Final Report

Hovering Through New Horizons
Saif Shraideh

2017
3rd Year Individual Project

I certify that all material in this thesis that is not my own work has been identified and that no material has been included for which a degree has previously been conferred on me.

Signed Saif Shraideh

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Final Report

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Abstract

Despite the concept of aviation dating back to the early 19th century, engineers and designers have yet to develop an optimal efficiency model. There is a constant focus on improving aviation and increasing the efficiency of flying machines. This project focuses on aviation, and aims to test and put forth a new concept design for flying crafts that is more efficient, environmentally friendly, and safer to operate than currently employed transportation methods. The idea is to reverse engineer the concept of aerofoils, by using engines to thrust air along two semi-circular, stationary aerofoils to obtain lift. The structure was conceived first by drawing a series of 2D sketches and 3D models using SolidWorks. Afterwards, optimal materials for each component of the craft were chosen, with the aim of having the highest strength-to-weight ratio. This was followed by mathematical calculations for density, mass, lift, airspeed, angle of attack, and several other factors. This paper clearly demonstrates that the aerofoils can generate enough lift with relatively low air velocity, such that the concept model is able to hover and move around. Moreover, it confirms that the model is energy efficient, environmentally friendly and safe to operate. As this concept is backed by theory, it stands to have several promising applications, most importantly, an effective transportation method.

Key Words:

- Aerofoil
- Strength-to-Weight ratio
- Efficient
- Environmentally Friendly
- Safety

Table of Contents

1. Nomenclature

m	Total mass of honeycomb structure
m_f	Mass of the facing material
m_c	Mass of the honeycomb core
a	Length/Span of a sandwich panel or beam
b	Breadth of the sandwich panel or beam
t_f	Thickness of the facing material
ρ_f	Density of the facing material
h_c	Hight (Thickness) of the honeycomb core
ρ_{ca}	Relative density of the honeycomb core over the entire sandwich structure
d	Breadth of one edge of a honeycomb core cell
t_c	Wall thickness of a honeycomb core cell
ρ_c	Density of the honeycomb core material
A	Virtual area of a unit honeycomb core cell parallel to the facing material
L	Length of a honeycomb core cell
W	Width of a honeycomb core cell
α	Angle depending on the geometrical shape of a unit honeycomb core
L_i	Lift force
Cl	Lift coefficient
r	Air density
v	Air velocity
A_w	Wing area
θ	Angle of attack
Re	Reynolds number
L	Duct/Pipe length
μ	Dynamic viscosity

2. Introduction and Background

Over the years, aviation has become increasingly integrated into our lives, such that it has become an unavoidable necessity. It has branched into several areas of life, ranging from hobby and sport, to transport and war machinery. Since the conception of aviation, the challenge has always been to discover better concept designs to enhance these flying machines. The consistent tweaking and altering of the crafts' geometry provides physical laws more suited structures to play out their natural role in producing enhanced flight. The wings are the heart of any flying craft, as it is the part that mainly interacts with air. All wings have a common geometrical factor referred to as the aerofoil, such that its shape determines how well an aircraft can fly.

The concept of aviation has become standard: books, schools and universities all teach it in the same way. They are located outside the vessel, known as the fuselage, and an engine thrusts the entire craft through the air, such that the aerofoils splits the air around it, producing a lift force, which causes the craft to fly. Mathematics suggests reversibility: one plus two results in three, and two plus one also results in three. Similarly, if we reverse this concept of aviation, will the result still be 'three'?

The basis of this project is to reverse engineer aerofoils and their behaviour. Aerofoils are typically thrusted through air to obtain a lift force. However, the opposite, thrusting air along the aerofoil, may yield the same result. This phenomenon can be seen in wind tunnels, in which air is thrusted at stationary test models, which are secured to the ground, and a lift force is shown to be produced. In this project, air will be thrusted along a set of two stationary aerofoils using turbine fan blades.

This project is broken down into several sections leading to the final design upon which this paper is focused on. Two-dimensional rough sketches with practical dimensions were drawn (Appendix A), leading up to a preliminary 3D model design using SolidWorks. The material selection was then done, with the aim of obtaining a craft with the lightest weight possible, without jeopardizing its safety of operation. Subsequently, several mathematical calculations involving the mass and lift force were performed, resulting in the construction of the final model, as seen in Figure (1) and Figure (2), with proper dimensions (Appendix B). Additionally, these calculations assisted in finding proper wingspan, wing area, aerofoil shape, angle of attack, and air velocity, among other factors.

The objective of this project is to prove whether or not the concept of obtaining flight by thrusting air along an aerofoil is feasible. If this yielded a positive result, then this concept design can present a promising transportation method, which is potentially safer, more environmentally friendly, and more energy efficient than vehicles and aircrafts being used today.

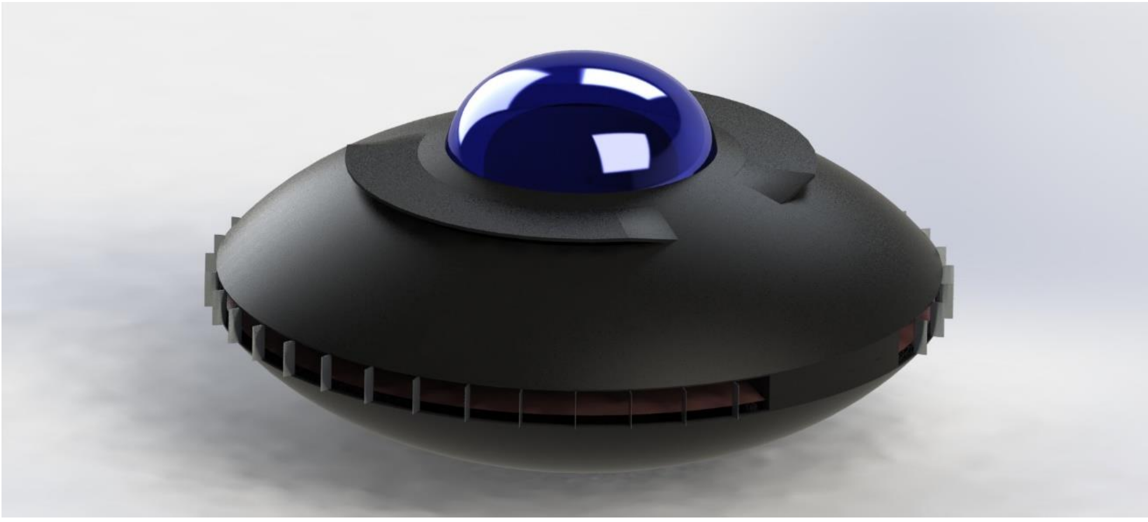


Figure (1): Isometric View of the Final Model

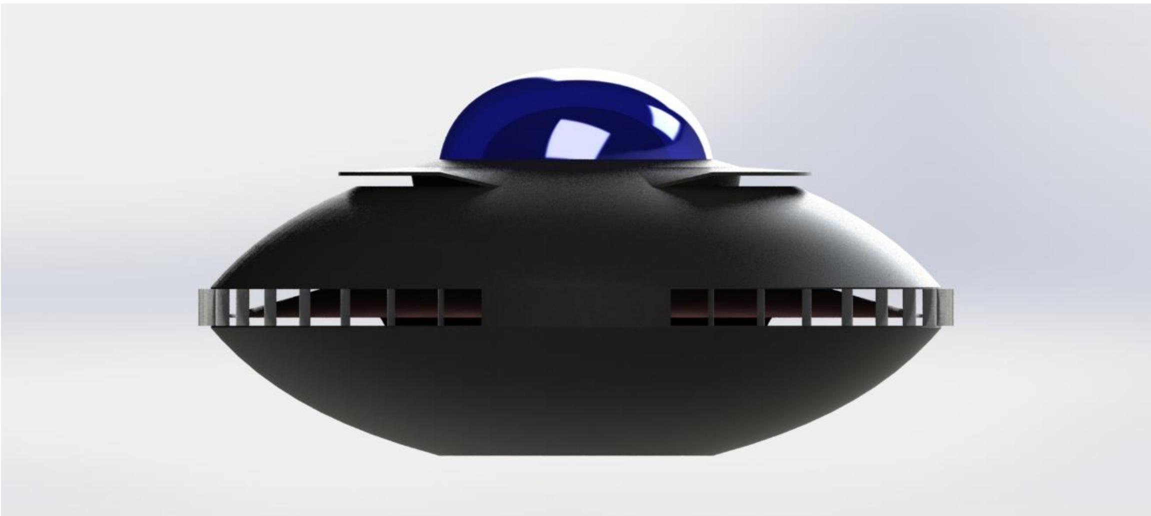


Figure (2): Front View of the Final Model

3. Literature Review

On December 17th, 1903, the Wright Brothers were successful in flying the first free controlled power-driven air plane, which flew for 59 seconds, and covered a distance of 852 feet (about 260m) [1]. The observation of birds angling their wings mid-flight for better control and balance inspired their wing design. This observation amended their design by the addition of moveable rudders to emulate the bird's wing behaviour during flight [1], which lead them to building the first heavier-than-air flying machine, known as the 'Flyer' [2].

On June 18th, 1914, inventor Lawrence Sperry demonstrated the first concept of an autopilot system in an 'Airplane Safety Competition' [3]. His invention was inspired by his father's gyrostabilizer, which earned him the winning prize at that competition [4]. Gyroscopes have an interesting phenomenon called 'Precession': Figure (3) shows a horizontal wheel spinning due to a force (shown by the black arrows). The top section will experience a torque to the left (shown by top red arrow), and will continue to experience this torque until it reaches the bottom. When that section starts moving upwards, continuing the rotation, it will experience a torque to the right (shown by bottom red arrow). As the wheel completes a full rotation, the torques cancel out resulting in precession, and so, the wheel balances itself with its axil hanging horizontally in the air [5]. Sperry adopted the precession concept to balance airplanes mid-flight.

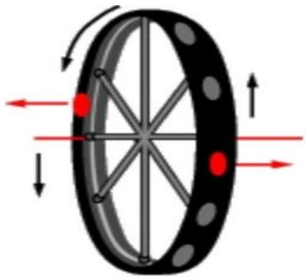


Figure (3): Demonstrating Precession by a Spinning Wheel [5]

On May 15th, 1941, the first jet-powered aircraft was tested for flight in the Royal Air Force Cranwell, which achieved a remarkable 17-minute flight [6]. Sir Frank Whittle was the mastermind behind inventing the jet engine, with the aim to achieve higher flight altitudes. Whittle stated in his thesis when he was a cadet that airplanes should fly at higher altitudes due to lower air resistance. Consequently, this will achieve long range flights with higher craft velocities [7]. However, the challenge at that time was the lack of a proper propulsion system to sustain flight at high altitudes. Whittle considered fan enclosed systems (ducted fans) to generate faster airflow propelling airplanes at high altitudes; however, the air ministry turned him down. However, in 1935, he was approved by the Royal Air-Force creating the first jet engine [7].

All these historical breakthroughs had something in common: inspiration. These breakthroughs started off as new concepts for aviation, which later found to enhance all aspects of flight. Despite most of the well-known aeronautical theories that were inspired by the people mentioned earlier, there was no mention of an idea to reverse engineer aerofoils. This is the concept upon which this paper lied. This paper is inspired by all the historical aviation innovations, and will adopt some integrated concept to suit the model being tested.

The idea of using aerofoils instead of a fan to thrust the model upwards was inspired by the Wright Brothers' model. Aerofoils are the main component in an airplane: by creating a linear lift force which moves along the aerofoil, the craft takes off. This project focuses on stationary semi-circular aerofoils and will study if this concept of using aerofoils will result in flight. Sperry's invention sparked the idea of enhanced stability, which can be adopted in this project. The turbine fan blades providing the air to the aerofoils also act as a gyrostabilizer, resisting any tilting motion stabilizing the craft. Whittle inspired the idea of using ducted fans, as they produce an increased airflow to propel a craft. This project will use ducted fans to increase the speed of the air thrusted along the aerofoils, and increase the efficiency of the turbines whilst operation.

Furthermore, the concept of vertical take-off was inspired by designer Igor Sikorsky, who redesigned the helicopter inventing the first successful flying model [8]. When the helicopter first appeared in the sky, it was thought to be the future transport method rather than an airplane [9]. However, this brilliant idea had several drawbacks, being noisy, fuel incompetent, and full of vibrations, which favoured conventional airplanes over helicopters.

Despite this, the idea of vertical take-off was still favoured by many engineers and designers since it eases transportation. Because of the favourability of vertical take-off, this concept is instrumental to the project. However, the difference is that this project will use different methods to result in vertical take-off. Fuel-inefficiency, vibration, and noise will not be issues in this new design. The most significant difference is that this design will get rid of the gyroscopic effect used to steer a helicopter. Helicopters use a complicated method by changing the blade pitch of the section 90^o to the intended direction due to the 90^o out of phase torque. This paper only uses the gyro effect as a stabilizer.

