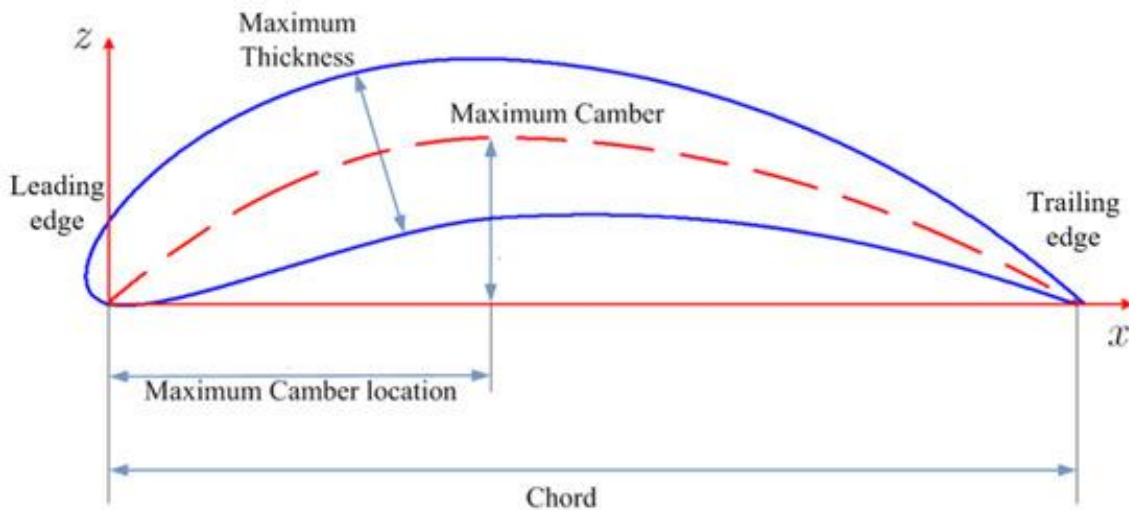


Figure 3 - Main geometric parameters in a wind turbine blade (Radi, et al., 2024)

NACA 4412 is often chosen for small wind turbines because its moderate camber provides good lift while maintaining relatively low drag, producing a favourable lift-to-drag ratio (Febriyanto, et al., 2019). Some other airfoils such as NACA 2412, 2421 and 4415, as shown in Figure 4, have also been studied for wind turbines, however the suitability is dependent on operating conditions and required aerodynamic characteristics (Karthikeyan & Hussain, 2025).

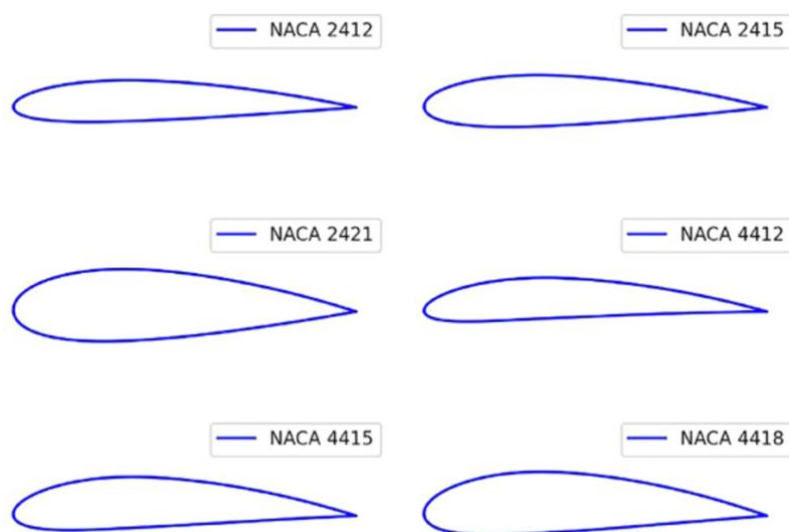


Figure 4 - Selection of NACA Airfoils used for small scale wind turbines (Karthikeyan & Hussain, 2025)

3.3 Blade Geometry

The blade geometry must balance between the aerodynamic efficiency and its structural requirements. The radius of the rotor plays a major role due to the fact that the swept area is proportional to the square of the radius (U.S Department of Energy, 2026). A bigger blade length means greater power generation capacity but at the same time higher bending moments, leading to different material requirements and increased costs (U.S Department of Energy, 2026). A visualisation of the relationship between swept area and power can be seen in Figure 5.

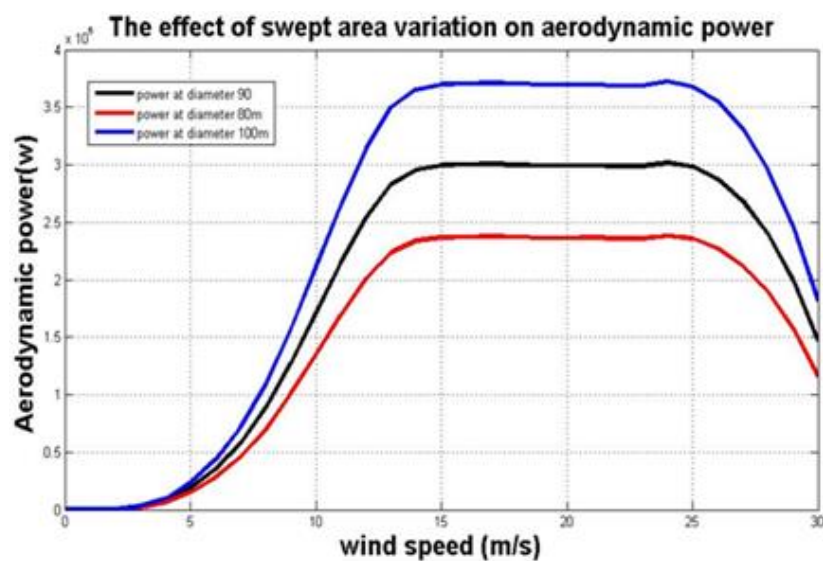


Figure 5 - The effect of Swept Area on Aerodynamic Power (Barua, 2011)

Typical blades are tapered, with a larger chord towards the root and a smaller chord towards the tip. Greater structural loading at the root requires increased blade area, while reducing the tip chord lowers blade mass and aerodynamic drag (WindFarmBOP, 2025). Blade twist is introduced because the relative wind angle varies along the blade as rotational velocity increases with radius, allowing sections to operate at more appropriate angles of attack (Electrical Academia, 2016; WindFarmBOP, 2025).

Tip speed ratio (TSR) describes the ratio of blade-tip speed to wind speed (Electrical Academia, 2016). High TSR designs generally require less blade solidity and can rotate at higher speeds than low tip speed ratio designs, which usually require wider blades. Existing small-scale three-bladed turbines commonly operate around TSR

values of 4–7, providing a useful reference range for domestic turbine design (Electrical Academia, 2016).

Table 1 compares existing turbines across a range of power outputs, together with their corresponding blade lengths, providing a good comparison on the relationship between blade geometry and operating characteristics.

Table 1 - Existing Turbine Power Output and Blade length

Existing Design	Power	Rotor Diameter	Blade Length	# of Blades
Turbine A (WATTUNEED, 2026)	1kW	2.5 m	1.25m	3
Turbine B (BritWind, 2026)	5kW	5.5m	2.25m	3
Turbine C (54Energy, 2026)	20kW	10m	5m	3
Turbine D (BritWind, 2026)	1MW	54.2m	27.1m	3

3.4 Environmental Conditions

Wind turbines do not operate under steady-state conditions as the speed, direction, and turbulence of wind vary continuously, therefore having a direct impact on the aerodynamic forces and subsequently power generation (Sahu, 2026). As available wind power increases rapidly with wind speed, a small increase in wind speed can produce a significant increase in available power (U.S Department of Energy, 2026). Furthermore, gusts can create sudden changes in loading, while turbulence results in repeated fluctuations that may lead to fatigue/fracture (Chen, et al., 2016).

Domestic wind turbines are also affected by their surroundings, as nearby buildings, trees and other obstructions can create turbulent airflow (Sahu, 2026). Blade design must therefore provide sufficient structural strength and fatigue resistance while maintaining aerodynamic performance across variable operating conditions.

3.5 Material Review

The materials used to manufacture wind turbines can depend on the particular component and its structural specifications. For example, steel and aluminium are commonly used in turbines, typically making up approximately 70% of the turbine (USGS, 2022). These metals are used in the tower, drive chain, hub and supporting structures to provide good structural integrity. However, these metals are generally not preferred for modern blades due to their higher density (Podmore, 2022).

Large-scale commercial turbines predominantly use fibre-reinforced polymer composites, particularly glass-fibre-reinforced polymer (GFRP), for blade construction (Podmore, 2022). GFRP provides a practical balance between weight, structural performance and cost (Mishnaevsky, et al., 2017). Carbon-fibre-reinforced polymer (CFRP) is also increasingly used in larger, highly loaded blades where its greater stiffness and lower density justify the higher cost.

Small-scale and domestic turbines similarly use GFRP, with its established manufacturing processes making it suitable for lower production volumes. Therefore, although metals remain fundamental and make up a big proportion of the overall turbine, polymer composites are the dominant material choice for modern blades themselves (Mishnaevsky, et al., 2017).

4 Design Specifications

The objective in the design of the turbine is to generate sufficient renewable energy to offset the electricity required for domestic EV charging. 3,000 kWh per year was set as the design requirement based on these considerations, as research suggests EVs typically consume an average of 2,000kWh per year (Lawrence, 2026). Given these requirements and the assumed turbine efficiency from Table 2, the required power and swept area have been determined for the turbine, subsequent calculations then highlight that the rotor radius should be approximately 1.44m.

Table 2 - Design Specification - Requirements, Assumptions and Calculations

Requirements	
To Charge an EV Car all year (kWh)	3000
Assumptions	
Windspeed (m/s)	6
Power Coefficient (Cp)	0.4
Air Density (p) (kg/m ³)	1.225
Total Hours Per Year (hrs)	8760
Calculations	
Required Power (W)	342.47
Swept Area (m ²)	6.47
Blade Length (radius) (m)	1.44

A design wind speed of 6 m/s was selected as representative of the conditions considered for a UK domestic application, with an air density of 1.225 kg/m³ assumed (Richardson, 2026). A three-bladed horizontal-axis wind turbine was selected due to its established application for electricity generation. The tip-speed ratio (TSR) chosen is 6, along with the power coefficient (Cp) value of 0.4 and lift coefficient (Cl) of 1.2. Such values were chosen based on the aerodynamic characteristics of existing wind turbines, as identified in the literature review and serve as realistic goals for the designed turbine. All design parameters used are summarised in Table 3.

Table 3 - Design Parameters

Design Parameters	
Windspeed (m/s)	6
Power Coefficient (Cp)	0.4
Air Density (p) (kg/m ³)	1.225
Total Hours Per Year (hrs)	8760
Number of blades	3
Lift Coefficient	1.2
Tip Speed Ratio	6
Maximum Thickness (m)	0.12
NACA Profile	4412
Maximum Camber (m)	0.04
Pos of Max Camber (p)	0.4
Required Power (W)	342.46575
Swept Area (m ²)	6.4713861
Blade Length (radius) (m)	1.4352373

The blade is to use a NACA 4412 airfoil, with a tapered chord distribution and varying twist along the blade to account for changes in the relative airflow between the root and tip. NACA 4412 has been selected for use due to its effective Lift-to-drag ratio identified in the literature review. The plot for this airfoil using the camber line and upper/lower values can be found in Table 4, this then produces the profile shown in Figure 6, previous calculations and graphs for camber line and thickness distribution can be found in Appendix A.

Table 4 - NACA4412 Airfoil Coordinates

yc	yu	yl	xc
0	0	0	0
0.0175	0.0643277	-0.0293277	0.1
0.03	0.08737543	-0.0273754	0.2
0.0375	0.09751727	-0.0225173	0.3
0.04	0.09803011	-0.0180301	0.4
0.03888889	0.09182914	-0.0140514	0.5
0.03555556	0.08118925	-0.0100781	0.6
0.03	0.06663907	-0.0066391	0.7
0.02222222	0.0484534	-0.004009	0.8
0.01222222	0.02669939	-0.002255	0.9
0	0.00126	-0.00126	1

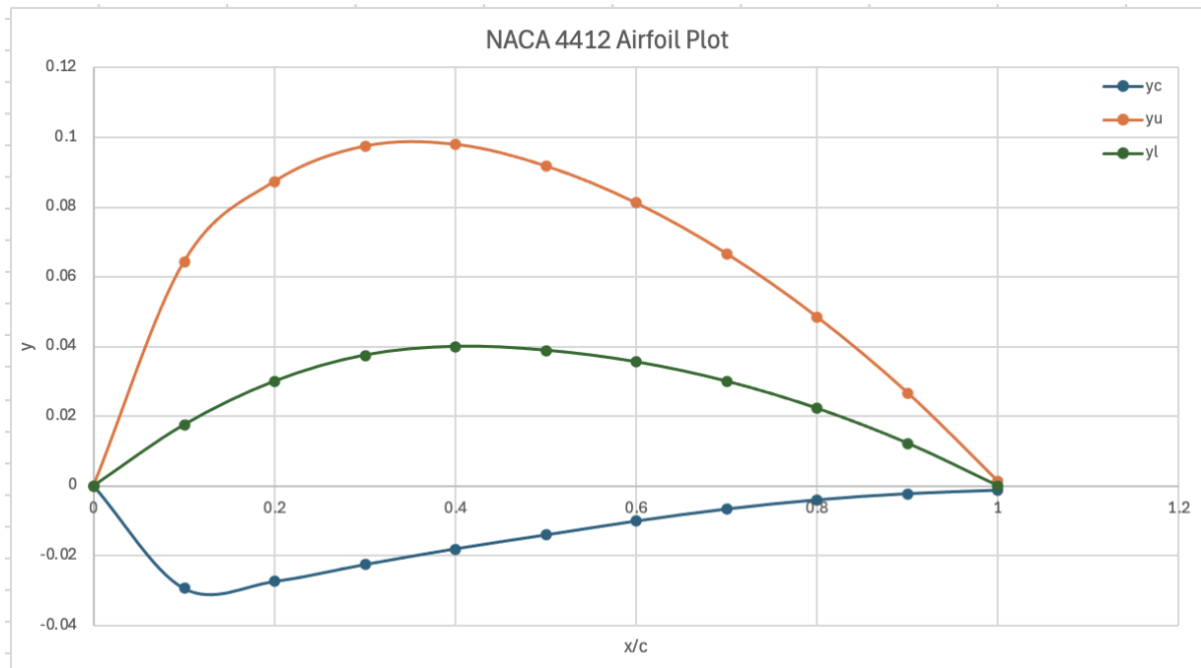


Figure 6 - NACA4412 Airfoil Plot

5 Blade Design Calculations

The design parameters established in Section 4 were used to determine the aerodynamic geometry of the blade. The blade was divided into five radial sections at $r/R = 0.2, 0.4, 0.6, 0.8$ and 1.0 , allowing chord and twist to vary along the blade. This produces a tapered and twisted blade designed to account for the changing aerodynamic conditions from root to tip. The calculated radial positions, chord lengths and twist angles are shown in Table 5 below.