4. Theory and Methodology

4.1 The Inner Workings of the Design

The way the design functions is going to be discussed in steps down below, with the aid of Figure (4):

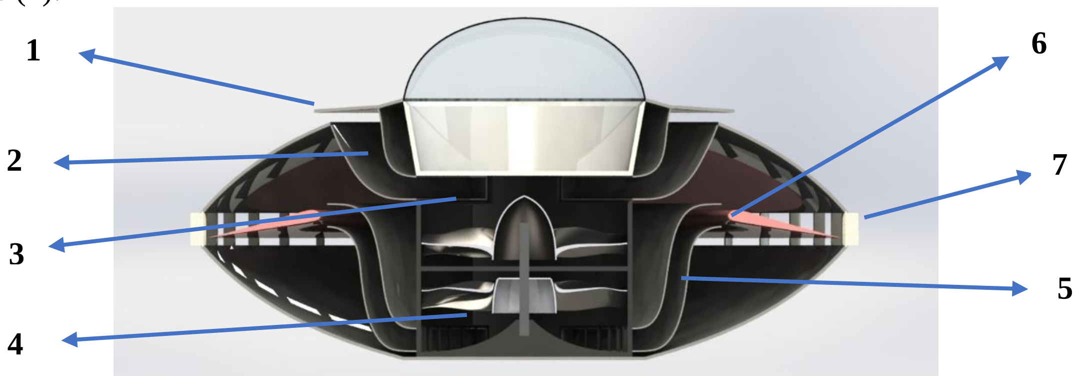


Figure (4): Final Rendered Design Sliced in Half

The idea of this concept design is to move air towards the stationary aerofoils, so as to the lift the craft off the ground. The concept is not complicated: it only involves a few air channels to guide the air to the turbines and then out to the aerofoils. The following explains a step-by-step description of the design function as air proceeds through it, and will include reasons for specific design structures.

Stage 1: Air flow first encounters the device at the opening of the air inlet channel. There is a hood covering the inlet channel in case of rain to prevent water from entering the engine. The opening has a larger cross-sectional area to allow the air to move into it at a slower rate. This is done to avoid the formation of any vortices that would hinder airflow.

Stage 2: As air enters the channel, the cross-section gets narrower to increase entering air velocity. This channel guides the air to the engine.

Stage 3: The air will enter the turbine casing, which houses a set of two engines directly connected to two long-chord fan blade turbines (with 22 blades per turbine). The turbines spin in opposite directions, compressing the air and thus, increasing the air velocity.

Stage 4: The air reached the area between the bottom of the turbine casing, which is cone-shaped at a 45^{o} incline, and the opening of the air outlet channel. The base guides the high-speed turbulent air into the outlet channel preventing the creation of vortices (eddies). At this stage, vortices would hinder air flow by creating uneven pressure areas, decreasing efficiency.

Air then passes through diffusers at the opening of the outlet channel. The diffusers rid the air stream of its swirling motion, which was caused by the turbines.

Stage 5: The air flows through the outlet air channel, which has a constant cross-sectional area to maintain the same airspeed until it reaches the aerofoils. The curvatures of the channels are smooth to eliminate the chances of vortices forming.

Stage 6: The moving air comes in contact with the stationary aerofoils, which are mounted at an angle of attack of 11^o, generating a lift force. The aerofoils are located at a point higher than the horizontal centre plane so as to guide the downward moving air out freely.

Stage 7: The air moves out through the air blades. They have a symmetrical aerofoil shape, so their rotation will change the direction of exiting airflow, thus controlling the direction of the craft.

4.2 Material Selection

Materials are the building blocks of our technological advancement. Most of engineering fields depend on materials: since they provide engineers with new limits to test their projects with. Materials are also vital when it comes to safety, and they are chosen according to their physical and chemical characteristics to avoid any catastrophic failures or disasters.

In this project, the materials were chosen according to many factors. Such factors include safety, strength, efficiency, reliability, durability, and ergonomics. All the chosen materials are similar in that they have a high strength to weight ratio. This allows for the lowest possible mass without risking safety. Additionally, the lower weight leads to decreased energy consumption, and thus, lower cost. The goal in regards to the mass is not to exceed one Tonnes, which is lighter than most vehicles.

One predicted outcome for this project is that this device can be used as an everyday transportation method, with flying hours reaching up to 5475 hours: an average of 45 minutes of flying per day for 20 years. This life span is more than that of most cars, which is up to 15 years or 300000 miles [10]. The materials must be strong and durable enough to withstand all the harsh environmental stresses, temperature gradients, storms, thunder, and humidity, and must be able to provide secure safe flights. The materials selected were based on the functionality of each component, and are discussed below:

Windshield:

The purpose of this component is to offer safety, proper visibility, shielding from harmful ultraviolet radiation, and protection from debris. The designated material was Plexiglas (Figure (5)), which offers a shatter-resistant alternative to glass. Additionally, a UV coat is added to protect from radiation. Plexiglas is not affected by moisture and offers very high visibility due to its capability of saving its optical abilities while heat formed [11]. Moreover, it has a high strength-to-weight ratio, and its tensile strength increases by about 80Mpa when the temperature drops to sub-zero values. However, this increases the brittleness [12], so plastic polymer lamination is added to improve shatter resistivity, making it suitable for all regions. (Appendix C)

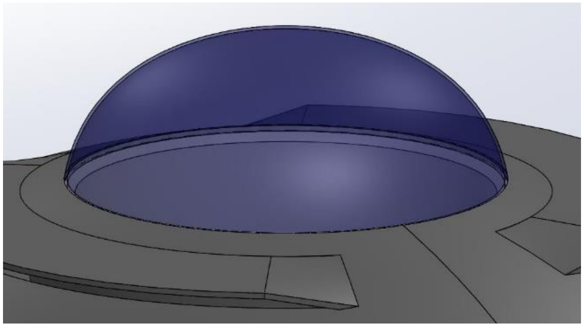


Figure (5): Windshield

Cockpit:

This component houses the individual controlling the device (Figure (6)). It must be strong, rigid, and able to offer protection in case of an accident. Additionally, it must withstand high impact forces and stresses before it fails. The material selected was Dry Carbon Fibre, which has similar properties to, and can create the same tensile strength as, Wet Carbon Fibre (Appendix C) [15]. In the manufacturing of the material, carbon fibre sheets are placed in a mould with just enough resin to bond all the fibres, producing minimal waste. Therefore, it has an overall weight of about 70% less than wet carbon fibre [14], [16].

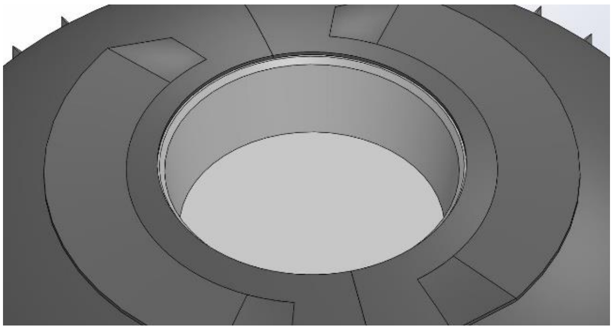


Figure (6): Cockpit

Turbine Casing:

This component houses the engines and long chord turbine fan blades (Figure (7)). It must be lightweight, strong, and able to contain any debris in the case of turbine failure. Dry Carbon fibre was chosen as it offers all these characteristics (as mentioned above). Moreover, the casing is located in the centre of the device, connected to all the other components, so it must be very rigid. Dry Carbon Fibre has a very rigid (stiff) structure, with very low deflection under stress [17], making it appropriate for this task.

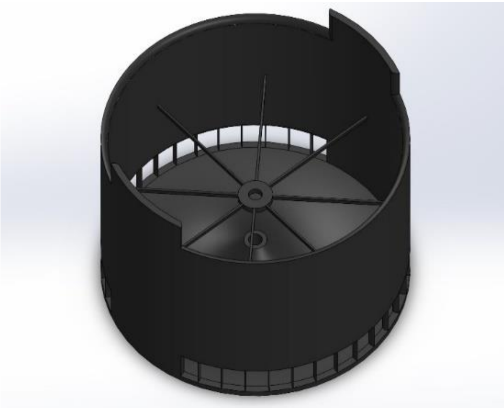


Figure (7): Turbine Casing

Inlet and Outlet Air paths:

The function of these components is simply to direct air to the compressor fan blades in the turbine casing, and out to the aerofoils. The design of this component has a specific geometry to allow proper airflow (Figures (8) & (9)). The optimal material chosen was Dry Carbon Fibre. Its method of production, moulding and curing, allows for the formation of proper dimensions. These components also offer a safety feature known as ‘crash zones’ (Technology used in Formula 1). The high rigidity and tensile strength of the Dry Carbon Fibre allows the components to absorb a lot of energy in the event of an impact, which can be life-saving.

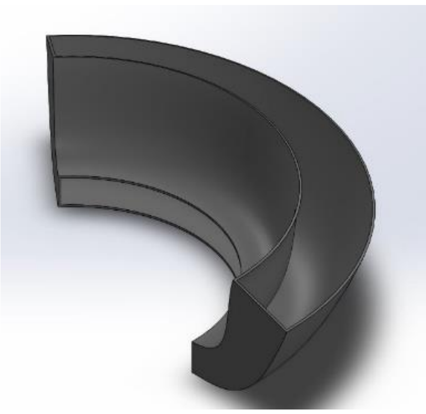


Figure (8): Air Inlet Path

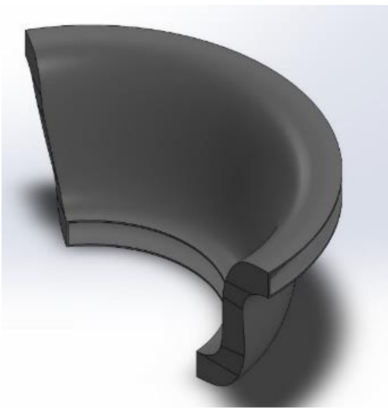


Figure (9): Air Outlet Path

Top and Bottom Body Parts:

These components are the outer shells of the device that shield the internal components, and offer extra protection for the driver. They include a bottom piece, which holds all the inner components, and two top halves that cover the inner components (Figures (10) & (11)). They are the largest parts of the device, and so, must be lightweight, in addition to being strong. Dry Carbon Fibre is chosen due to its high strength-to-weight ratio, high rigidity, and high tensile strength. Moreover, it is electrically conductive [17]: If the device encounters lightning when driven in stormy weather, the structure will not be damaged since electricity can pass through the outer shell, thus saving the driver and the inner electrical components.

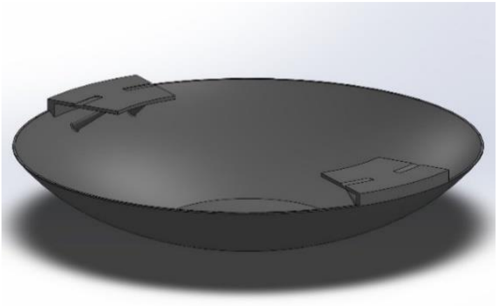


Figure (10): Bottom Body Part

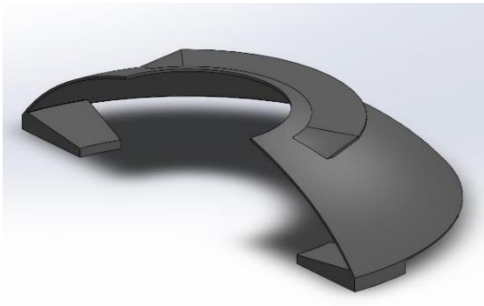


Figure (11): Top half Body Part

Turbines 1 & 2:

These components compress the air inside the device (Figure (12)). They rotate at very high velocities, and so, experience high centripetal loads. Therefore, the materials chosen for the turbines must withstand such forces. The turbines are made of two different materials for the fan hub and the fan blades.

The fan hub holds the blades in place, and so, must be strong and tough to avoid bending outwards when the turbine rotates at high speeds. The material chosen for the fan hub is Titanium alloy 'Ti6Al-4V.' It is suitable because of its high strength-to-weight ratio, low modulus of elasticity, high fracture toughness, and high fatigue resistance [18], [19], [20]. Moreover, it has good corrosion resistance [19], which is advantageous as the turbine is in constant contact with air.

The material chosen for the fan blades is carbon composite or Dry Carbon Fibre sheets. The fans are ducted to achieve higher efficiency, so there is a very small blade tip clearance. The high tensile strength [17] of Dry Carbon Fibre will prevent the blade from stretching during rotation, to eliminate the chance of the blades coming into contact with the inner wall of the turbine casing. Rotations can be considered load cycles: The Dry Carbon Fibre is a good fatigue resistor, allowing the blades to withstand a large number of stress cycles [17]. Additionally, the blades can be very thin (1cm) due to the material's high strength-to-weight ratio: this maximizes performance while withstanding stress.

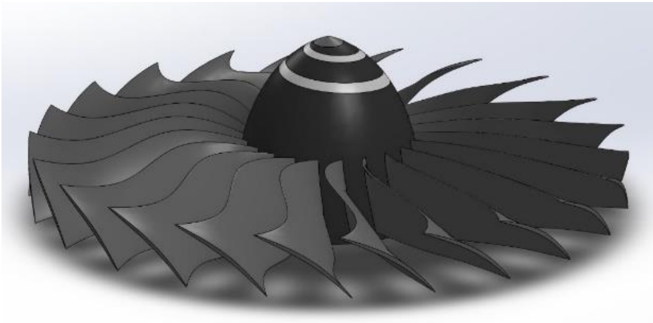


Figure (12): Long Chord Fan Blade Turbine

Air Blades:

These components steer the craft mid-flight by directing the air flow from the outlet channel (Figure (13)). Their angle of rotation determines how fast the craft turns. While they do not experience strong forces, airflow constantly passes through them, so their designated material must be able to withstand environmental impacts. The material chosen was aluminium, because it is corrosion resistant [21]: rain, snow, or humidity will have little to no impact on the material. Aluminium is also easy to manufacture and work with, which is ideal, due to the Air Blade's intricate design details, and it is considerably strong and lightweight.

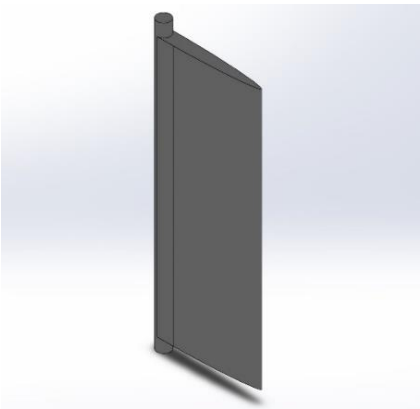


Figure (13): Air Blade

Aerofoil:

The aerofoils provide lift for the object to hover, and so, are the most important components in the device (Figure (15)). They face various types of load and load cycles. Additionally, since they are fixed at both ends, they must withstand bending, shear, and tensile forces. They are made of a combination of two materials to form a honeycomb sandwich structure, with an aluminium honeycomb core and a Wet Carbon Fibre surface layer (Figure (14)). Honeycomb sandwich structures are widely used in weight-sensitive applications due to their high flexural rigidity, high bending strength and lightweight structure [22]. It is usually utilized in the place of thicker materials when the strength of the object needs to be increased. It is formed by adhering two, thin, rigid, identical facing materials with a low-density honeycomb core of lower rigidity, stiffness, and strength than the facing material [22], [23]. The thicknesses of the facing material and the core are varied to achieve the highest strength-to-weight ratio [24].

The material chosen for the facing material was Wet Carbon Fibre, due to its high strength-to-weight ratio, high rigidity, and good fatigue resistance [17]. The production method of WCF is similar to that of DCF, but it uses excess epoxy resin to produce a clear, seamless finish. Although this causes increased weight [16], the seamless finish is crucial, as the surface finish on an aerofoil determines how well the wing performs. The flow of fluid around an object creates a boundary layer, which tends to stick to the wing's surface (Coanda effect), moving along the surface and creating lift. The smoother the surface, the higher the tendency of the boundary layer to stick. If the boundary layer detaches, the aerofoil will stall.

The core structure requires a low-density material, with a considerably strong structure. The material chosen was aluminium, which has a high strength-to-weight ratio, having a great fatigue resistance [25], and high shear modulus. Aluminium has one-third the density of steal, which makes it an ideal lightweight material for the core structure. Moreover, it can be easily manufactures and processed to attain the core's geometry, and can adhere easily to resin [26].

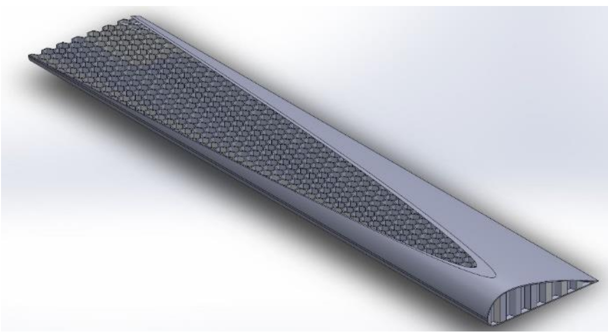


Figure (14): An Aerofoil Honeycomb Structure

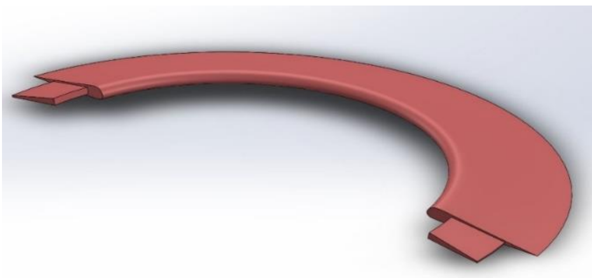


Figure (15): Aerofoil

4.3 Solar Cells

Performance: Monocrystalline solar cells have the highest efficiency to weight ratio, and perform well under all weather conditions. They were chosen due to their superior performance. A common misconception about solar panels is that they require hot weather to function efficiently; however, since they work by absorbing photons and turning them into useful electrical energy [34], they work just as well in cold temperature [35]. As long as there is light, there is electricity. (Refer to Appendix D for alternative types of solar cells)

When installing custom-made monocrystalline solar cells [36] onto the device, the cells will be placed at an angle ranging between 15-50^o. The advantage of this is that rain will slide down the cells, rinsing them of dust and debris, increasing their efficiency. Additionally, snow will slide off as soon as it touches the cell, due to the higher temperature of the cell when absorbing photons.

Temperature and efficiency: Temperature is a vital factor that affects energy output of a solar cell. The more sunshine present, the higher the energy output; however, the increased temperature of the cells counteracts the benefits of the sun [37]. Manufacturers provide a temperature coefficient for each type of solar cell, which shows the percentage decrease in power output for each degree increased over room temperature (25^{o}C). Thus, increased temperature can cause a decrease in power output up to 10% [37].

Cold sunny environments offer the ideal conditions for solar cells [38], and can be replicated by cooling the solar cells as they absorb photons. The device in this project flies at relatively low altitudes (up to 2000 feet or about 610m), and temperatures there are relatively low, as shown in Table (1) below:

Table (1): U.S. Standard Atmosphere Hight and Temperatures [39]

Altitude,	Pressure,		Temperature,	
feet	hPa	inches	°C	°F
0	1013.2	29.92	15.0	59.0
1,000	977.2	28.86	13.0	55.4
2,000	942.1	27.82	11.0	51.9
3,000	908.1	26.82	9.0	48.3
4,000	875.1	25.84	7.1	44.7

Table (1) shows that the temperatures at 1000ft (304.8m) and 2000ft (609.6m) are 13^{o}C and 11^{o}C respectively, which are well below room temperature. So, the monocrystalline cells will perform at maximum efficiency.

5. Experiment Work/Analytical Investigation

5.1 Density Calculations

The densities of the chosen material are listed in the table below:

Table (2): Densities of materials [13]; [14]; [16]; [21]; [40]; [41]

Part		Material	Density	
			in gcm^{-3}	in kgm^{-3}
Wind Shield		Plexiglass	1.18	1180.00
Cockpit		Dry Carbon Fibre	0.48	480.00
Turbine Casing		Dry Carbon Fibre	0.48	480.00
Air Inlet Path		Dry Carbon Fibre	0.48	480.00
Air Outlet Path		Dry Carbon Fibre	0.48	480.00
Turbine 1	Fan Hub	Ti6Al-4V	4.43	4430.00
	Fan Blades	Dry Carbon Fibre	0.48	480.00
Turbine 2	Fan Hub	Ti6Al-4V	4.43	4430.00
	Fan Blades	Dry Carbon Fibre	0.48	480.00
Bottom Body Half		Dry Carbon Fibre	0.48	480.00
Top Body Half		Dry Carbon Fibre	0.48	480.00
Air Blades		Aluminium	2.70	2700.00
Aerofoil	Surface layer	Wet Carbon Fibre	1.60	1600.00
	Core	Aluminium	2.70	2700.00

- Calculation for relative density of the honeycomb sandwich core:

The volume of the unique honeycomb core structure is mostly filled with air voids (Figure (16)), so its relative density value will be calculated bellow. The following equation is the relative density equation:

$$\rho_{ca} = \frac{8d.tc}{A} \cdot \rho_c \qquad \text{Eq. (1)}$$

'A' is the virtual area of a unit honeycomb core at the cross-section parallel to the surface skin layer (Figure (17)):

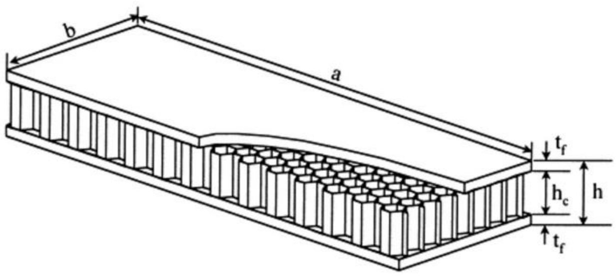
$$A = L.W \qquad \text{Eq. (2)}$$

Where,

$$L = 2d\,(1 + \mathrm{Cos}(\alpha/2)) \qquad \text{Eq. (3)}$$

$$W = 2\,(t_c + d.\mathrm{Sin}\,(\alpha/2)) \qquad \text{Eq. (4)}$$

Alpha ('α') will be taken as $\frac{2\pi}{3}$ or 120^o due to the hexagonal honeycomb core.



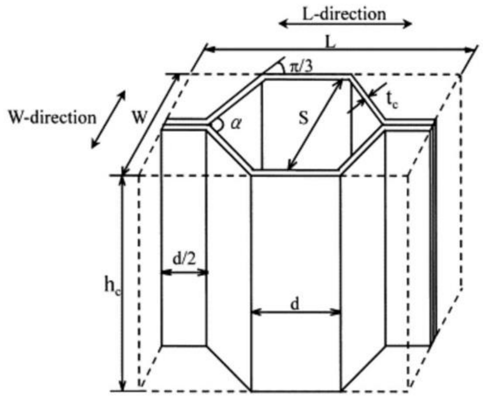


Figure (16): Honeycomb sandwich panel [23]   *Figure (17):* Honeycomb core unit [23]

The values are identified as follows:

ρ_c = 2700kgm^{-3} t_c = 1×10^{-3}m   d = 7×10^{-3}m   α = 120^o

They are inserted into equations (3) & (4) to calculate virtual length and width:

$$L = 2 \times 7\times10^{-3} \times (1 + \text{Cos}\ (120/2)) = 0.021\text{m}$$

$$W = 2\ (1\times10^{-3} + (7\times10^{-3}).\text{Sin}\ (120/2)) = 0.014\text{m}$$

Hence, using equation (2), the virtual area is:

$$A = 0.021 \times 0.014 = 2.966\times10^{-4}\text{m}^2$$

By using equation (1), the relative density is:

$$\rho_{ca} = \frac{8\times(7\times10^{-3})\times(1\times10^{-3})}{2.966\times10^{-4}} \times 2700 = \underline{509.76\text{kgm}^{-3}}$$

5.2 Mass Calculations

5.2.1 Mass of the Components

The mass can be obtained by multiplying the quantity, volume and density of the material. All the volume values were obtained by using SolidWorks in millimetres then transformed to metres, for increased accuracy as shown in the table below:

Table (3): Mass of Components

Part		Quantity	Volume (m^3)	Density (kgm^{-3})	Mass (kg)
Wind Shield		1	27864880.42×10^{-9}	1180.00	32.88
Cockpit		1	98458482.67×10^{-9}	480.00	47.26
Turbine Casing		1	187189198.05×10^{-9}	480.00	89.85
Air Inlet Path		2	32270619.68×10^{-9}	480.00	30.98
Air Outlet Path		2	54764366.07×10^{-9}	480.00	52.57
Turbine 1	Fan Hub	1	4056258.74×10^{-9}	4430.00	24.04
	Fan Blades		12656957.11×10^{-9}	480.00	
Turbine 2	Fan Hub	1	3311207.17×10^{-9}	4430.00	20.74
	Fan Blades		12655700.99×10^{-9}	480.00	
Bottom Body Half		1	344953582.20×10^{-9}	480.00	165.58
Top Body Half		2	197861391.38×10^{-9}	480.00	189.95
Air Blades		34	34139.40×10^{-9}	2700.00	3.13

5.2.2 Mass of the Aerofoil

By theoretical analysis, if the honeycomb core mass satisfies about 50 – 66.7% of the total mass of the aerofoil, the honeycomb sandwich structure will have optimal flexural rigidity and bending moment [22]. Since the aerofoil cross-section has a varying thickness, the average thickness was calculated, treating the aerofoil structure as a rectangular honeycomb sandwich panel, to ease the calculations. This was done by drawing 23 parallel lines that are all perpendicular to the wing's chord line with an equal distance of 29.71mm between each two lines, as shown in Figure (18):

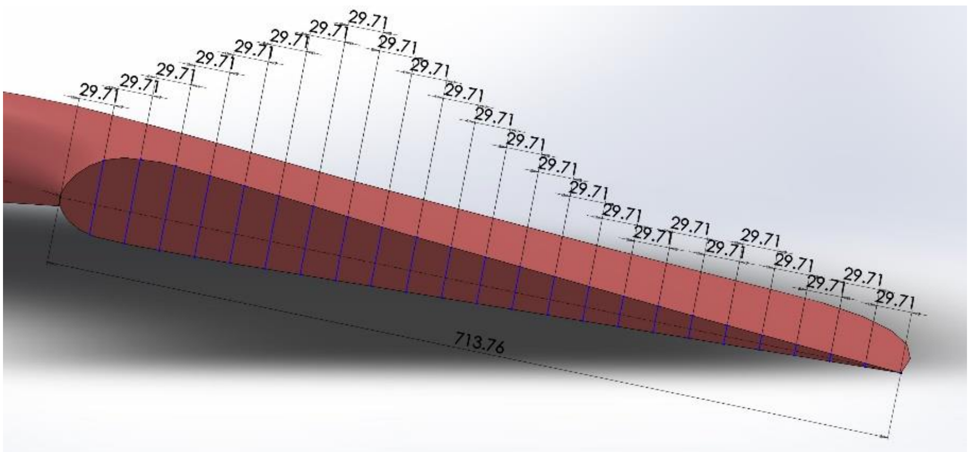


Figure (18): Aerofoil Cross-Section

Subsequently, the length of each line was calculated in millimetres, and shown in Table (4) below. Line number 1 is the first line on the left in Figure (18).