Table 5 - Blade Geometry - Chord Length, Twist and Distance Calculations

r/R	r	R	Chord Length	Twist	Distance From Root (m)
0.2	0.28704746	1.44	0.211126861	26.5370474	0.288
0.4	0.57409493	1.44	0.138017721	15.07991	0.576
0.6	0.86114239	1.44	0.097810814	10.3494073	0.864
0.8	1.14818986	1.44	0.075031088	7.84552595	1.152
1	1.43523732	1.44	0.060668047	6.30821481	1.44

The NACA 4412 profile was then scaled, using the airfoil coordinates from the profile's geometry and transformed using the calculated chord values (See Appendix B), which subsequently produced individual airfoil sections for each section of the blade. The profiles at each section, displayed in Figure 7, demonstrate the reduction in chord towards the blade tip. These calculated profiles were subsequently transferred to CAD and used to generate the final blade geometry through lofting and twisting between the individual sections, this can be found in Section 10.

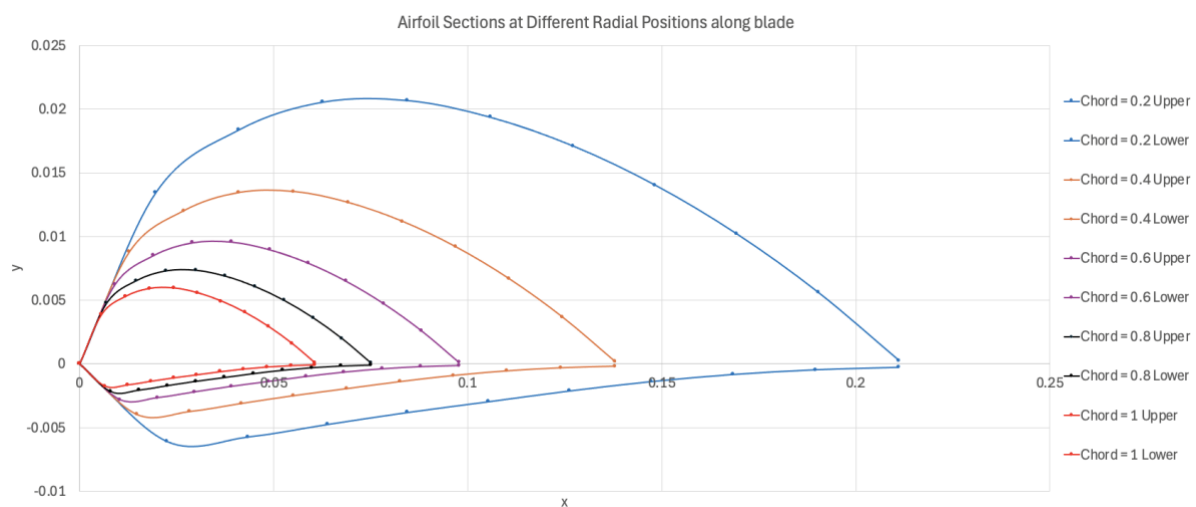


Figure 7 - Plot of Airfoil Sections at Different radial positions along blade

6 Material Selection

Material selection was undertaken to identify a suitable blade material based on mechanical performance, weight, manufacturability, cost and sustainability. A preliminary graph was created via Granta (Granta Design, 2026) to identify suitable material families. The Young's modulus vs density chart shown in Figure 8, indicates that composites provide a favourable combination of stiffness and low density compared with metals and ceramics. GFRP (Glass Fibre Reinforced Polymer) and CFRP (Carbon Fibre Reinforced Polymer) were therefore identified as promising candidates for use. However, to assess additional criteria for efficient blade design, including tensile strength, manufacturability and cost, aluminium alloys and alumina were taken forward for a more in-depth selection process.

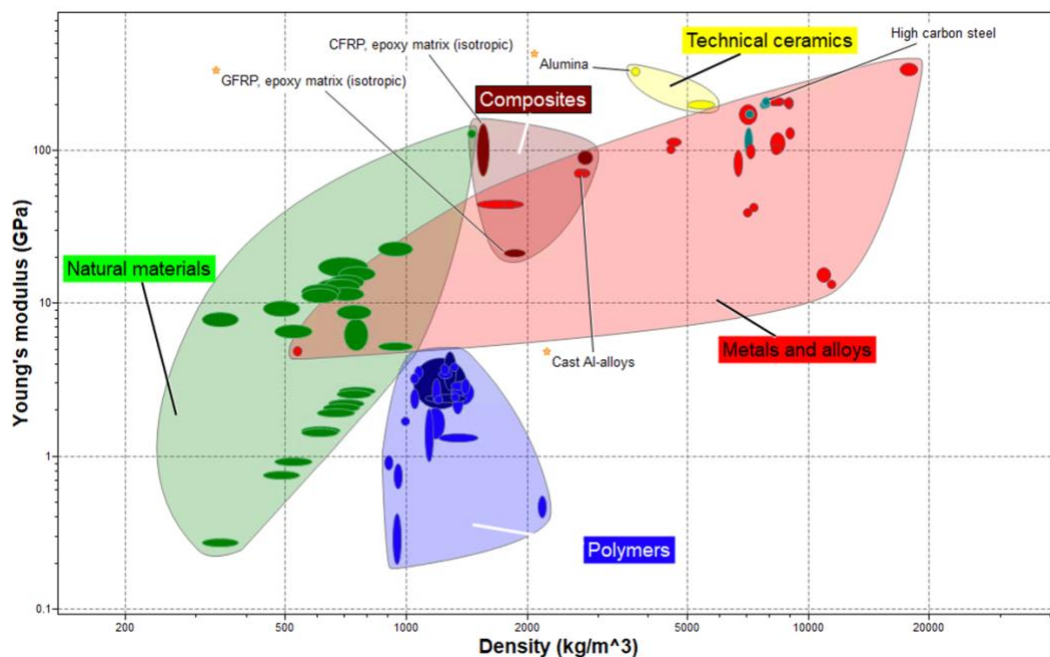


Figure 8 - Granta Comparison Graph - Young's Modulus vs Density (Granta Design, 2026)

A weighted decision matrix, presented in Table 6, was then used to make the final selection. Tensile strength, fatigue resistance and density were given the greatest weighting because these properties are directly related to blade performance and durability. The blade experiences aerodynamic bending forces and repeated cyclic loading, making high fatigue resistance essential. Low density is also desirable as reducing blade mass decreases inertial and gravitational loading, while high tensile

strength provides greater resistance to operational stresses. Manufacturability and cost were also included to ensure the material remains practical to manufacture, while sustainability was included as an additional design factor which appeals to the EV market.

Table 6 - Weighted Decision Matrix (Granta Design, 2026; TrueNorthEngineering, 2026)

Criteria	Weight	Composite		Metal	Ceramic
		GFRP	CFRP	Aluminium Alloy	Alumina
Tensile strength (MPa)	0.2	1000.00	2000.00	500.00	200.00
Scaled (Max)		50.00	100.00	25.00	10.00
Score		10.00	20.00	5.00	2.00
Fatigue resistance	0.2	300.00	600.00	120.00	30.00
Scaled (Max)		50.00	100.00	20.00	5.00
Score		10.00	20.00	4.00	1.00
Density (kg/m3)	0.2	1800.00	1550.00	2770.00	3700.00
Scaled (Min)		86.11	100.00	55.96	41.89
Score		17.22	20.00	11.19	8.38
Manufacturability	0.15	8.00	6.00	8.00	3.00
Scaled (Max)		100.00	75.00	100.00	37.50
Score		15.00	11.25	15.00	5.63
Cost (GBP/Kg)	0.15	25.40	30.00	2.20	16.00
Scaled (Min)		8.66	7.33	100.00	13.75
Score		1.30	1.10	15.00	2.06
Sustainability	0.1	6.00	3.00	7.00	4.00
Scaled (Max)		85.71	42.86	100.00	57.14
Score		8.57	4.29	10.00	5.71
Total Score	1	62.09	76.64	60.19	24.78
Rank		2	1	3	4

The matrix produced the highest overall score for CFRP, with a total score of 76.64, compared with 62.09 for GFRP, 60.19 for aluminium alloy and 24.78 for alumina. CFRP therefore provides the best overall balance of the selected criteria. Although aluminium alloy scores highly for manufacturability and cost, its substantially greater density and lower tensile and fatigue resistance make it less suitable for the blade. A heavier blade increases structural and inertial loading and can reduce the overall effectiveness of the turbine. CFRP also provides substantially greater tensile and fatigue resistance than GFRP, while its cost is only moderately higher. Therefore, the additional material cost is justified by its superior mechanical performance and lower density. CFRP was consequently selected as the blade material, as the key material property advantages outweigh its increased cost and manufacturing requirements.

7 Exploration of Manufacturing routes

Manufacturing methods for metals, ceramics and polymer composites were investigated based on material suitability, blade geometry, production scale and potential defects, as presented in Table 7.

Table 7 - Comparison of Manufacturing Techniques (Velling, 2021; Nolan, 2026; Allied Composites, 2026; Eureka, 2026; Formlabs, 2023; MATaluminium, 2024; Almath, 2026; Composite Manufacturer, 2026)

Material	Manufacturing Route	Production Scale	Advantages	Disadvantages	Potential Defects / Issues	Suitability for Proposed Blade
Aluminium alloy	Extrusion / forming	Large	High Repeatability	Limited ability to produce a hollow/twisted geometry	Cracking	Moderate – suitable for simple blade geometries but less suitable for the complex aerodynamic profile
			Low Material Cost	Additional Machining May be Required	Residual Stresses	
			Good Dimensional Accuracy		Distortion	
					Surface defects	
Aluminium alloy	CNC machining	Medium	Can produce complex profiles	High Material Waste	Poor Surface Finish	Low-moderate - technically capable but inefficient for a 1.44 m blade
			Excellent Dimensional Accuracy	Long Machining Times	Residual Stresses	
				Can be expensive for Large Blades	Surface defects	
Alumina ceramic	Pressing + sintering	Medium	High Hardness	Brittle Material	Porosity	Low – poor resistance to impact and fatigue makes it unsuitable for a rotating wind-turbine blade
			Excellent Wear and Temperature Resistance	High Processing Temperatures	Shrinkage	
			Repeatability	Limited tolerance to impact and cyclic loading	Cracking	
					Warping during sintering	
Alumina ceramic	Slip casting + sintering	Small-medium	Can Produce Relatively Complex Shapes	Slow Processing time	Cracking	Low – complexity is achievable but brittleness remains a major limitation
			Suitable for Low-Volume Production	Unsuitable for Large Scale production	Porosity	
				Brittle Material	Uneven wall thickness	
				Dimensional Shrinkage	Shrinkage	
GFRP	Hand lay-up	Small	Very Low Tooling Cost	Labour Intensive	Voids	High for prototypes – economical but quality can vary. Not suitable for medium to large scale production
			Suitable for Low-Volume Production	Inconsistent quality	Resin Rich Areas	
			Simple Equipment	Slower Production	Variable Fibre Orientation	
			Suitable for Prototypes	Limited Repeatability	Inconsistent Resin Content	
GFRP	Vacuum Infusion	Small-medium	Flexible Fibre orientation			Very high – excellent balance between cost, quality and suitability for the 1.44 m blade
			Good Fibre/Resin Ratio	Requires vacuum equipment (High Initial Cost)	Dry Spots	
			Reduced Void Content	Requires careful Process control	Resin Starvation	
			Good Surface Finish	Longer Preparation Time	Air Entrapment	
GFRP / CFRP	Resin Transfer Moulding (RTM)	Medium-large	Suitable for large components	Resin Flow must be controlled	Incomplete Infusion	High – excellent for larger-scale production but potentially excessive for the proposed turbine
			Relatively Low Tooling Cost		Wrinkles	
			High Repeatability	High Tooling and Equipment Costs	Dry Areas	
			Good Dimensional Accuracy	More Complex Process	Incomplete Filling	
GFRP / CFRP	Compression moulding	Medium-large	Controlled Resin Content	Less Economical for very low volumes	Voids	High for mass production – suitable commercially but unnecessary for low production volumes
			Good Surface Finish		Fibre Misalignment	
			Fast Cycle Times	High Tooling Costs	Fibre Movement	
			Highly Repeatable	Requires Specialised Equipment	Voids	
GFRP / CFRP			Suitable for High- Volume Production	Less Flexible for design changes	Incomplete Consolidation	
			Good Dimensional Accuracy	High tooling costs; requires specialised equipment; less flexible for design changes	Thickness variation	

It can be seen that aluminium alloys are relatively cheap per kg of material, can be manufactured through forming, extrusion or CNC machining, which provide dimensional accuracy and repeatability. However, producing the required twisted and tapered profile may require additional machining or joining, increasing material waste and cost. Alternatively, alumina ceramics can be produced through pressing or slip casting followed by sintering. Although these processes can produce complex geometries, defects such as porosity, shrinkage and cracking can occur. More importantly, the brittle nature of ceramics makes them unsuitable for a rotating blade subjected to repeated aerodynamic loading and potential impact.

On the other hand, Polymer composites offer greater flexibility for manufacturing the blade geometry. GFRP and CFRP can be produced using hand lay-up, vacuum infusion, RTM and compression moulding. Hand lay-up is low-cost but has greater variability in fibre orientation and resin content. Conversely, vacuum infusion provides improved control of the fibre-to-resin ratio while remaining suitable for small-to-medium production volumes. RTM and compression moulding offer greater repeatability and faster production rates but require greater tooling investment, making them less appropriate for smaller scale production.

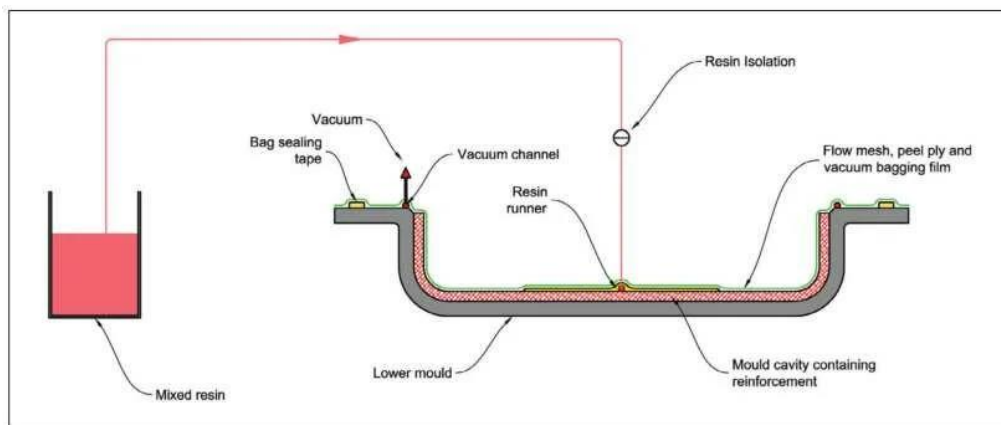


Figure 9 - Vacuum Infusion Process (Zin, 2016)

Vacuum-infused CFRP was therefore chosen to be the ideal manufacturing process for the 1.44m blade design. The method, shown in Figure 9, places carbon fibre reinforcement in a mold covered by a vacuum bag. Air is then removed to draw resin through the fibres, forming the composite material (PMIComposites, 2021). It offers a cost-effective method of manufacturing on small to medium scales while ensuring dimensional accuracy for the tapering and twisting NACA 4412 airfoil shape. The main manufacturing concern for vacuum-infused CFRP is the formation of voids or resin-rich regions, which can reduce fibre volume fraction and create local stress concentrations (Eureka, 2026). These defects are particularly important for a cyclically loaded blade because they can initiate delamination or fatigue damage. In order to mitigate these potential defects, it is essential to maintain careful control of resin flow, vacuum integrity and fibre lay-up (Explore Composites, 2021). Other process procedures such as visual inspection and non-destructive testing can provide additional quality assurance.

The Vacuum infusion process can also be scaled by introducing additional moulds and production stations as demand increases. However, if production capacity increases significantly, the higher tooling investment associated with RTM or compression moulding could become economically justified due to their greater automation, repeatability and faster production rates (Composite Manufacturer, 2026). Vacuum infusion therefore gives the right combination of affordability, manufacturing time, production rate and scale-up capability for the proposed turbine.

8 Cost Evaluation

The cost evaluation was undertaken to compare the economic suitability of aluminium alloy, alumina ceramic and CFRP for the proposed wind turbine blade. The calculations presented in Table 8 use the CAD blade volume, assumed material densities and Granta material prices, which allowed estimation of the raw material requirement and associated costs for each material.

Table 8 – Estimated Raw Material Cost Calculation (Granta Design, 2026; EasyComposites, 2026)

Raw Material Cost Calculation			
Calculation	Aluminium Alloy	Alumina Ceramic	CFRP
CAD blade volume (m ³)	0.003108	0.003108	0.003108
Material density (kg/m ³)	2,770	3,990	1,550
Blade mass (Kg)	8.609	12.401	4.817
Granta material cost (£/Kg)	£2.20/kg	£16.00/kg	£30.00/kg*
Base material cost	£18.94	£198.41	See Below
Carbon fibre content	N/A	N/A	60%
Resin content	N/A	N/A	40%
Carbon fibre required (Kg)	N/A	N/A	2.89
Resin required (Kg)	N/A	N/A	1.927
Carbon fibre cost	N/A	N/A	£86.71
Resin cost (assuming £14/kg)	N/A	N/A	£26.98
Base CFRP material cost	N/A	N/A	£93.65
Wastage/consumables allowance (%)	10%	20%	15%
Wastage/consumables allowance (£)	£1.89	£39.68	£14.05
Estimated raw material cost per blade	£20.83	£238.10	£131.50
Estimated raw material cost per turbine (3 blades)	£62.50	£714.29	£323.09

As seen from the table, there is a significant difference in the cost of raw materials for the three materials. Aluminium is the cheapest among the materials with a raw material cost of about £20.83 per blade, due to its low price of roughly £2.20/kg. The cost of alumina is approximately £238.10 per blade due to its higher material cost of about £16/kg and higher density. The estimated raw material cost of CFRP is roughly £131.50 per blade. Even though the cost of carbon fibre and resin are relatively expensive (£30/kg and £14/kg respectively), its low density decreases the amount of material needed.

Manufacturing costs were then estimated by considering labour, initial tooling, equipment running costs and defect/rework allowances, this is shown in Table 9. The stacked bar chart, Figure 10, illustrates how these factors contribute to the overall manufacturing cost.

Table 9 – Estimated Manufacturing Cost Calculation (Granta Design, 2026; TrueNorthEngineering, 2026; Mascera, 2024; Eureka, 2026)

Manufacturing Cost Calculation			
Calculation	Aluminium Alloy	Alumina Ceramic	CFRP
Manufacturing process	CNC machining/forming	Press forming + sintering + finishing	Vacuum infusion
Estimated labour time per blade	2.0 h	4.0 h	1.5 h
Assumed labour rate	£30/h	£30/h	£30/h
Estimated Labour Cost Per Blade	£60.00	£120.00	£45.00
Initial tooling cost (Approximate)	£900	£1,500	£750
Assumed production run (# of blades)	30	30	30
Estimated Tooling Cost Per Blade	£30.00	£50.00	£25.00
Estimated Equipment Running cost	£50/h	£20/h	£10/h
Estimated Equipment RunningCost Per Blade	£100.00	£80.00	£15.00
Estimated Defect/rework allowance	£5.00	£20.00	£10.00
Estimated Raw material + wastage	£20.83	£238.10	£131.50
Estimated manufacturing cost per blade	£210.83	£508.10	£226.50
Estimated manufacturing cost per turbine (3 blades)	£632.49	£1,524.29	£679.50

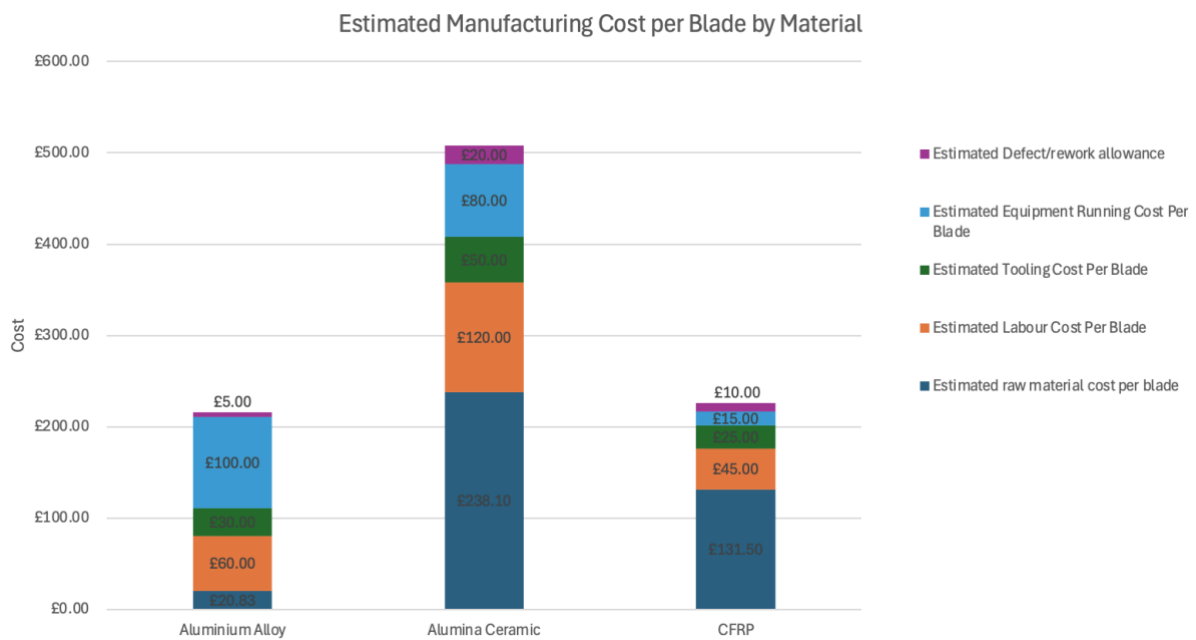


Figure 10 - Stacked bar chart representing estimated manufacturing cost per blade by material

One of the major advantages that aluminium has is the fact that it uses a relatively straightforward and well-developed manufacturing process that gives it the lowest cost estimate of £210.83 per blade, including the material cost. The second highest cost estimate is CFRP at approximately £226.50 per blade, primarily due to its higher material cost. Nevertheless, vacuum infusion is a relatively viable way of manufacturing due to re-usable tooling, low running cost and reasonable labour costs. The highest manufacturing cost is alumina at approximately £508.10 per blade and this is mainly because of the relatively long process time, high material costs, specialised equipment and greater defect risk.

Although aluminium provides the lowest overall cost, owing to relatively low material and manufacturing cost, CFRP offers the best overall cost-performance balance. The additional cost is justified by its substantially lower mass, high specific strength and superior fatigue resistance, which are important for a blade subjected to continuous cyclic loading. CFRP therefore remains the preferred material despite its higher initial manufacturing cost.

9 Mechanical Properties Analysis

The blade was assessed under the aerodynamic loading calculated at the five design sections, this is presented in Tables 10 and 11, calculation equations can be found in Appendix C. Relative velocity was determined from the 6 m/s design wind speed and TSR of 6, with lift and drag calculated using a lift coefficient (C_l) of 1.2 and an assumed drag coefficient (C_d) of 0.012 (Bakırcı, et al., 2023). The drag coefficient was treated as a representative engineering assumption, as the drag coefficient varies with Reynolds number and angle of attack (Bakırcı, et al., 2023).

Table 10 - Lift and Drag Calculations

Section	(r/R)	Chord (m)	Vrel (m/s)	Flow angle (°)	Lift (N)	Drag (N)	Fn (N)	Ft (N)
1.00	0.20	0.2111	9.37	39.81	3.92	0.08	3.05	2.44
2.00	0.40	0.1380	15.60	22.62	7.11	0.14	6.60	2.60
3.00	0.60	0.0978	22.42	15.52	10.41	0.21	10.05	2.58
4.00	0.80	0.0750	29.42	11.77	13.74	0.27	13.47	2.53
5.00	1.00	0.0607	36.50	9.46	17.12	0.34	16.87	2.47

As shown in Table 10, the relative velocity increases from 9.37 m/s at 0.2R to 36.50 m/s at the tip. This increase is caused by the increasing velocity with radius and results in greater lift and drag forces despite the reduction in chord. The lift and drag were then resolved into normal (F_n) and tangential (F_t) forces using the calculated flow angle. Subsequently, the bending moment along the blade was calculated from the normal force whereas F_t represents the tangential loading contributing to torque.

Table 11 - Stress Analysis Calculations

Radial Position	Bending Moment (Nm)	Bending Stress (MPa)	Factor of Safety
0.2R	38.76	3.66	119.57
0.4R	25.23	8.54	51.34
0.6R	13.60	12.93	33.90
0.8R	4.86	10.24	42.84

The bending moment decreases from 38.76 Nm at 0.2R to 4.86 Nm at 0.8R as shown in Table 11, because as the section moves towards the blade tip, there is less blade length remaining to generate a bending moment about that section. However, the maximum bending stress occurs at Section 3 (0.6R), reaching approximately 13.0 MPa. This occurs because the decreasing chord reduces the second moment of area of the NACA 4412 section, making the smaller sections more susceptible to bending stress despite experiencing lower bending moments. Comparison of this level of stress with the compressive strength of the conservative CFRP at 440 MPa results in a factor of safety of at least 33.9, meaning that the blade is structurally sound for the aerodynamic forces calculated.

Overall, the results show that the chosen blade is structurally strong under the applied loading. However, the analysis only provides preliminary static analysis on a simplified block model. In reality, the proposed blade would use a laminate structure, and other effects such as fatigue, gust loading and the fibre alignment should be considered. Further finite element analysis (FEA) could therefore be conducted to incorporate laminate thickness and fibre orientation, providing greater confidence in structural performance under variable real-world conditions.