Table (4): Length of lines drawn on the Aerofoil's Cross-Section:

Line Number	1	2	3	4	5	6
Length	63.21mm	72.20mm	71.92mm	69.07mm	65.66mm	61.94mm
Line Number	7	8	9	10	11	12
Length	58.07mm	54.13mm	50.18mm	46.31mm	42.58mm	39.04mm
Line Number	13	14	15	16	17	18
Length	36.49mm	32.33mm	29.06mm	25.77mm	22.42mm	19.02mm
Line Number	19	20	21	22	23	-
Length	15.62mm	12.27mm	8.99mm	5.83mm	2.84mm	-

By adding the length of all the lines and divide them by 23, the average thickness (including both facing layers and the honeycomb core) was found to be 39.35mm. However, the honeycomb sandwich structure has varying core and skin thickness ratios, which are chosen depending on the properties needed. They are usually chosen to obtain the highest strength-to-weight ratio. Figure (19) shows skin and core thickness ratio that results in the best relative stiffness, relative strength, and flexural rigidity: (Note: Figure (19) was redrawn for illustration purposes)

Figure (19): Honeycomb Sandwich Skin Core Thickness Ratio [42]

The thickness of both the facing material and the core were obtained by adding the thickness ratios and equating them to the average height, as shown in equation (5):

$$\frac{T}{2} + 4T + \frac{T}{2} = 39.35 \qquad \text{Eq. (5)}$$

Hence, T = 7.87

The surface layer thickness (t_f) = 3.935mm

The core thickness (h_c) = 31.48mm

To calculate the mass of the facing material, an offset line of thickness 3.935mm was drawn on the aerofoil's cross-section by using SolidWorks, and was emptied from the inside to show the facing material only (Figure (20)); the volume of the facing material was then found.

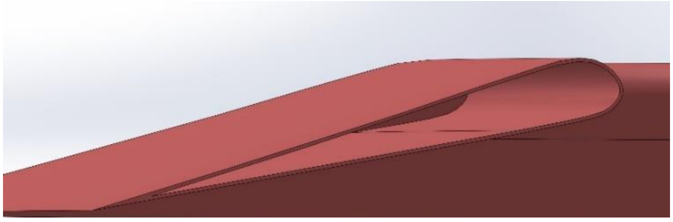


Figure (20): Aerofoil Facing Material

By using SolidWorks, the volume was 22420124.56×10^{-9}m, and by multiplying this value by the density, the mass was: $m_f = 1600 \times 22420124.56\times10^{-9} = 35.72$kg

The honeycomb core also has an aerofoil profile with a variable thickness as illustrated in Figure (14). Since the average height and the thickness ratio of the skin and the core were calculated as shown in Figures (18) & (19) and equation (5), the core thickness can be taken as 31.48mm. The mass of the honeycomb core can be found by the following equation:

$$m_c = a.b.h_c.\rho_{ca} \qquad \text{Eq. (6)}$$

ρ_{ca} was found using equations (1) to (4) to be 509.76kgm^{-3}; h_c equals 31.48mm; 'a' and 'b' can be found by using SolidWorks as shown in Figure (21). To have a rough estimate, the inner surface area (coloured green) is the total surface area, which equals the honeycomb's core surface area, and is about 5302479.73×10^{-6}m^2. The area is then divided by two to have only to top area, since the core was assumed to be a rectangle planked shaped core. So, the surface area will be: $a.b = 2651239.87\times10^{-6}$m^2

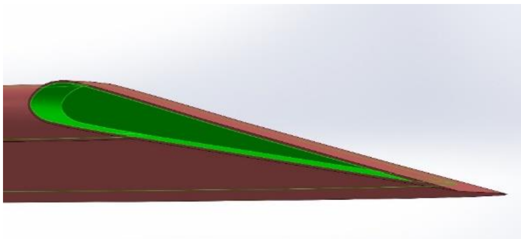


Figure (21): Inner Surface Area

By filling in these values in equation (6), the mass of the core will be:

$$m_c = (2651239.87\times10^{-6}) \times (31.48\times10^{-3}) \times (509.76) = 42.55\text{kg}$$

Henceforth, the total mass of the aerofoil is:

$$m = 35.72 + 42.55 = 78.27\text{kg}$$

And the total mass for both aerofoils equals to: 156.54kg.

Thus, the honeycomb sandwich aerofoil structure has the optimal flexural rigidity and bending moment. This was shown by taking the mass of the honeycomb core as a percentage of the mass of the total honeycomb sandwich structure: (42.55 ÷ 78.27) × 100 = 54.36%. This satisfies the theoretical analysis mentioned before.

5.2.3 Number and Mass of the Solar Cells

Number: This was done by calculating the surface area of the top half cover shell, and multiplying this value by 2 to get the surface area of both sides, then dividing it by the area of one solar cell. By using SolidWorks, the surface area was calculated and is shown in Figure (22) below:

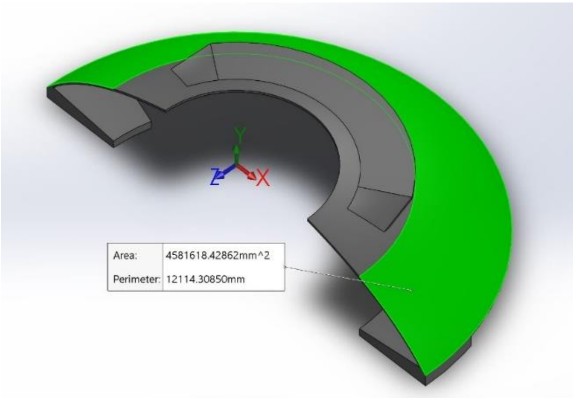


Figure (22): Surface Area of the Top Half Cover Shell

As shown in the figure above, the surface area is equal to 4581618.43mm^2. The surface area for both halves is equal to 9163236.86mm^2. The area of one solar cell is 24336mm^2 (Appendix E); the number of solar cells that can fit is:

9163236.86 ÷ 24336 = 376.53 ➔ <u>376 Solar Cells</u>

Mass: Research shows that a square metre of solar cells weigh 10-20kg [45]. A square metre fits about 41 ‘156×156mm’ solar cells. Taking the average weight of a square metre of solar cells to be 15kg:

15kg ÷ 41cells = 0.365kg per solar cell

The total weight of the solar cells will be:

376 × 0.365 = 137.62kg

To limit the overall weight, the total mass of solar cells was restricted to 100kg, reducing the number of cells to 270, weighing a total of <u>98.55kg</u>.

5.2.4 Mass of the Remaining Components

The remaining components include the 2 engines and the batteries used to power the engine. After doing some research, their collective masses can be assumed to equal 100kg. Additionally, the average weight of the driver is 80kg.

5.2.5 Total Mass (including the parachute system)

The total mass of all the components, aerofoils, engines, batteries, and the driver equals to: 1002.52kg. This does not satisfy the mass goal, since the total mass is just above one Tonne.

As a safety measure, a heavy-duty parachute would be installed to guarantee that the device would land safely on the ground. A research study suggests that for every 0.5kg of material, 0.1 square metre of surface area of the parachute is needed to bring the load down safely [46]. Since the calculated total mass is 1002.52kg, the amount of parachute in square metres is:

$\frac{1002.52}{0.5} \times 0.1 = 200.5$ square metres of parachute.

There will be two parachute systems, each one accounting for a surface area of $100.25m^2$. The parachutes in use have a hemisphere shape, and by using equations (7), the diameter of a 100.25 square metre surface area parachute can be known:

$$2 \times \pi \times r^2 = \text{Surface Area of a hemi-sphere} \qquad \text{Eq. (7)}$$

Thus;

$$2 \times \pi \times r^2 = 100.25m^2$$

So, the radius will equal to about 4m (8m diameter) for each parachute. As this study suggested [47], a circular modified ring-sail parachute of a diameter of 16.6m, which was used in Planetary Entry Parachute Program (to slow space-crafts down when entering the atmosphere) weighs 32.8kg. An estimate can be calculated to find the approximate mass of the parachutes used. By cross multiplication, the mass is:

$\frac{32.8 \times 8}{16.6} = 15.81$kg

Since there are two parachutes, the total mass of the parachutes is 31.61kg, thus the total mass of the device will account for 1034.13kg.

5.3 Lift Force Calculations

In order to fly a craft, the lift force generated must at least equal the weight of the craft to just lift off of the ground. In this project, the total mass was calculated to be 1034.13kg, and by multiplying this value by the gravitational acceleration ($9.81ms^{-2}$); the total weight will be 10144.82N. Accordingly, the minimum lift force required will be 10144.82N. Subsequently, by using the lift equation, the minimum wind speed required (created by the turbines) to create the lift force needed will be calculated as shown below:

$$L_i = Cl \times \frac{r \times v^2}{2} \times A_w \qquad \text{Eq. (8)}$$

'Cl' is the lift coefficient:

$$Cl = 2\pi\theta \qquad \text{Eq. (9)}$$

Theta 'θ' is the angle of attack, chosen to be 11^o (0.192^{rad}). The lift coefficient will equal to:

$Cl = 2\times\pi\times0.192 = 1.206$ (Refer to Appendix F, which explains the chosen angle)

The area 'A_W' of the aerofoil was calculated using SolidWorks as shown in Figure (23) (coloured blue). It equals to $3008755.97\times10^{-6}m^2$. The device includes 2 aerofoils, so the total area will be: $2 \times 3008755.97\times10^{-6} = 6017511.94\times10^{-6}m^2$. The air density was found to be $1.225kgm^{-3}$, so by using equation (8), the minimum wind velocity required can be found below:

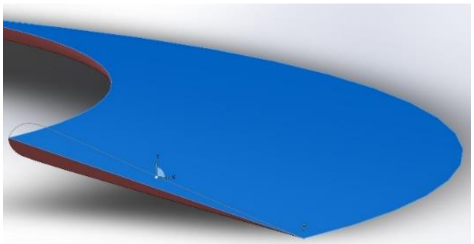


Figure (23): Area of Aerofoil

$$10144.82 = 1.206 \times \frac{1.225 \times v^2}{2} \times 2 \times 3008755.97\times10^{-6}$$

$$v = \underline{47.77ms^{-1}} = \underline{171.97kmh^{-1}}$$

This value is much lower than the average aircraft take-off velocity, which is about $73ms^{-1}$ ($262.8kmh^{-1}$) [52]. Due to the air having an incredibly low mass, it is much easier to accelerate air than heavy aircrafts to high velocities, as per Newton's second law. Thus, the energy consumption is considerably lower. The craft will accelerate upwards for any wind velocities generated by the turbines faster than $47.77ms^{-1}$.

6. Description of the Final Concept Product

6.1 Energy Losses

The project was designed to increase energy efficiency. The design shape and air being the fluid lifting the object minimises the energy and the head losses. This will reduce costs and increase the life span of the electric motors and the batteries. Because the aerofoils have an optimal angle of attack (11^{o}), the air velocity required to lift the object is lowered, so there is less load acting on the engine and less battery consumption, thus preserving the battery and its life span.

When considering head loss, a proper air duct design is crucial to minimising energy losses. Therefore, the inlet and the outlet air ducts have smooth bends and transitions as shown in Figures (8) and (9). This allows air to flow without creating concentrated pressure areas due to vortices, which hinders the flow. Moreover, the opening of the inlet air duct has a wider cross-section than the rest of the component. This allows the air to go inside the device at a considerably lower velocity, thus reducing the risk of formation of vortices in the inlet duct. Afterwards, the cross-section becomes narrower to increase the wind speed reaching the engines.

The head loss depends on the fluid's velocity, viscosity, surface roughness, speed variation due to changes in the cross-section of the ducts or pipes, and change in the fluid's direction. Air has a very low density and viscosity, such that, when air flows through ducts, the viscous forces are very low, so they cause very little energy loss. Henceforth, the shear forces in the fluid can, ideally, be considered negligible.

Another important factor that affects efficiency and energy is the speed of air, which determines if the flow is laminar or turbulent. Turbulent flow reduces friction forces, because simply the fluid has no time to shear. As previously shown, the air velocity at lift-off is 47.77ms^{-1}. This is turbulent flow, as shown by equation (10), which calculates Reynolds number:

$$Re = \frac{rvL}{\mu} \qquad \text{Eq. (10)}$$

By taking the air density to be 1.225kgm^{-3}, the velocity to be 47.77ms^{-1}, the dynamic viscosity at about 15^{o}C (The average temperature between the altitudes 0 to 2000 feet as shown in Table (1)) to be 1.78×10^{-5}kgm^{-1}s^{-1}, and the average duct length to be 3m (calculated by using

SolidWorks: the length starts from the beginning of the inlet air duct and ends just before reaching the aerofoil), Reynolds number will equal to:

$$Re = \frac{1.225 \times 47.77 \times 3}{1.78 \times 10^{-5}} = 9862626.4$$

This value is much greater than 4000, showing that the flow will always be turbulent. The faster the air, the more turbulent it gets, the lower the resistive forces are. Moreover, the use of Dry Carbon Fibre for the air inlet and outlet ducts, and the turbine casing, is advantageous because it has a considerably rough surface. The lack of excess resin this leaves a portion of the fibres exposed, roughening the surface. The rough surface induces the flow to become more turbulent, even at lower air velocities. Thus, the boundary layer will not attach to the surface, further reducing the already-low shear forces due to viscosity, and reducing the overall resistance to airflow.

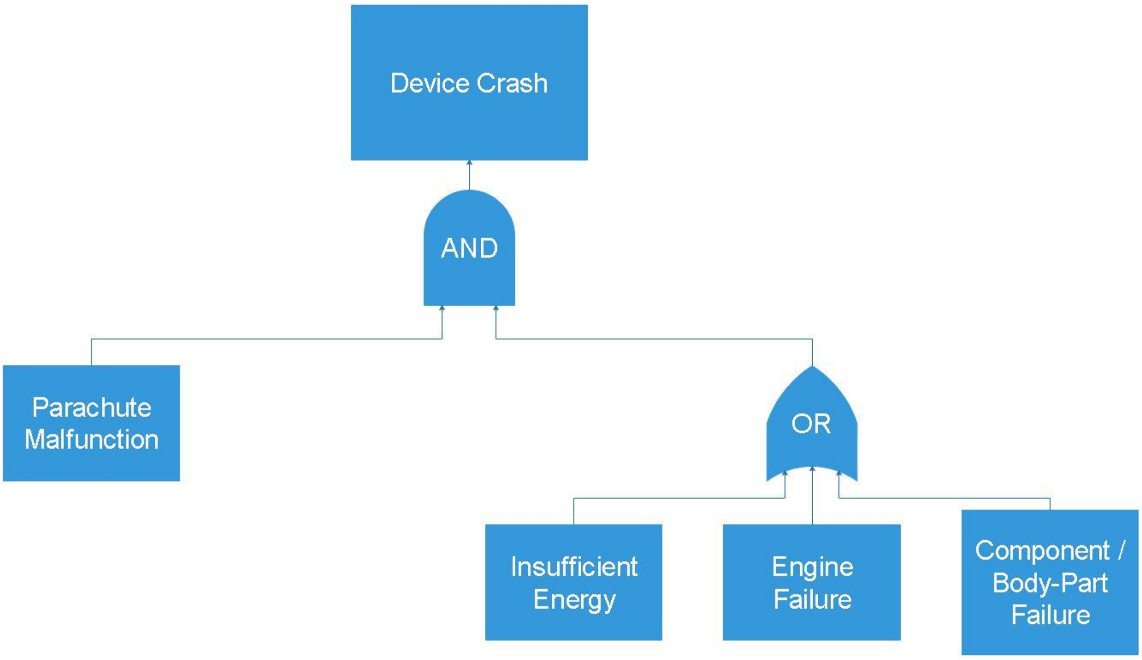
Upon analysis to design structure, it appeared to include an area that produces high-energy losses as shown in Figure (24):

Figure (24): Outlet Air Duct Opening

The area circled in orange is an edge, so the air exiting the turbine casing at high pressure and velocity will experience vortices, thus hindering airflow. This issue can be overcome by simply extending the upper lip to widen the opening to the outlet duct.

6.2 Fault Tree Analysis (FTA)

No matter how much a design is perfected, there is always some probability of a system failure or accident. An extensive risk analysis and assessment was made to avoid such accidents or errors. An FTA will be conducted on failures causing an in-flight device crash, as that would produce the most dangerous (and possibly fatal) outcome. Other failures that involve the device while it is still on the ground are not as dangerous. (Note: Due to insufficient space, please refer to Appendix G for the complete FTA chart)



The above chart shows the main four potential problems lead to the undesired outcome. In reference to Appendix G, each of the four main issues, Parachute Malfunction, Insufficient Energy, Engine Failure, and Component/Body-Part Failure, branch out to show more problems, until the root cause is reached. If a parachute malfunction occurred alone, the device is safe. If one, or a combination of two, or all three of the remaining three main issues occurred, the device would still not crash. The problem occurs when there is a parachute malfunction, in addition to one or more of the other three issues. The safety precautions taken to avoid such problems from happening are discussed in the following section.

7. Discussion and Conclusion

7.1 Safety Measures and Project Design Advantages

This novel idea aims to offer a new method of transportation that is safe, energy efficient, and environmentally friendly.

7.1.1 Safety Measures

To examine the effectiveness of the safety measures built into the device, several hypothetical scenarios were applied. The first measure is addition of an autopilot and safety integrated system, which is safer than pilots or craft users [53]. It utilizes a powerful computer built in the device to perform several tasks. First, it uses a GPS system to analyse the safest and shortest route to reach the destination. During flight, it measures wind speeds and adjusts the craft accordingly. Moreover, there is a manual controlling system in case of a system malfunction.

In case of lightning, the outer shell and most inner components are made of electrically conductive Dry Carbon Fibre. Thus, lightning can pass through the device without electrocuting the driver or damaging any inner electrical components. In the case of any component failure, an automatic parachute deployment system, which continuously tracks the conditions of the components, will take over. It will deploy two large parachutes sideways with high pressure to avoid the parachutes colliding or tangling together. The parachutes will allow the device and driver to land safely.

If the device does crash, there is a high probability for the driver to escape with minor injuries. The crash zones will absorb most of the energy in the crash. Moreover, the cockpit contains a surround air-bag system, which would inflate automatically. Finally, seatbelts are available to hold the person in place.

If the device tilted upside down, the laminated plexiglass windshield can prevent the driver from suffering injuries. The hemisphere shape of the windshield is such that its geometry requires incredible powerful forces to collapse onto itself. This is because any [compression] force applied to the windshield will be distributed along the whole structure. Moreover, the lack of sharp corners eliminates point stress failures.

7.1.2 Design Advantages

This concept design has the potential to be advantageous to everyday transport methods. It is new, safe, compact, energy efficient, and highly ergonomic. Thus far, the design is suitable for only one passenger; however, it can be redesigned to fit more in the future. Alternatively, it can be used for transporting cargo, reallocating and positioning products in a field, hospital and delivery services, and much more. The breadth of possibilities is due to the design and its adaptability. The advantages of will be discussed in order of the aerofoils, the engine, the fan blades and turbines, the batteries and the device as a whole.

Aeroplanes deploy flaps to increase their lift force at lower velocities, causing a significant loss of energy and gain of drag forces during the flap deployment, due to the changing geometry of the wing. This occurs in mere seconds as the boundary layer detaches then reattaches to the wing. Simply, it stalls for a short moment. Utilizing stationary aerofoils with fixed geometry avoids this drawback. As shown in equation (8), faster wind speed leads to greater lift force: this is how the device gains altitude. Moreover, the aerofoils are thinner because they don't contain hydraulic components to deploy flaps or air breaks, thus increasing wing efficiency and decreasing its weight.

The engine contains two electric motors that are directly connected to the fan blades. First, this is environmentally friendly due to zero carbon emissions. Moreover, electric motors induce low noise pollution: 8 to 20dBA for a 1MW motor, which powers a regional jet-size aircraft [54]. The electric motor utilized in the design has similar specifications. Road cars are now limited to 64-74dBA [55], and aircrafts to 58.3-89.7dBA [56]; this proves that the device emits lower noise than the transportation methods used today. The fan blades may produce some aerodynamic noise; however, this is limited due to the low air velocity required at take-off, and thus, low engine rpm. Henceforth, the craft will be suitable in residential areas without producing harmful noise levels or provoking noise complaints. Finally, the direct connection between the engine and turbines without transmission reduces weight, friction, and sound levels.

The fan blades are ducted long chord fan blades, which offer high airflow rates with fewer blades than the conventional clappered fan blades, due to greater blade area. There are 22 blades per fan, each blade with a surface area of $0.17m^2$ and thickness of 0.01m. This leads to lower weight, while maintaining high efficiency and performance. The set of two turbines spinning in opposite directions to eliminates residual rotational velocities that would affect the device. Additionally, they are centred in the middle of the device and act as a gyro, opposing tilting and increasing the balance and stability of the device. Finally, the fans are ducted with a blade tip clearance of about 0.4% of the fan’s diameter to avoid blade tip vortices, thus increasing efficiency while further decreasing aerodynamic noise.

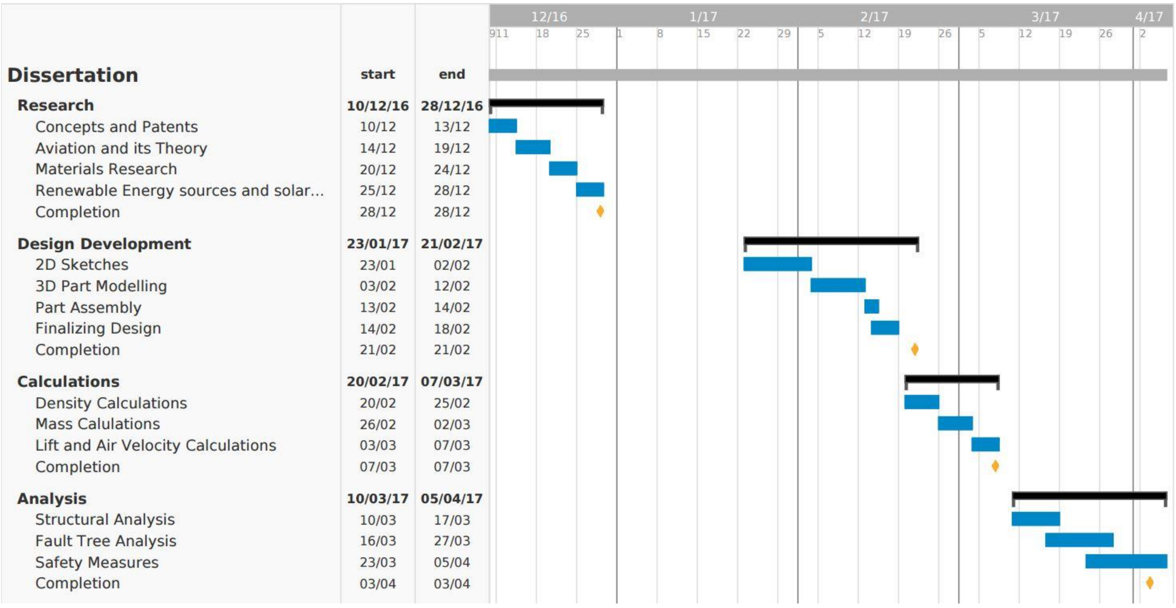
While most transportation methods use forms of heat exchangers to dissipate heat and keep internal components cool, this design does not require any because it acts as one itself. The same air that lifts the device also cools the engines and batteries. This eliminates the need for a radiator, thus reducing weight. Moreover, the design is advantageous because battery life span and performance increases when working under relatively cool conditions.

The device takes off vertically, so there a runway is not needed; it requires a 5x5 metre platform, which is affordable and suitable for residential areas. Additionally, since it does not fly to high altitudes, it is not a pressure-tight vessel, reducing weight, cost and energy.

The design has potential to be safer and more stable than an aircraft. It is safer because of the intensive backup computerized safety systems, in addition to the automatic parachute deployment system, besides, the manual deployment system, which adds to the safety factor. It is more stable due to the circular lift force generated. For example: It is more stable to hold a tray full of glasses from both sides than just from the middle. Similarly, the lift force moves along the aerofoils close to the outer edges, making the craft more stable.

This project provides a concept design that is safe, green, cost effective, and energy efficient. It is a novel idea that is malleable in nature, being suitable as a vehicle for personal use, a commercial vehicle, and a cargo transport mechanism, among many other applications. In a time in which the world is fighting to be more environmentally friendly and sustainable, this project proposes a greener transport method.

8. Project Management



The above Gantt Chart shows an approximation of the project's lifetime: by dividing it properly throughout the year. It was divided into four sections, the first starting in December. Research was completed as early as possible to give extra time for the examination period. The second section started on the 23^{rd} of January, as soon as the exams ended. The project ended on the 5^{th} of April using the remaining time to edit and finalise the project.

Since the project was based on a novel idea, it required a lot of research to guarantee the possibility of this project to be feasible. One of the bases that built this project was the consideration of the environmental impacts in the sense of future technology is becoming more environmental friendly. When building this project, the processes included to produce the components have zero carbon emotions, even the project itself is powered electrically, and this concludes that it has zero carbon footprint. A solid reason of testing the project's concept is to provide an alternative way of aviation, which is safer, more energy efficient, and hazard free; and can be operated by individuals. When built, a proper inspection should take place regularly to avoid any accidents as shown in Appendix G.

During the research period, some of the taught modules helped in producing a proper analysis allowing the concept to come to life. CAD helped to construct the first 3D model with the practical dimensions, Thermo-Fluids helped in the theoretical analysis and calculations to redefine the final model measurements with the proper aerodynamic properties. Finally, the module Materials aided in understanding the characteristics of the materials, which gave the author the enough knowledge to choose the proper materials to obtain high strength-to-Wight ratio, without jeopardizing the safety features.