10 Blade Drawing

10.1 Overall Blade

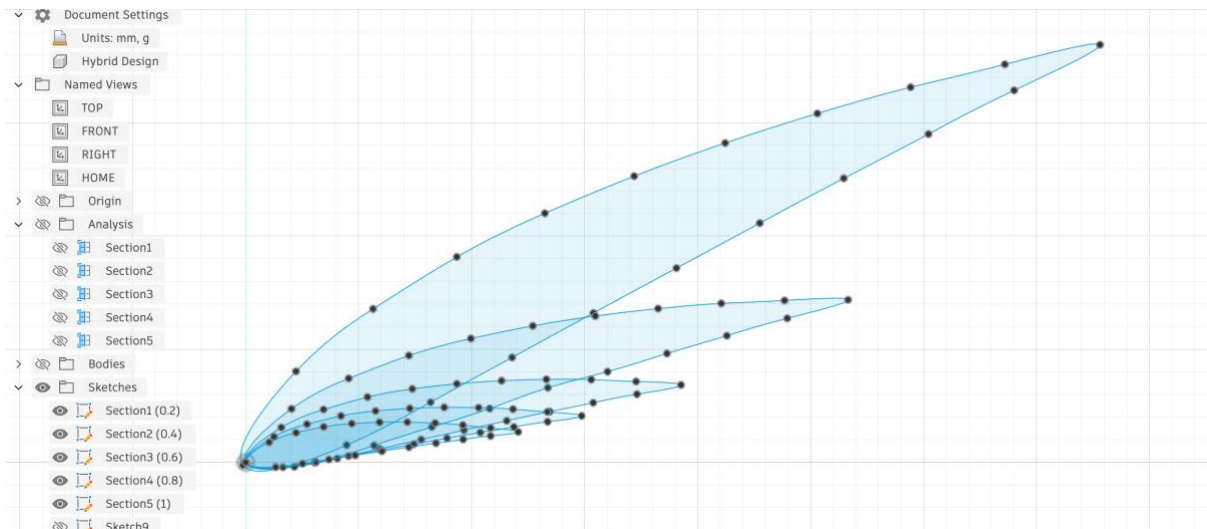


Figure 11 – Airfoil plot imported into CAD and twisted

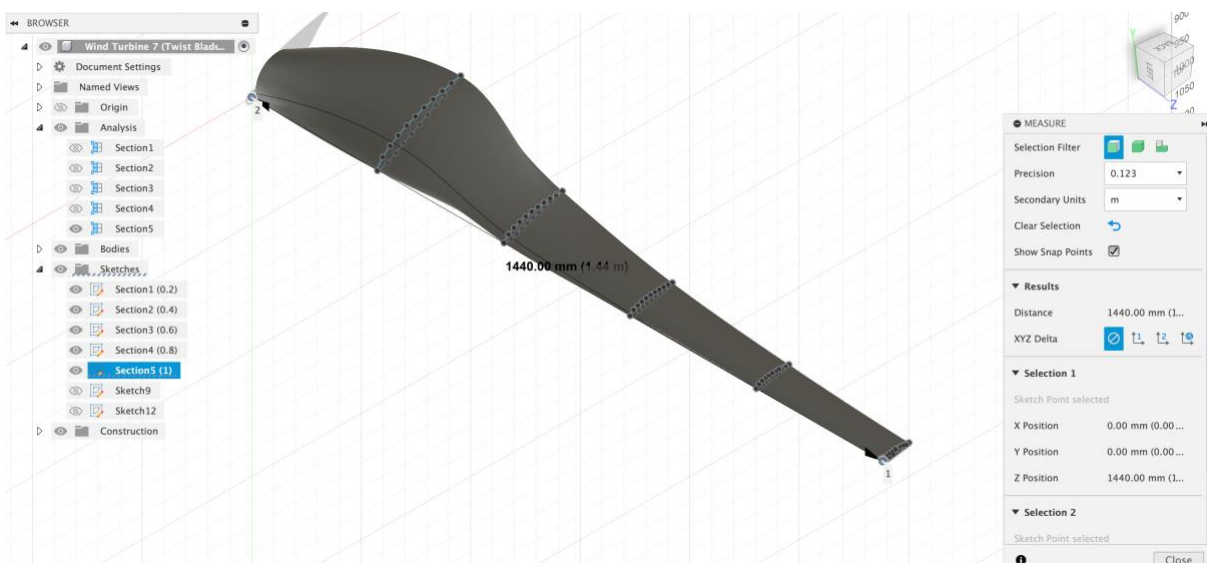


Figure 12 - Wind turbine Blade Length and Sections

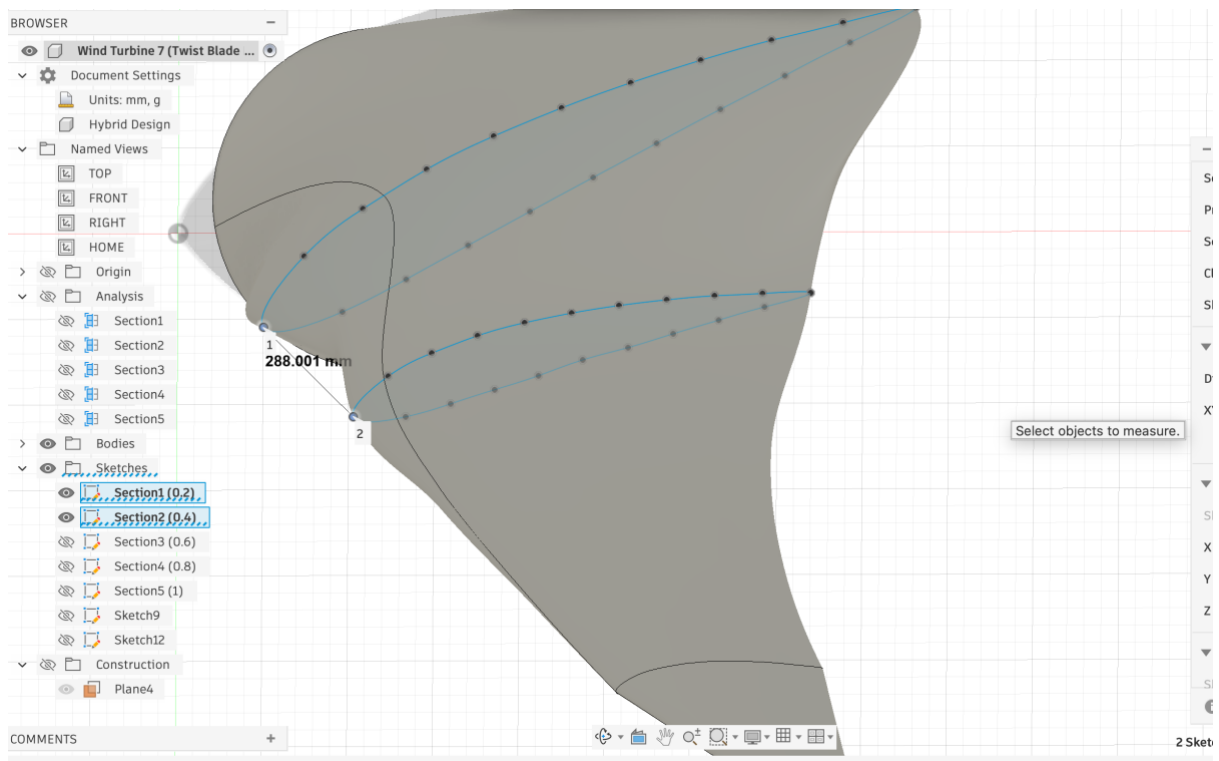


Figure 13 - Blade Section Distance

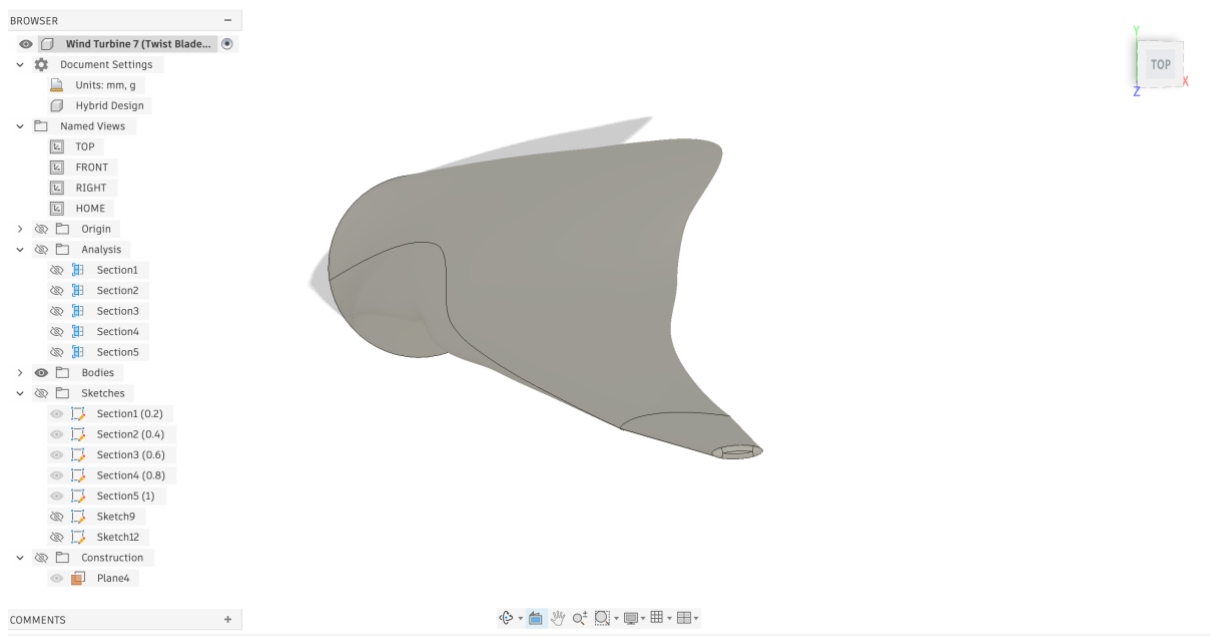


Figure 14 - Blade Model - End View

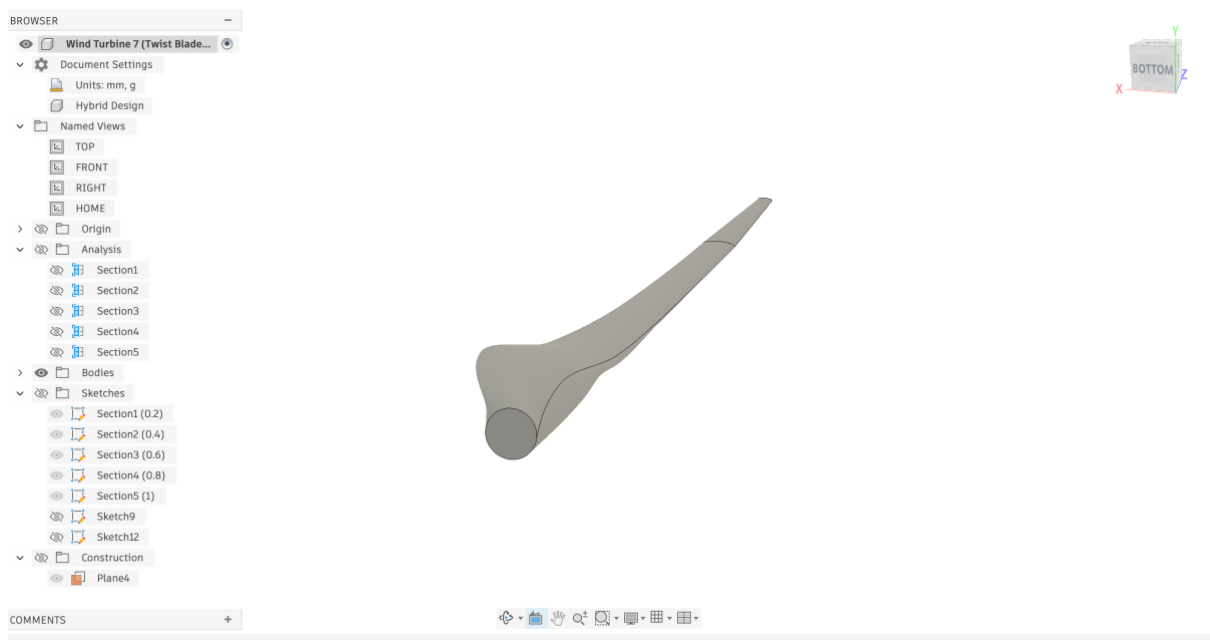


Figure 15 - Blade Model - Root View

10.2 Section 1 (0.2R)

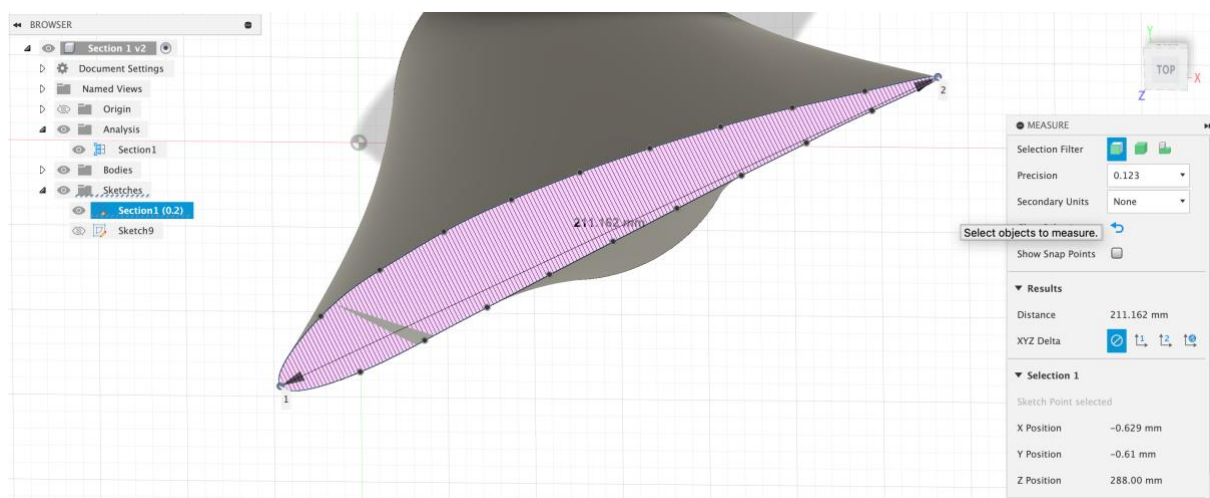


Figure 16 - Section 1 Section View (0.2R) Chord Length

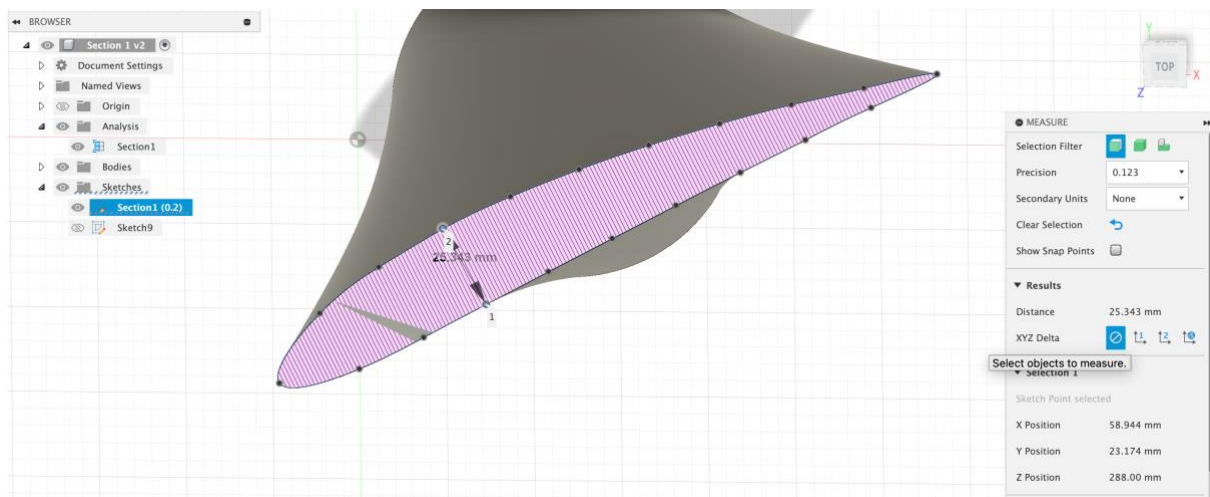


Figure 17 - Section 1 Section View (0.2R) Maximum thickness

10.3 Section 2 (0.4R)

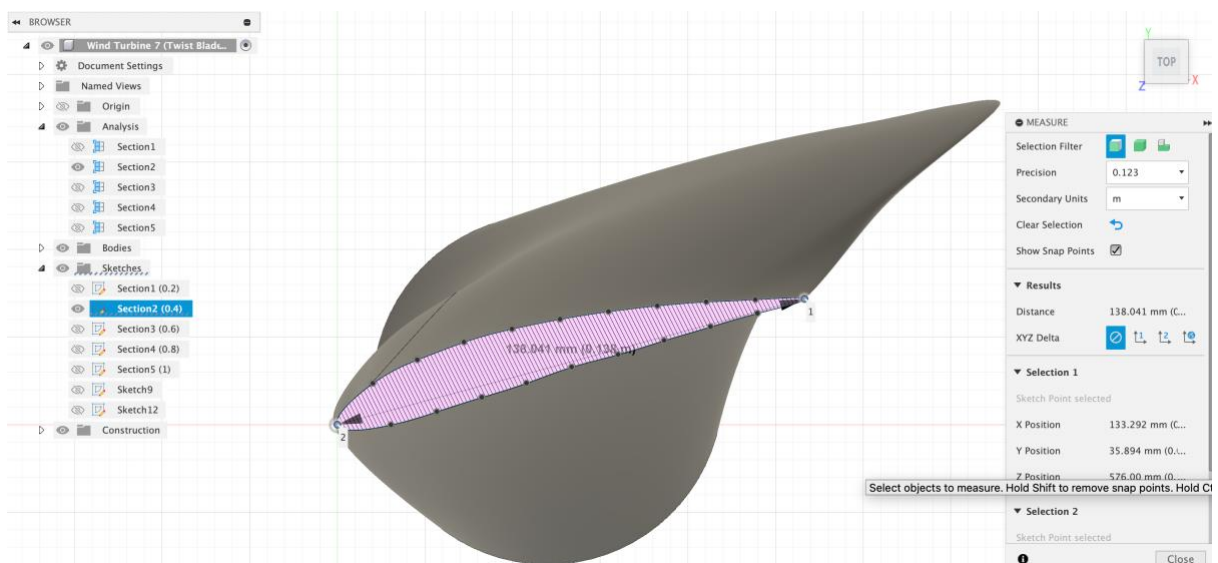


Figure 18 – Section 2 Section View (0.4R) Chord Length

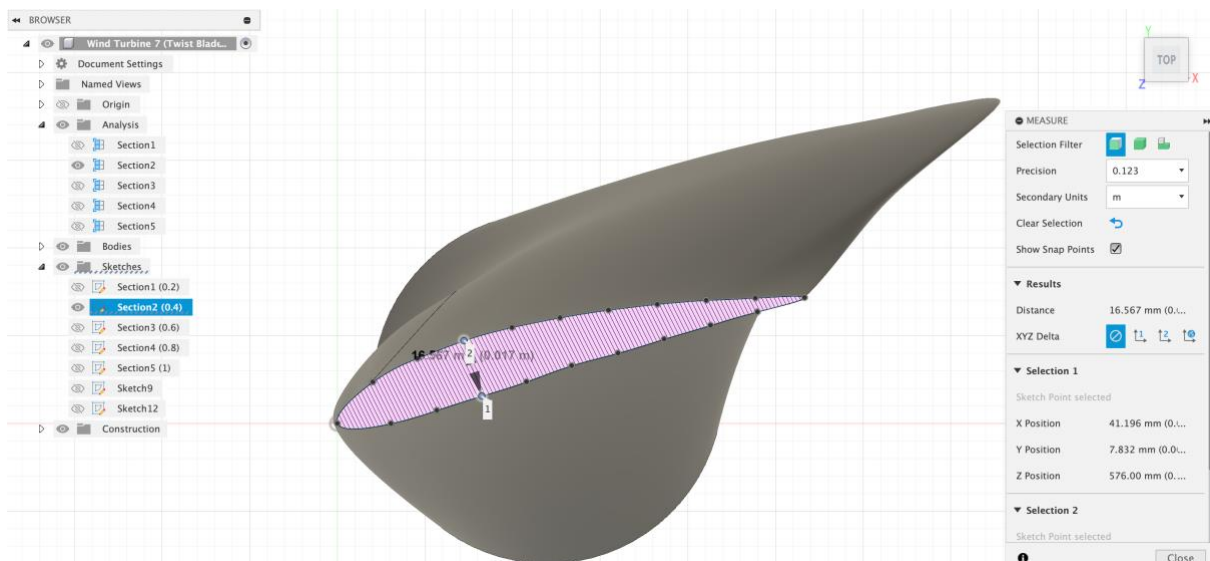


Figure 19 - Section 2 Section View (0.4R) Maximum thickness

10.4 Section 3 (0.6R)

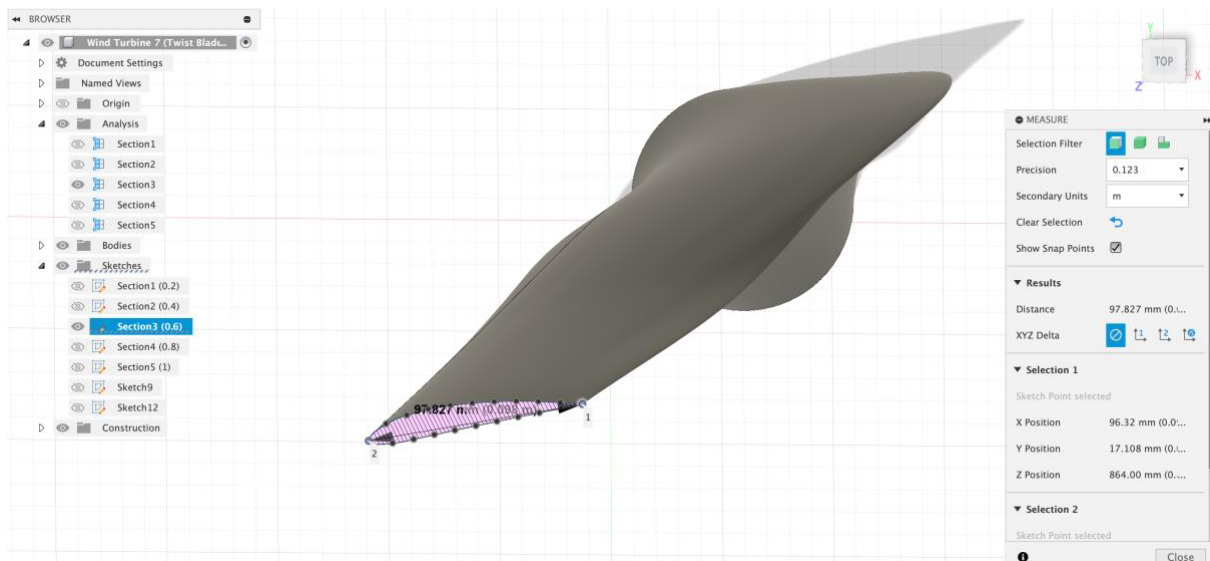


Figure 20 - Section 3 Section View (0.6R) Chord Length

10.5 Section 4 (0.8R)

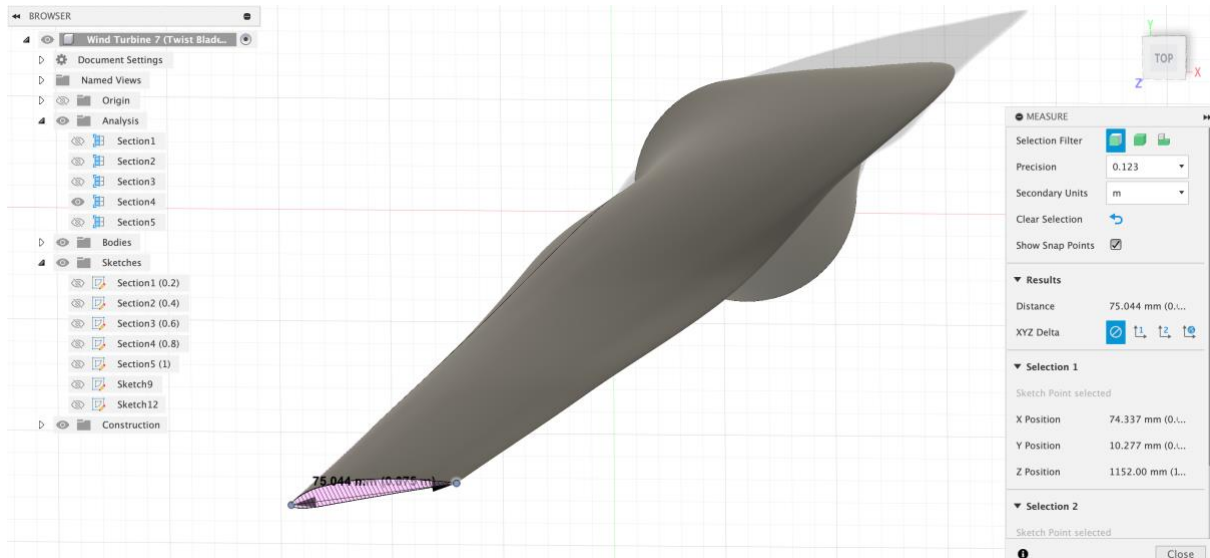


Figure 21 - Section 4 Section view (0.8R) Chord Length

10.6 Section 5 (1R)

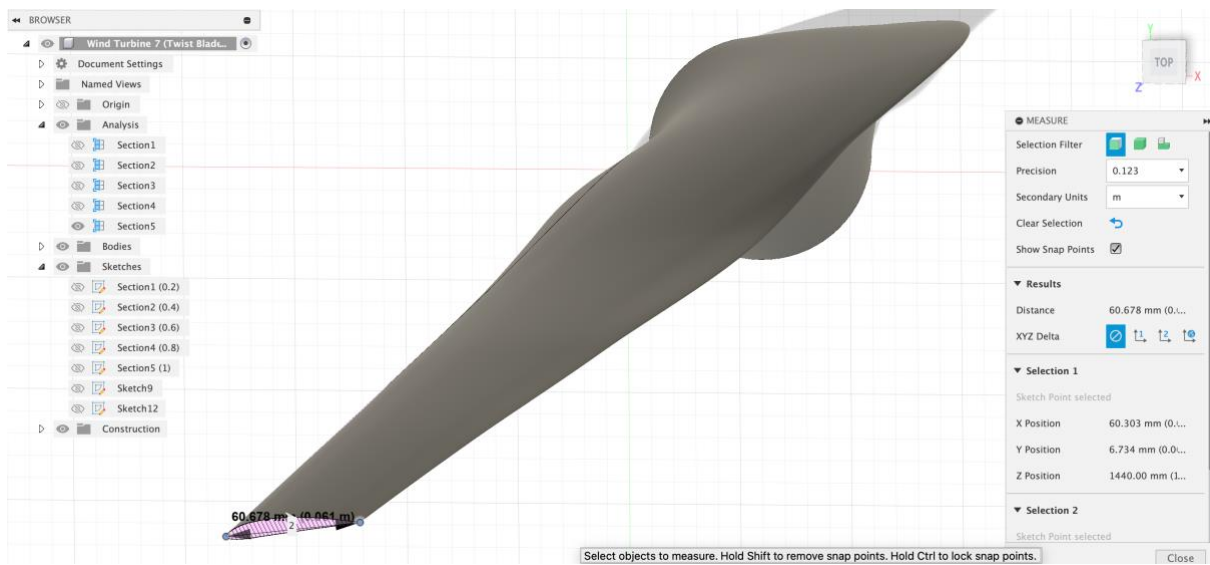


Figure 22 - Section 5 Section View (1R) Chord length

11 Conclusions and Recommendations

In summary, the investigation developed a wind turbine blade design for the proposed domestic EV charging application. A three-bladed configuration with a 1.44 m blade length, NACA 4412 profile, TSR of 6 and tapered chord and twist distribution was selected based on the design requirements. CFRP achieved the highest weighted decision matrix score due to its combination of strength, fatigue resistance and low density, while vacuum infusion was selected as the most suitable manufacturing route. The cost analysis identified that CFRP was economically viable, and although not the cheapest, its material characteristics are better suited to the application. Mechanical analysis indicated that the calculated bending stresses were substantially below the assumed CFRP strength, providing a high static safety factor. However, the analysis remains preliminary as fatigue, gust loading, fibre orientation and manufacturing defects were not fully considered. Further work should include FEA, fatigue analysis and improved aerodynamic data. Prototype manufacture and testing should also be undertaken to validate the predicted structural and aerodynamic performance.

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13 Appendix

13.1 Appendix A – NACA 4412 Calculations

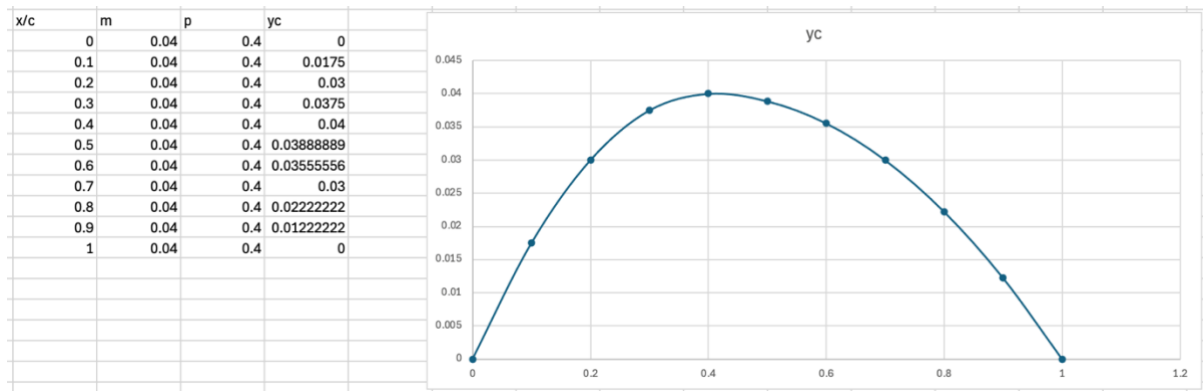


Figure 23 - NACA 4412 Camber line Table and Graph

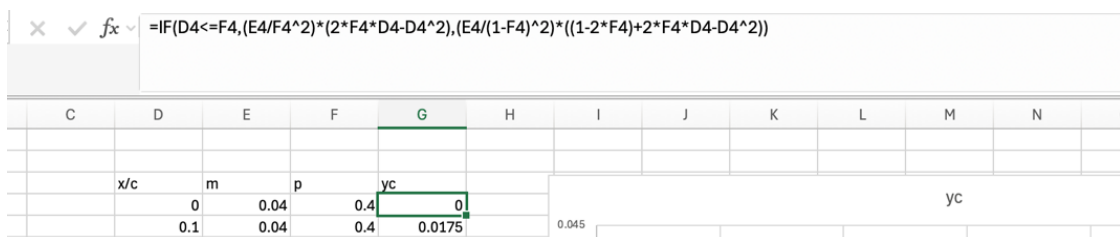


Figure 24 - NACA 4412 Camber Line Calculation Formula

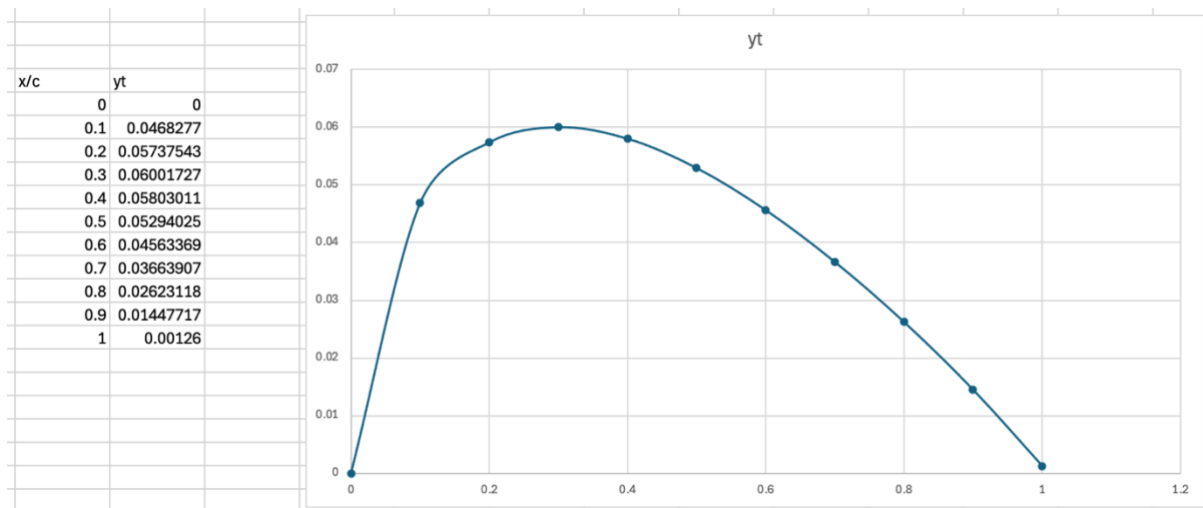


Figure 25 - NACA 4412 Thickness Calculation and Graph

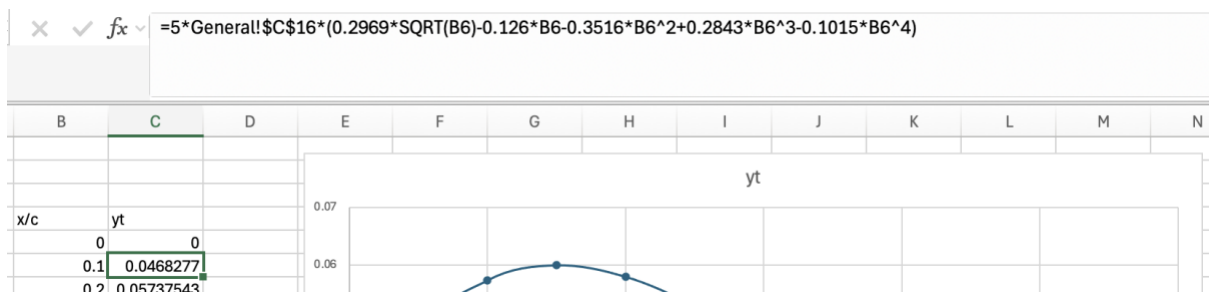


Figure 26 - NACA 4412 Thickness Calculation Formula

13.2 Appendix B – Blade Profile Calculations

Table 12 – Blade Profile calculation for each section

c	yc	yu	yl	xc	x	y	theta	m	p	xl	xu	yt
0.2111269	0	0	0	0	0	0	0	0.1973956	0.04	0.4	0	0
0.2111269	0.0036947	0.0134719	-0.006082	0.1	0.0211127	-0.001284	0.1488899	0.04	0.4	0.0225793	0.0196461	0.0098866
0.2111269	0.0063338	0.0183872	-0.00572	0.2	0.0422254	-0.001208	0.0996687	0.04	0.4	0.0434307	0.04102	0.0121135
0.2111269	0.0079173	0.0205727	-0.004738	0.3	0.0633381	-0.001	0.0499584	0.04	0.4	0.0639708	0.0627053	0.0126713
0.2111269	0.0084451	0.0206968	-0.003807	0.4	0.0844507	-0.000804	0	0.04	0.4	0.0844507	0.0844507	0.0122517
0.2111269	0.0082105	0.0193848	-0.002964	0.5	0.1055634	-0.000626	-0.022219	0.04	0.4	0.1053151	0.1058117	0.0111771
0.2111269	0.0075067	0.0171317	-0.002118	0.6	0.1266761	-0.000447	-0.044415	0.04	0.4	0.1262483	0.1271039	0.0096345
0.2111269	0.0063338	0.0140522	-0.001385	0.7	0.1477888	-0.000292	-0.066568	0.04	0.4	0.1472742	0.1483034	0.0077355
0.2111269	0.0046917	0.0102081	-0.000825	0.8	0.1689015	-0.000174	-0.088656	0.04	0.4	0.1684111	0.1693918	0.0055381
0.2111269	0.0025804	0.0056183	-0.000457	0.9	0.1900142	-9.66E-05	-0.110657	0.04	0.4	0.1896766	0.1903517	0.0030565
0.2111269	0	0.0002637	-0.000264	1	0.2111269	-5.57E-05	-0.132552	0.04	0.4	0.2110917	0.211162	0.000266
0.1380177	0	0	0	0	0	0	0	0.1973956	0.04	0.4	0	0
0.1380177	0.0024153	0.0088069	-0.003976	0.1	0.0138018	-0.000549	0.1488899	0.04	0.4	0.0147605	0.012843	0.0064631
0.1380177	0.0041405	0.0120201	-0.003739	0.2	0.0276035	-0.000516	0.0996687	0.04	0.4	0.0283915	0.0268156	0.0079188
0.1380177	0.0051757	0.0134488	-0.003097	0.3	0.0414053	-0.000428	0.0499584	0.04	0.4	0.041819	0.0409917	0.0082834
0.1380177	0.0055207	0.0135299	-0.002488	0.4	0.0552071	-0.000343	0	0.04	0.4	0.0552071	0.0552071	0.0080092
0.1380177	0.0053674	0.0126722	-0.001938	0.5	0.0690089	-0.000267	-0.022219	0.04	0.4	0.0688465	0.0691712	0.0073067
0.1380177	0.0049073	0.0111993	-0.001385	0.6	0.0828106	-0.000191	-0.044415	0.04	0.4	0.082531	0.0830903	0.0062983
0.1380177	0.0041405	0.0091862	-0.000905	0.7	0.0966124	-0.000125	-0.066568	0.04	0.4	0.096276	0.0969488	0.0050568
0.1380177	0.0030671	0.0066732	-0.000539	0.8	0.1104142	-7.44E-05	-0.088656	0.04	0.4	0.1100936	0.1107347	0.0036204
0.1380177	0.0016869	0.0036728	-0.000299	0.9	0.1242159	-4.13E-05	-0.110657	0.04	0.4	0.1239953	0.1244366	0.0019981
0.1380177	0	0.0001724	-0.000172	1	0.1380177	-2.38E-05	-0.132552	0.04	0.4	0.1379947	0.1380407	0.0001739
0.0978108	0	0	0	0	0	0	0	0.1973956	0.04	0.4	0	0
0.0978108	0.0017117	0.0062413	-0.002818	0.1	0.0097811	-0.000276	0.1488899	0.04	0.4	0.0104605	0.0091016	0.0045803
0.0978108	0.0029343	0.0085184	-0.00265	0.2	0.0195622	-0.000259	0.0996687	0.04	0.4	0.0201206	0.0190038	0.0056119
0.0978108	0.0036679	0.0095309	-0.002195	0.3	0.0293432	-0.000215	0.0499584	0.04	0.4	0.0296364	0.0290501	0.0058703
0.0978108	0.0039124	0.0095884	-0.001764	0.4	0.0391243	-0.000172	0	0.04	0.4	0.0391243	0.0391243	0.005676
0.0978108	0.0038038	0.0089806	-0.001373	0.5	0.0489054	-0.000134	-0.022219	0.04	0.4	0.0487904	0.0490204	0.0051781
0.0978108	0.0034777	0.0079368	-0.000981	0.6	0.0586865	-9.6E-05	-0.044415	0.04	0.4	0.0584883	0.0588847	0.0044635
0.0978108	0.0029343	0.0065101	-0.000641	0.7	0.0684676	-6.27E-05	-0.066568	0.04	0.4	0.0682292	0.068706	0.0035837
0.0978108	0.0021736	0.0047292	-0.000382	0.8	0.0782487	-3.74E-05	-0.088656	0.04	0.4	0.0780215	0.0784758	0.0025657
0.0978108	0.0011955	0.0026028	-0.000212	0.9	0.0880297	-2.07E-05	-0.110657	0.04	0.4	0.0878734	0.0881861	0.001416
0.0978108	0	0.0001222	-0.000122	1	0.0978108	-1.19E-05	-0.132552	0.04	0.4	0.0977945	0.0978271	0.0001232
0.0750311	0	0	0	0	0	0	0	0.1973956	0.04	0.4	0	0
0.0750311	0.001313	0.0047877	-0.002162	0.1	0.0075031	-0.000162	0.1488899	0.04	0.4	0.0080243	0.0069819	0.0035135
0.0750311	0.0022509	0.0065345	-0.002033	0.2	0.0150062	-0.000153	0.0996687	0.04	0.4	0.0154346	0.0145779	0.0043049
0.0750311	0.0028137	0.0073112	-0.001684	0.3	0.0225093	-0.000126	0.0499584	0.04	0.4	0.0227342	0.0222844	0.0045032
0.0750311	0.0030012	0.0073553	-0.001353	0.4	0.0300124	-0.000102	0	0.04	0.4	0.0300124	0.0300124	0.0043541
0.0750311	0.0029179	0.0068891	-0.001053	0.5	0.0375155	-7.9E-05	-0.022219	0.04	0.4	0.0374273	0.0376038	0.0039722
0.0750311	0.0026678	0.0060883	-0.000753	0.6	0.0450187	-5.65E-05	-0.044415	0.04	0.4	0.0448666	0.0451707	0.0034239
0.0750311	0.0022509	0.0049939	-0.000492	0.7	0.0525218	-3.69E-05	-0.066568	0.04	0.4	0.0523389	0.0527046	0.0027491
0.0750311	0.0016674	0.0036278	-0.000293	0.8	0.0600249	-2.2E-05	-0.088656	0.04	0.4	0.0598506	0.0601991	0.0019682
0.0750311	0.000917	0.0019966	-0.000163	0.9	0.067528	-1.22E-05	-0.110657	0.04	0.4	0.067408	0.0676479	0.0010862
0.0750311	0	9.371E-05	-9.37E-05	1	0.0750311	-7.03E-06	-0.132552	0.04	0.4	0.0750186	0.0750436	9.454E-05
0.060668	0	0	0	0	0	0	0	0.1973956	0.04	0.4	0	0
0.060668	0.0010617	0.0038712	-0.001748	0.1	0.0060668	-0.000106	0.1488899	0.04	0.4	0.0064882	0.0056454	0.0028409
0.060668	0.00182	0.0052836	-0.001644	0.2	0.0121336	-9.97E-05	0.0996687	0.04	0.4	0.01248	0.0117873	0.0034809
0.060668	0.0022751	0.0059116	-0.001362	0.3	0.0182004	-8.26E-05	0.0499584	0.04	0.4	0.0183822	0.0180186	0.0036411
0.060668	0.0024267	0.0059473	-0.001094	0.4	0.0242672	-6.64E-05	0	0.04	0.4	0.0242672	0.0242672	0.0035206
0.060668	0.0023593	0.0055703	-0.000852	0.5	0.030334	-5.17E-05	-0.022219	0.04	0.4	0.0302627	0.0304054	0.0032118
0.060668	0.0021571	0.0049229	-0.000609	0.6	0.0364008	-3.69E-05	-0.044415	0.04	0.4	0.0362779	0.0365238	0.0027685
0.060668	0.00182	0.0040379	-0.000398	0.7	0.0424676	-2.41E-05	-0.066568	0.04	0.4	0.0423198	0.0426155	0.0022228
0.060668	0.0013482	0.0029333	-0.000237	0.8	0.0485344	-1.44E-05	-0.088656	0.04	0.4	0.0483935	0.0486753	0.0015914
0.060668	0.0007415	0.0016144	-0.000131	0.9	0.0546012	-7.97E-06	-0.110657	0.04	0.4	0.0545043	0.0546982	0.0008783
0.060668	0	7.577E-05	-7.58E-05	1	0.060668	-4.6E-06	-0.132552	0.04	0.4	0.0606579	0.0606782	7.644E-05