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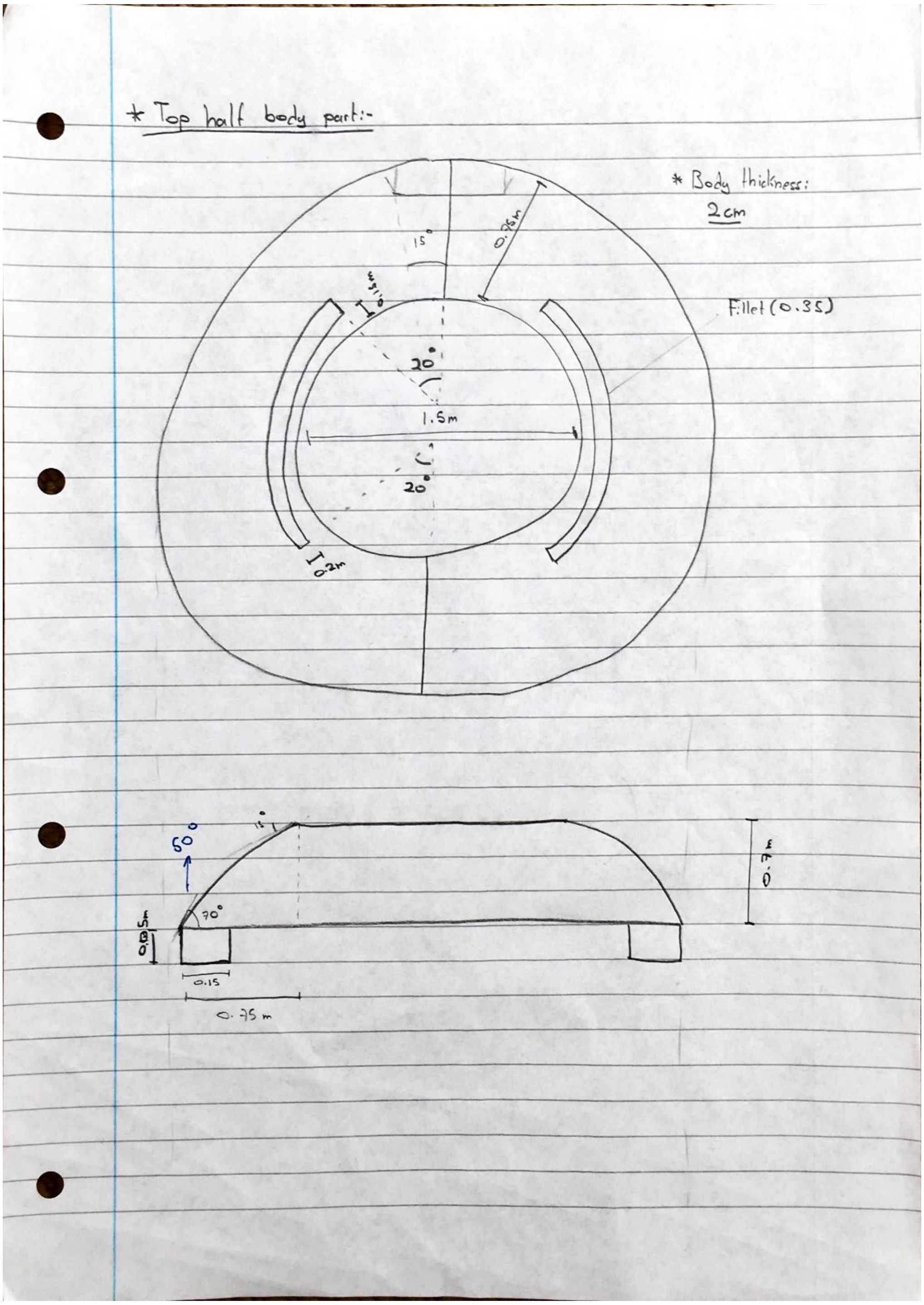
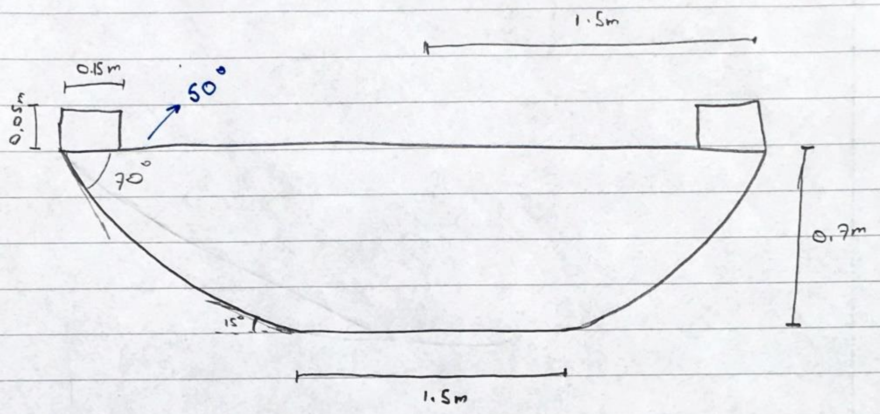
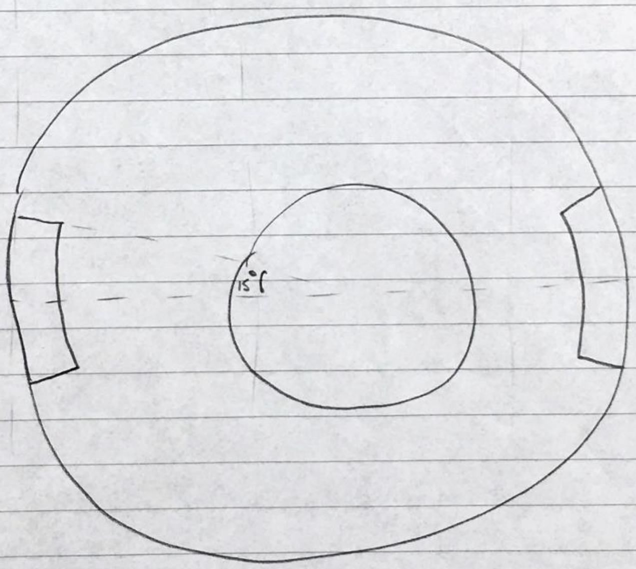
10. Appendices:

Appendix A: 2D Preliminary Design Sketches

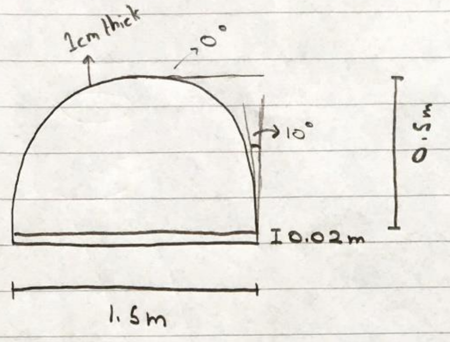


* Bottom half body part:-

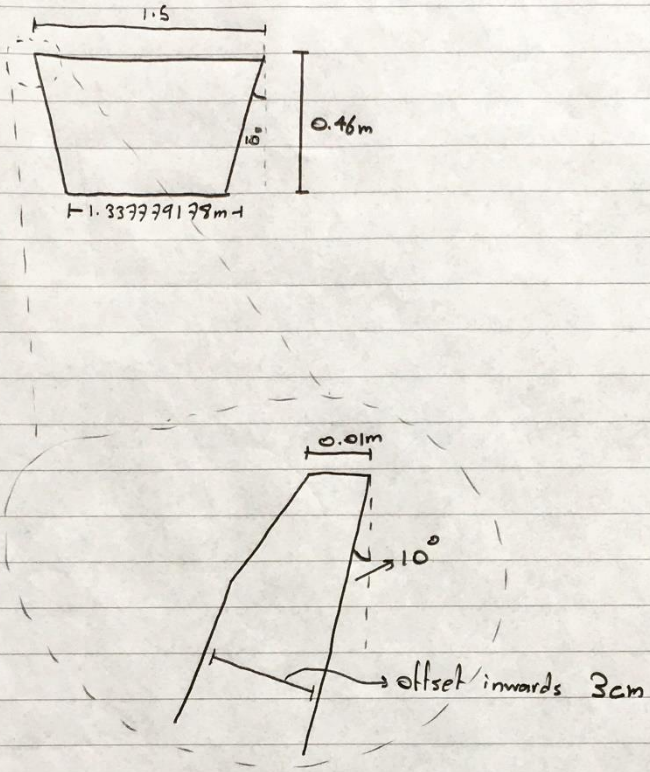




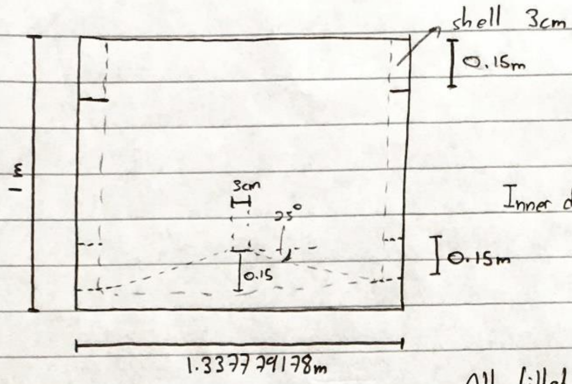
* Wind sheild:-



* Cockpit:



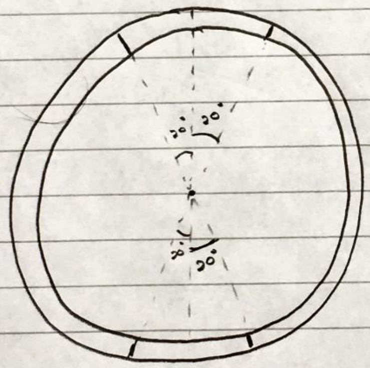
* Turbine casing:-



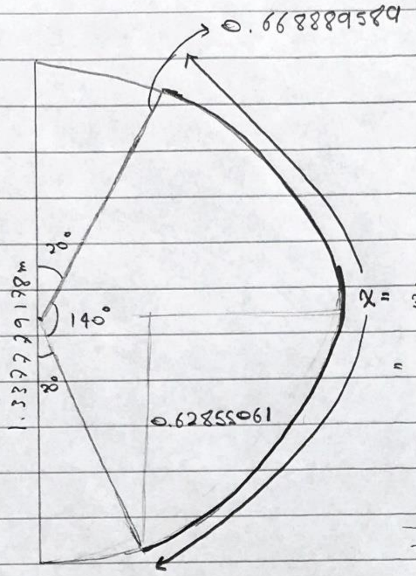
Inner diameter: 1.277779178m

All fillet used: 3cm

- Top grooves:



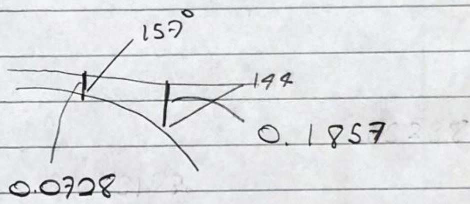
* Inlet Air path:

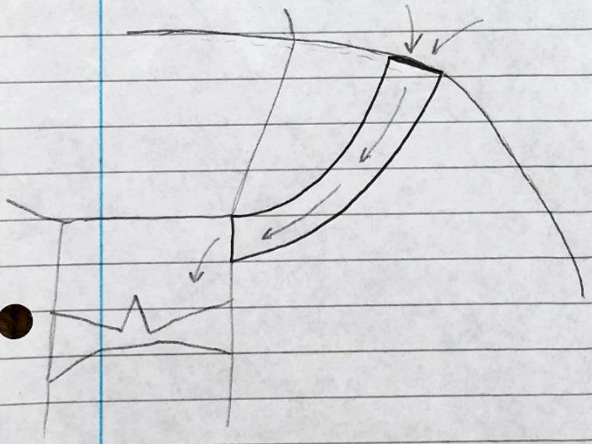


*2cm thick

$$x = \frac{n^\circ}{360} \times 2\pi r$$

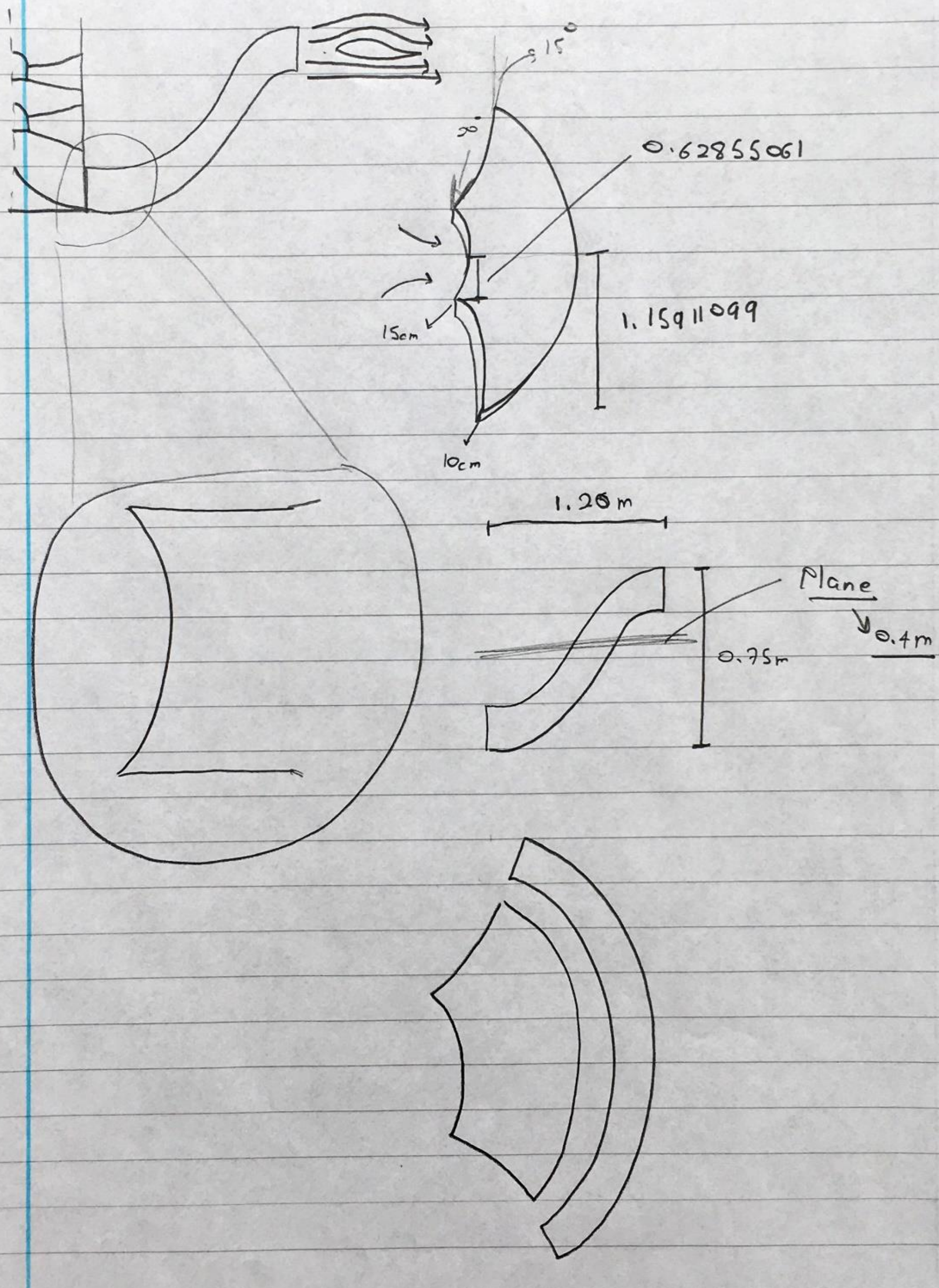
$$= \frac{140}{360} \times 2 \times \pi \times 0.668\ldots = 1.634405592\,m$$





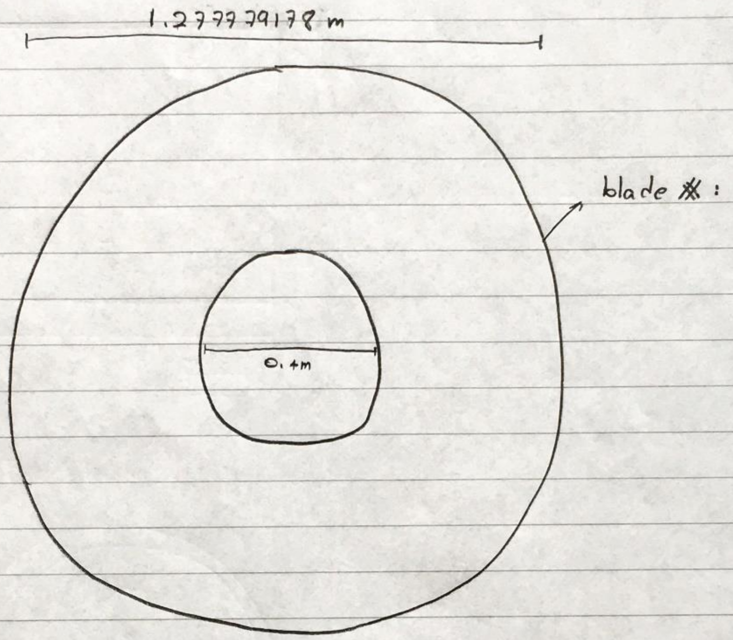
*Air out let path:

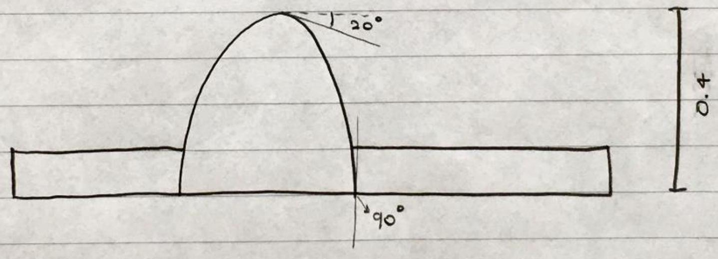
Shell 1cm



*Turbine :-

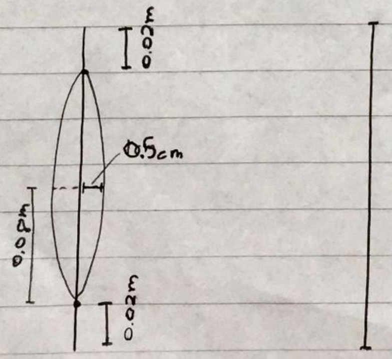
- Clearance 0.005 m





- Wing Profile :
  - Plane 1 :
  - Plane 2 :
  - Plane 3 :
  - Plane 4 :

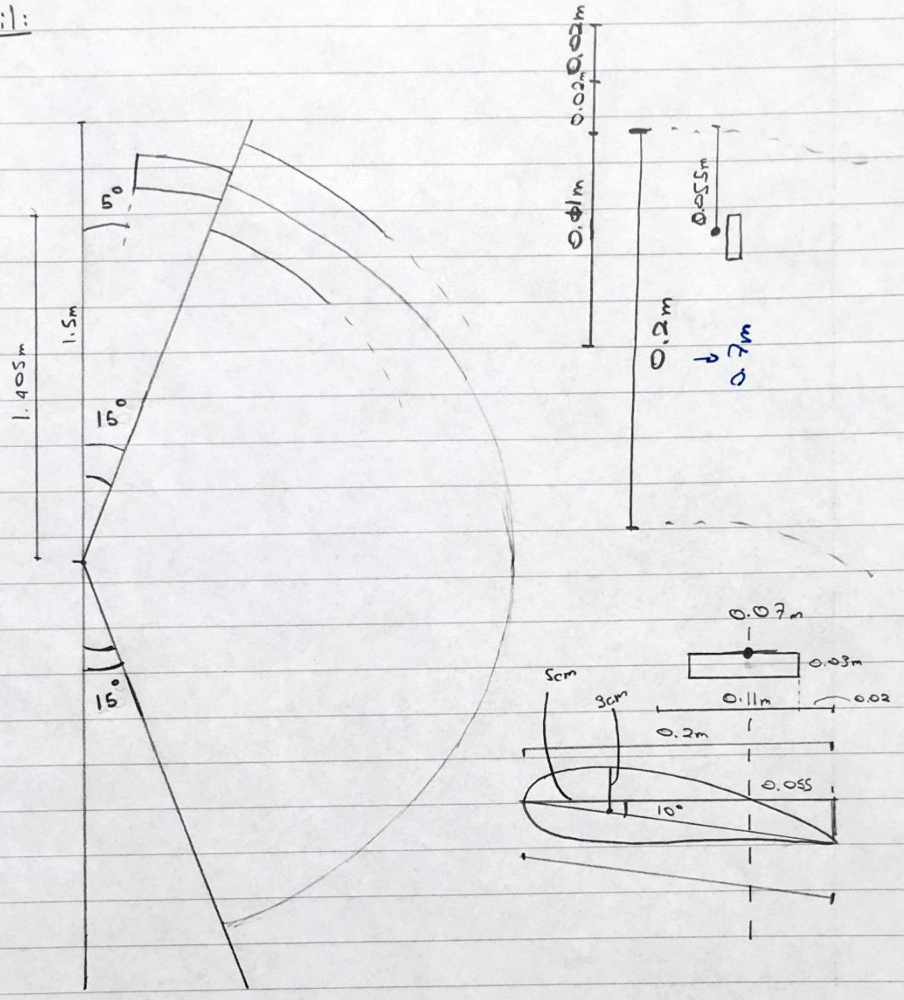
Tilt 17.5° with spline



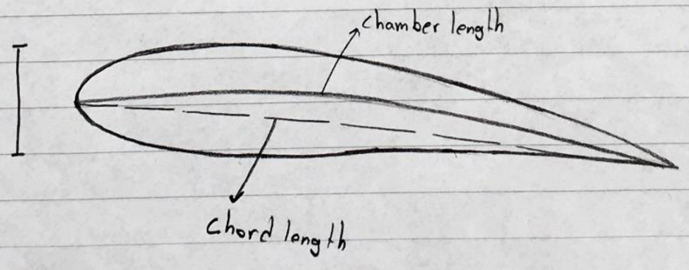
Turbine 2 :

Nose is cut 20cm, the chamfer (0.01m at 30°)

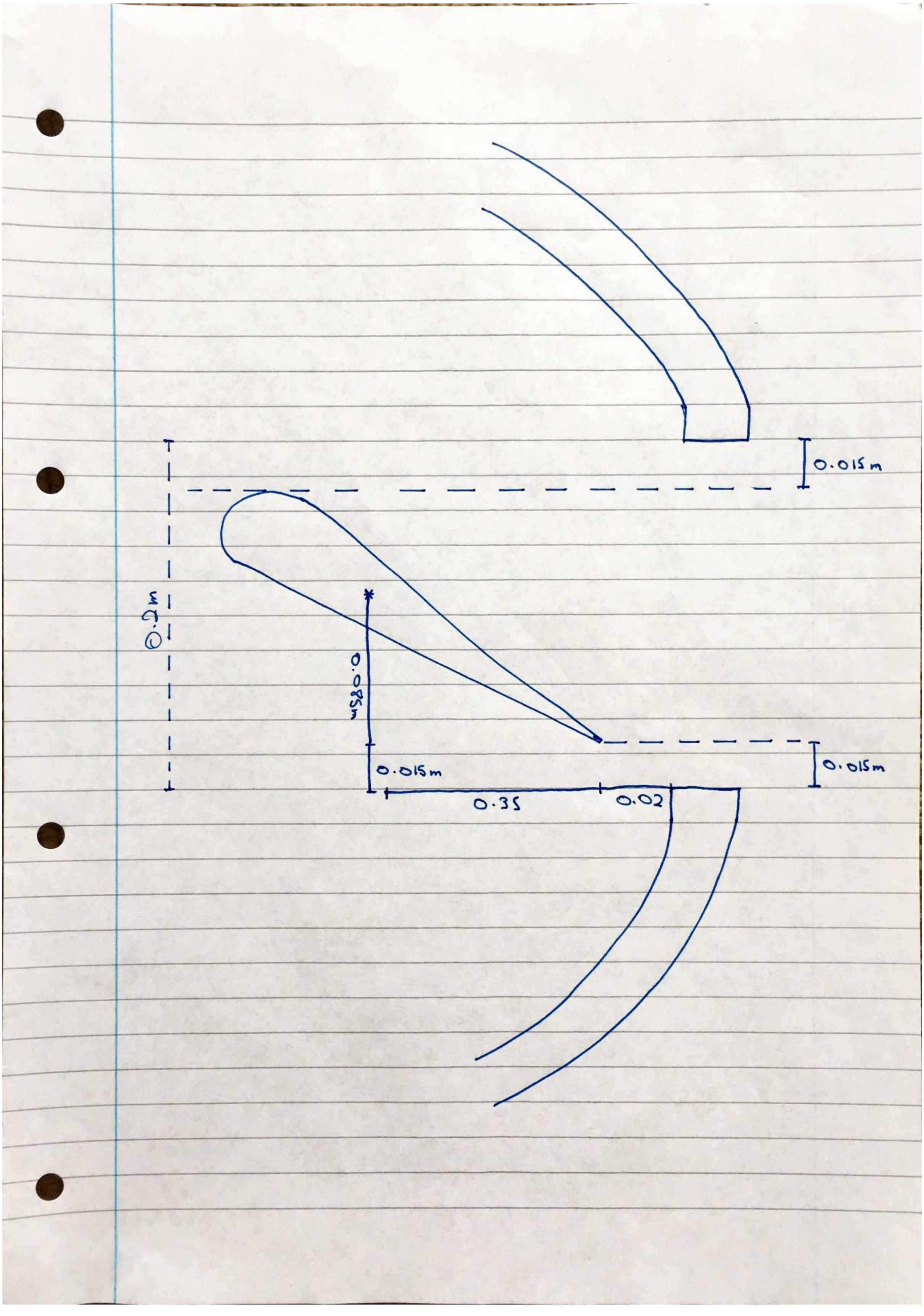
***Airfoil:**



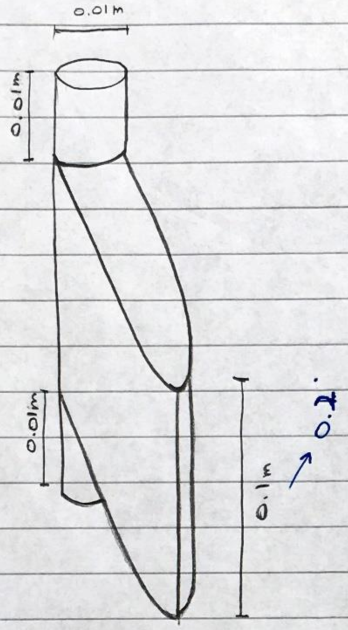
5°
1.5m
1.405m
15°
15°
0.02m
0.01m
0.055m
0.2m
0.7m
0.07m
0.03m
5cm
9cm
0.11m
0.02
0.2m
0.055
10°