B25 $\times$ $\checkmark$ f_x $=IF(E25<=\$J25,(\$I25/(\$J25^2))*(2*\$J25*E25-E25^2)*A25,(\$I25/((1-\$J25)^2))*((1-2*\$J25)+2*\$J25*E25-E25^2)*A25)$

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
23																	
24	c	yc	yu	yl	xc	x	y	theta	m	p	xl	xu	yt				0.2
25	0.211127	0	0	0	0	0	0	0.197396	0.04	0.4	0	0	0	0.025			

Figure 27 - Blade Yc Calculation Formula

C25 $\times$ $\checkmark$ f_x $=B25+M25*COS(H25)$

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
23																	
24	c	yc	yu	yl	xc	x	y	theta	m	p	xl	xu	yt				0.2
25	0.211127	0	0	0	0	0	0	0.197396	0.04	0.4	0	0	0	0.025			

Figure 28 - Blade Yu Calculation Formula

D25 $\times$ $\checkmark$ f_x $=B25-M25*COS(H25)$

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
23																	
24	c	yc	yu	yl	xc	x	y	theta	m	p	xl	xu	yt				0.2
25	0.211127	0	0	0	0	0	0	0.197396	0.04	0.4	0	0	0	0.025			

Figure 29 - Blade Yl Calculation Formula

F25 $\times$ $\checkmark$ f_x $=A25*E25$

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
23																	
24	c	yc	yu	yl	xc	x	y	theta	m	p	xl	xu	yt				0.2
25	0.211127	0	0	0	0	0	0	0.197396	0.04	0.4	0	0	0	0.025			

Figure 30 - Blade X Calculation Formula

G25 $\times$ $\checkmark$ f_x $=D25*A25$

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
23																	
24	c	yc	yu	yl	xc	x	y	theta	m	p	xl	xu	yt				0.2
25	0.211127	0	0	0	0	0	0	0.197396	0.04	0.4	0	0	0	0.025			

Figure 31 - Blade Y Calculation Formula

H25 $\times$ $\checkmark$ f_x $=ATAN(IF(E25<=\$J25,(2*\$I25/\$J25^2)*(\$J25-E25),(2*\$I25/(1-\$J25)^2)*(\$J25-E25)))$

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
23																	
24	c	yc	yu	yl	xc	x	y	theta	m	p	xl	xu	yt				0.2
25	0.211127	0	0	0	0	0	0	0.197396	0.04	0.4	0	0	0	0.025			

Figure 32 - Blade theta Calculation Formula

K25 $\times$ $\checkmark$ f_x $=F25+M25*\text{SIN}(H25)$

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
23																	
24	c	yc	yu	yl	xc	x	y	theta	m	p	xl	xu	yt				0.2
25	0.211127	0	0	0	0	0	0	0.197396	0.04	0.4	0	0	0	0.025			

Figure 33 - Blade xl Calculation Formula

L25 $\times$ $\checkmark$ f_x $=F25-M25*\text{SIN}(H25)$

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
23																	
24	c	yc	yu	yl	xc	x	y	theta	m	p	xl	xu	yt				0.2
25	0.211127	0	0	0	0	0	0	0.197396	0.04	0.4	0	0	0	0.025			

Figure 34 - Blade xu Calculation Formula

M25 $\times$ $\checkmark$ f_x $=5*0.12*A25*(0.2969*\text{SQRT}(E25)-0.126*E25-0.3516*E25^2+0.2843*E25^3-0.1015*E25^4)$

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
23																	
24	c	yc	yu	yl	xc	x	y	theta	m	p	xl	xu	yt				0.2
25	0.211127	0	0	0	0	0	0	0.197396	0.04	0.4	0	0	0	0.025			

Figure 35 - Blade yt Calculation Formula

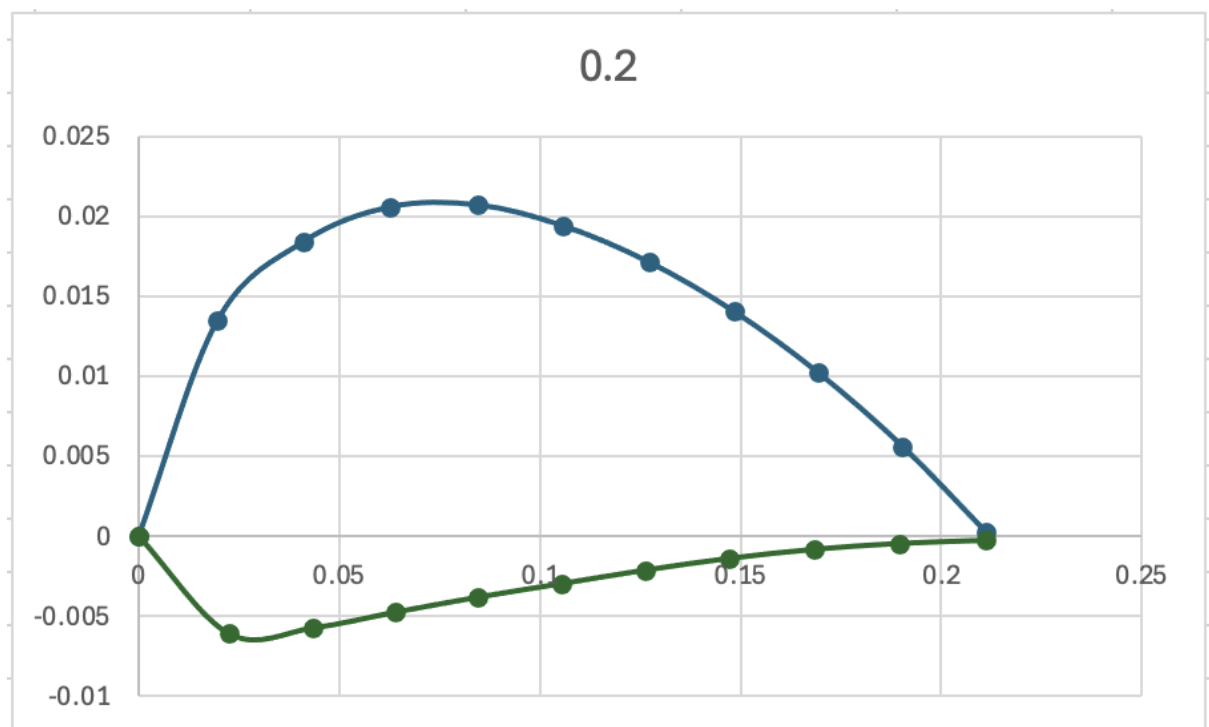


Figure 36 - Blade 0.2 Section Profile

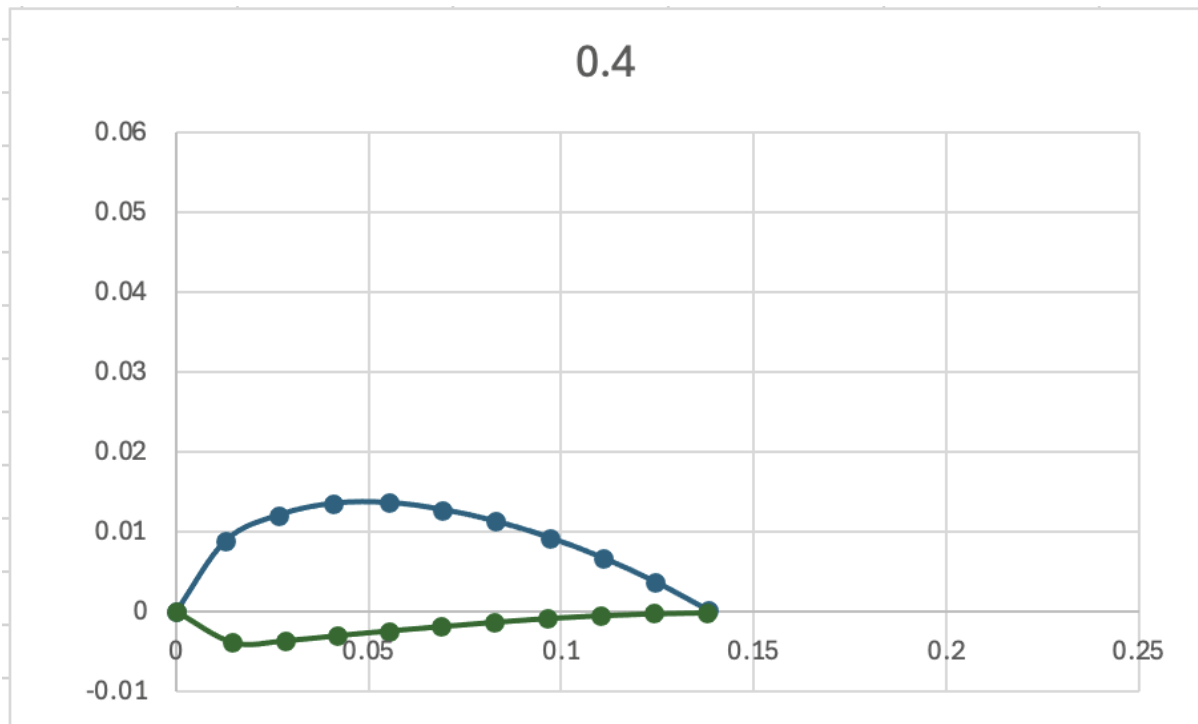


Figure 37 - Blade 0.4 Section Profile

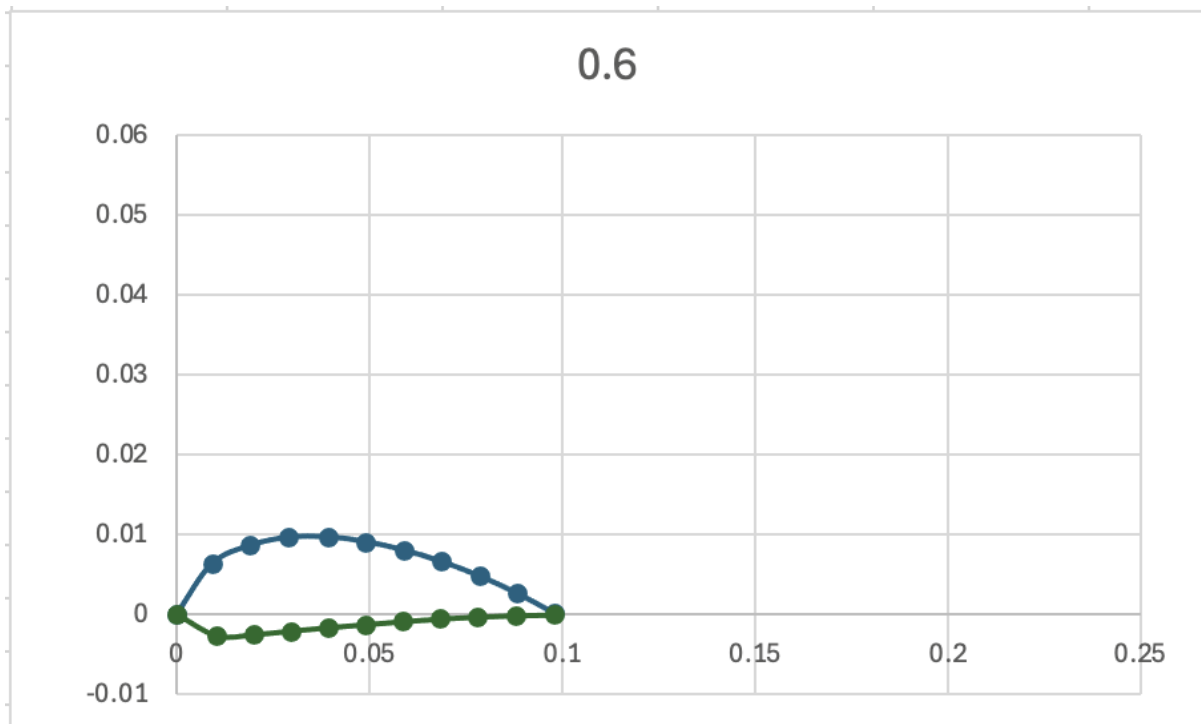


Figure 38 - Blade 0.6 Section Profile

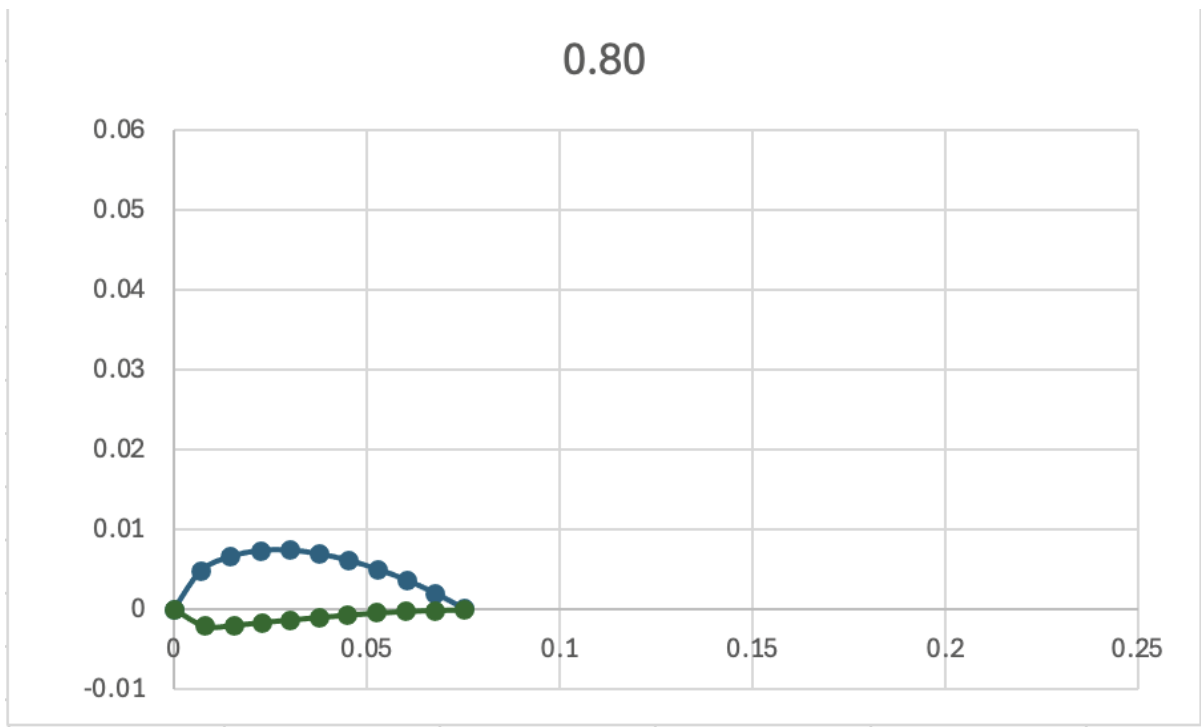


Figure 39 - Blade 0.8 Section Profile

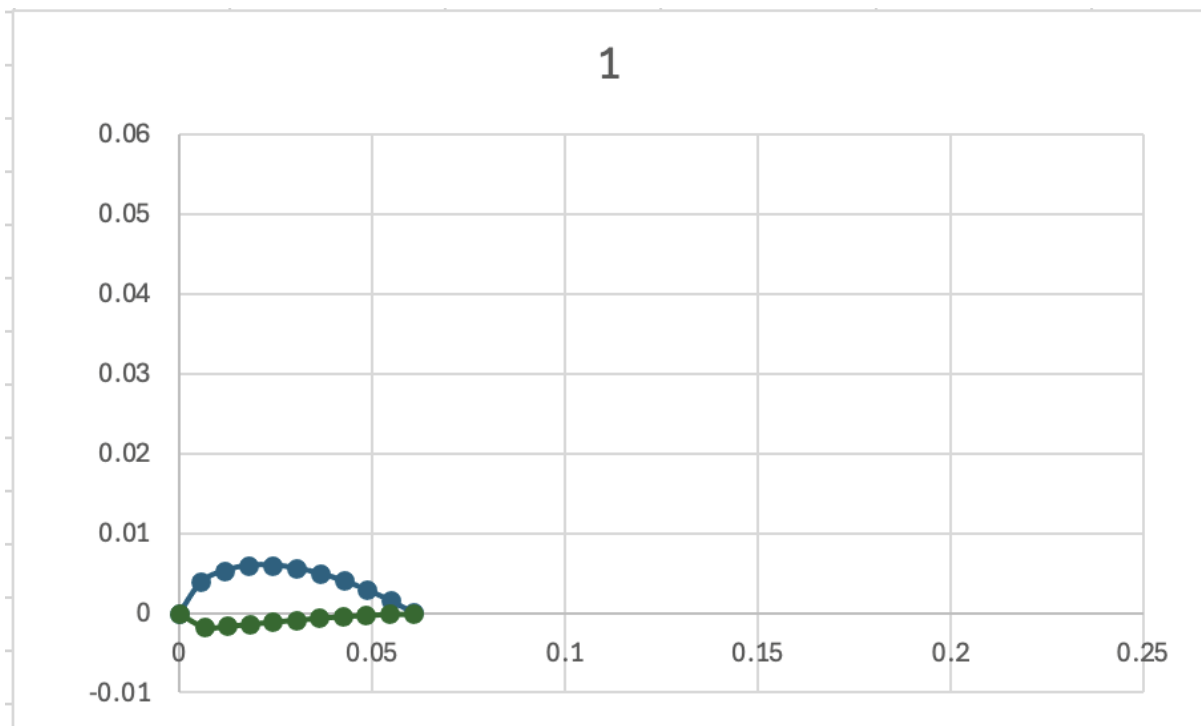


Figure 40 - Blade 1 Section Profile

0.2 section			0.4 section			0.6 section			0.8 section			1 section		
X	Y													
0	0		0	0	0	0	0	0	0	0	0	0	0	0
0.01964611	0.01347192		0.01284304	0.00880686	0	0.00910164	0.00624127	0	0.00698191	0.00478771	0	0.00564538	0.0038712	0
0.04102003	0.01838718		0.02681559	0.01202006	0	0.01900375	0.00851841	0	0.01457786	0.00653451	0	0.01178725	0.00528362	0
0.06270529	0.0205727		0.04099166	0.01344878	0	0.02905009	0.00953092	0	0.02228445	0.00731121	0	0.01801858	0.00591164	0
0.08445074	0.02069679		0.05520709	0.01352989	0	0.03912433	0.0095884	0	0.03001244	0.00735531	0	0.02426722	0.0059473	0
0.10581175	0.01938484		0.06917119	0.01267225	0	0.04902045	0.0089806	0	0.03760379	0.00688906	0	0.03040538	0.0055703	0
0.12710389	0.01713173		0.08309028	0.01119934	0	0.05888467	0.00793678	0	0.04517068	0.00608834	0	0.03652375	0.00492286	0
0.14830336	0.01405216		0.09694878	0.00918617	0	0.06870595	0.00651008	0	0.05270463	0.00499391	0	0.04261549	0.00403794	0
0.16939183	0.01020806		0.11073472	0.00667321	0	0.07847582	0.00472919	0	0.06019913	0.00362778	0	0.04867534	0.00293332	0
0.19035171	0.00561826		0.1244366	0.00367277	0	0.08818611	0.00260283	0	0.06764793	0.00199664	0	0.05469823	0.00161443	0
0.21116202	0.0026369		0.1380407	0.0017238	0	0.0978271	0.0012216	0	0.07504358	9.371E-05	0	0.06067815	7.5771E-05	0
0.18967664	-0.0004574		0.1239953	-0.000299	0	0.08787336	-0.0002119	0	0.06740802	-0.0001625	0	0.05450425	-0.0001314	0
0.16841115	-0.0008246		0.11009363	-0.0005391	0	0.07802149	-0.000382	0	0.05985061	-0.0002931	0	0.04839354	-0.000237	0
0.14727425	-0.0013846		0.09627603	-0.0009051	0	0.06822919	-0.0006414	0	0.0523389	-0.000492	0	0.04231977	-0.0003979	0
0.12624834	-0.0021183		0.08253099	-0.0013847	0	0.05848831	-0.0009813	0	0.04486663	-0.0007528	0	0.03627791	-0.0006087	0
0.10531511	-0.0029639		0.06884653	-0.0013847	0	0.04879037	-0.0013731	0	0.0374273	-0.0010533	0	0.03026267	-0.0008517	0
0.08445074	-0.0038066		0.05520709	-0.0024885	0	0.03912433	-0.0017635	0	0.03001244	-0.0013528	0	0.02426722	-0.0010939	0
0.06397083	-0.0047382		0.04181897	-0.0030974	0	0.02963639	-0.0021951	0	0.0227342	-0.0016839	0	0.01838224	-0.0013615	0
0.04343071	-0.0057196		0.0283915	-0.003739	0	0.02012057	-0.0026498	0	0.01543458	-0.0020326	0	0.01247997	-0.0016435	0
0.02257927	-0.0060825		0.0147605	-0.0039762	0	0.01046052	-0.0028179	0	0.00802431	-0.0021616	0	0.00648823	-0.0017478	0
0	0		0	0	0	0	0	0	0	0	0	0	0	0

Figure 41 - X,Y,Z Co-ordinates for CAD importation

13.3 Appendix C – Mechanical Properties Analysis

$f_x = 6 \cdot \text{SQRT}(1 + (6 \cdot D4)^2)$							
B	C	D	E	F	G	H	I
	Section	(r/R)	Chord (m)	Vrel (m/s)	Flow angle (°)	Lift (N)	Drag (N)
	1.00	0.20	0.2111	9.37	39.81	3.92	0.08

Figure 42 - Relative Velocity Calculation Formula

$f_x = \text{DEGREES}(\text{ATAN}(1/(6 \cdot D4)))$							
B	C	D	E	F	G	H	I
	Section	(r/R)	Chord (m)	Vrel (m/s)	Flow angle (°)	Lift (N)	Drag (N)
	1.00	0.20	0.2111	9.37	39.81	3.92	0.08

Figure 43 – Flow Angle Calculation Formula

$\times$ $\checkmark$ f_x $\vee$ $=0.5*1.225*F4^2*1.2*E4*0.288$

B	C	D	E	F	G	H	I
	Section	(r/R)	Chord (m)	Vrel (m/s)	Flow angle (°)	Lift (N)	Drag (N)
	1.00	0.20	0.2111	9.37	39.81	3.92	0.08

Figure 44 - Lift Calculation Formula

$\times$ $\checkmark$ f_x $\vee$ $=H4*(0.024/1.2)$

B	C	D	E	F	G	H	I
	Section	(r/R)	Chord (m)	Vrel (m/s)	Flow angle (°)	Lift (N)	Drag (N)
	1.00	0.20	0.2111	9.37	39.81	3.92	0.08

Figure 45 - Drag Calculation Formula

$\times$ $\checkmark$ f_x $\vee$ $=H4*\text{COS}(\text{RADIANS}(G4))+I4*\text{SIN}(\text{RADIANS}(G4))$

B	C	D	E	F	G	H	I	J
	Section	(r/R)	Chord (m)	Vrel (m/s)	Flow angle (°)	Lift (N)	Drag (N)	Fn (N)
	1.00	0.20	0.2111	9.37	39.81	3.92	0.08	3.05

Figure 46 - Fn Calculation Formula

$\vee$ f_x $\vee$ $=H4*\text{SIN}(\text{RADIANS}(G4))-I4*\text{COS}(\text{RADIANS}(G4))$

C	D	E	F	G	H	I	J	K
Section	(r/R)	Chord (m)	Vrel (m/s)	Flow angle (°)	Lift (N)	Drag (N)	Fn (N)	Ft (N)
1.00	0.20	0.2111	9.37	39.81	3.92	0.08	3.05	2.44

Figure 47 - Ft Calculation Formula

$f_x = J5*(D5-D4)*1.44+J6*(D6-D4)*1.44+J7*(D7-D4)*1.44+J8*(D8-D4)*1.44$

	C	D	E	F	G	H	I	J	K	L	M	N	
Section	(r/R)	Chord (m)	Vrel (m/s)	Flow angle (°)	Lift (N)	Drag (N)	Fn (N)	Ft (N)			Radial Position	Bending Moment (Nm)	Bei
1.00	0.20	0.2111	9.37	39.81	3.92	0.08	3.05	2.44			0.2R	38.76	

Figure 48 - Bending moment Calculation Formula

$f_x = 6*N4/(E4*(0.082*E4)^2/1000000$

	C	D	E	F	G	H	I	J	K	L	M	N	O
Section	(r/R)	Chord (m)	Vrel (m/s)	Flow angle (°)	Lift (N)	Drag (N)	Fn (N)	Ft (N)			Radial Position	Bending Moment (Nm)	Bending Stress (MPa)
1.00	0.20	0.2111	9.37	39.81	3.92	0.08	3.05	2.44			0.2R	38.76	3.66

Figure 49 - Bending Stress Calculation Formula

$f_x = 440/O4$

	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Section	(r/R)	Chord (m)	Vrel (m/s)	Flow angle (°)	Lift (N)	Drag (N)	Fn (N)	Ft (N)			Radial Position	Bending Moment (Nm)	Bending Stress (MPa)	Factor of Safety
1.00	0.20	0.2111	9.37	39.81	3.92	0.08	3.05	2.44			0.2R	38.76	3.66	119.57

Figure 50 - Factor of Safety Calculation Formula