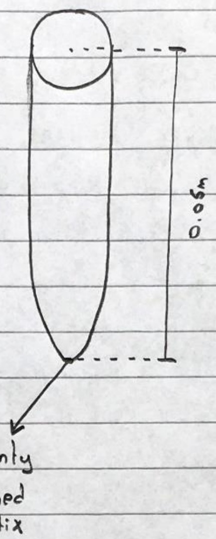


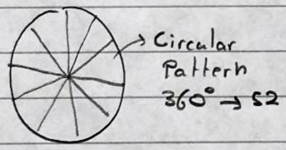
chamber length
Chord length


0.015m
0.2m
0.085m
0.015m
0.015m
0.35
0.02

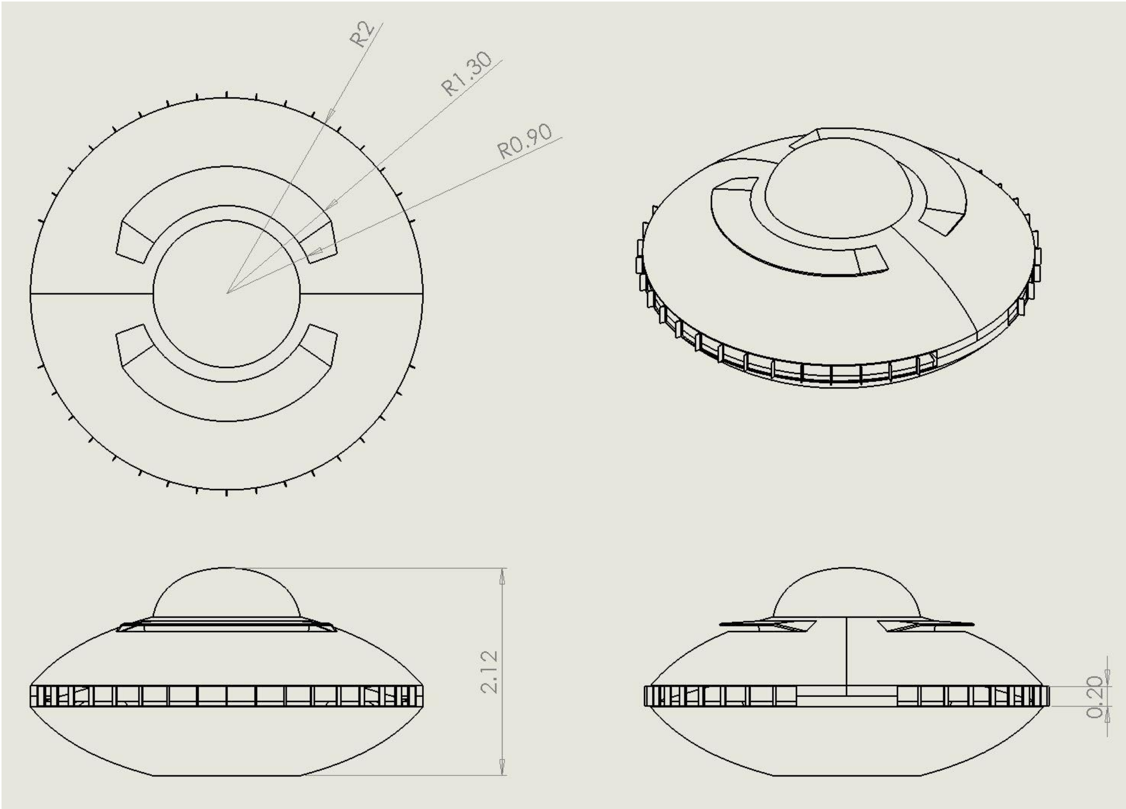
* Air Blades:-


0.01m
0.01m
0.01m
0.1m
0.7

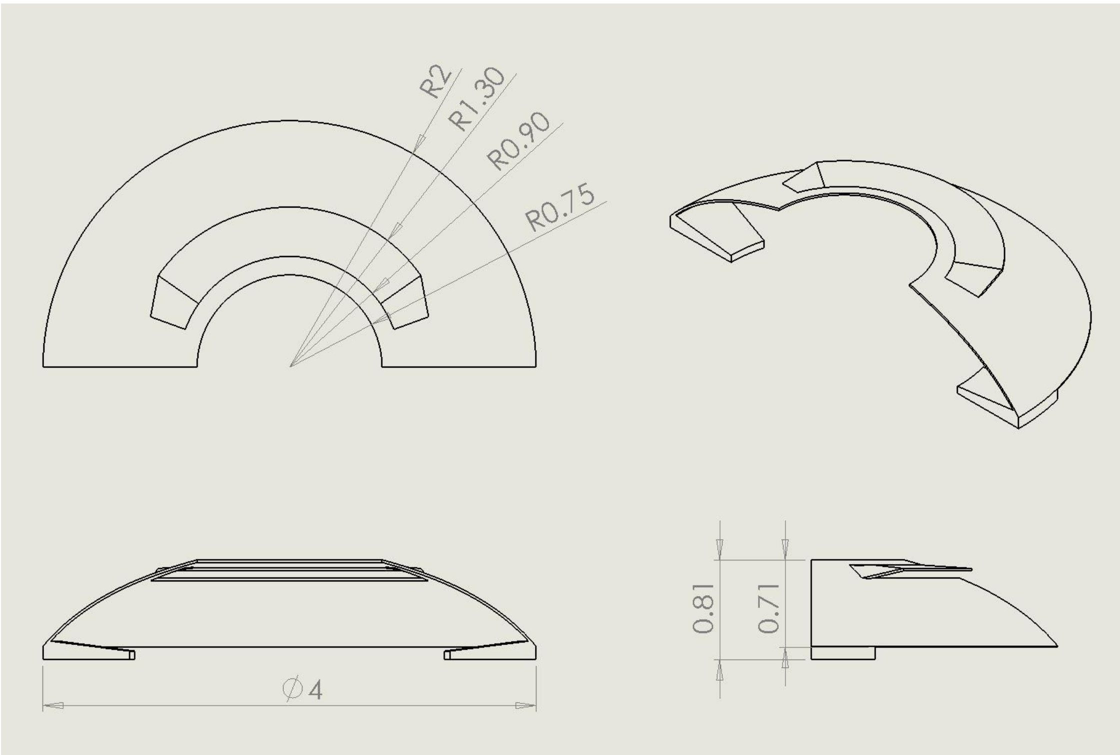

0.05m
Pointy
To shed
vortix


Circular
Pattern
360° → 52

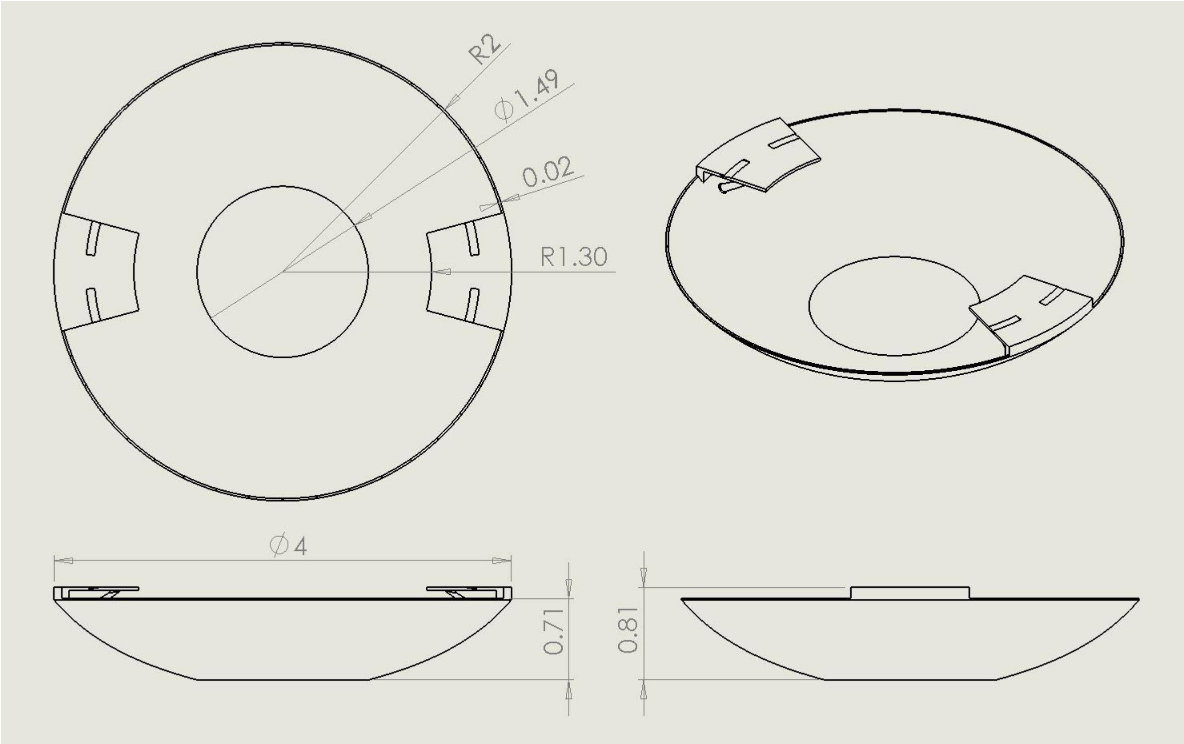
Appendix B: Measurements of the Final Design's Components



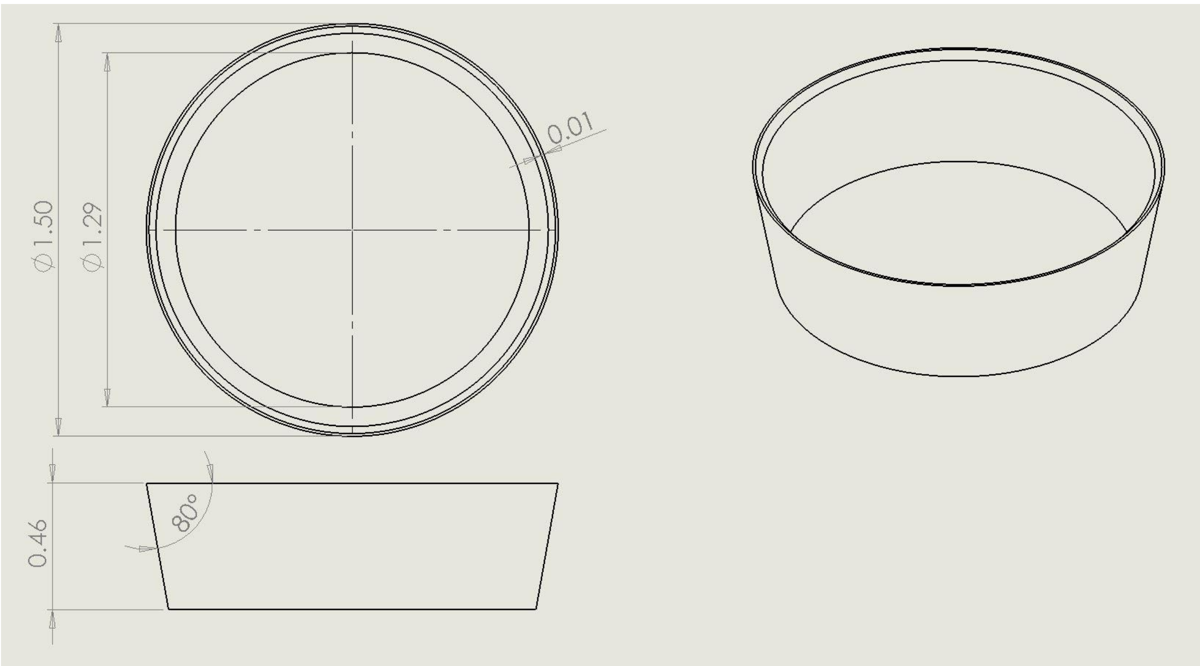
The Device



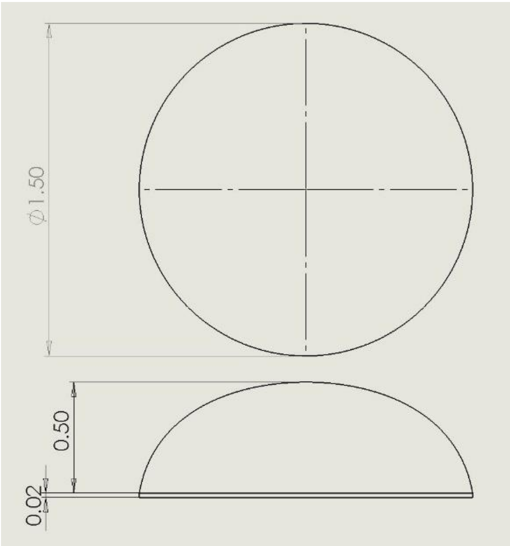
Top Half Body



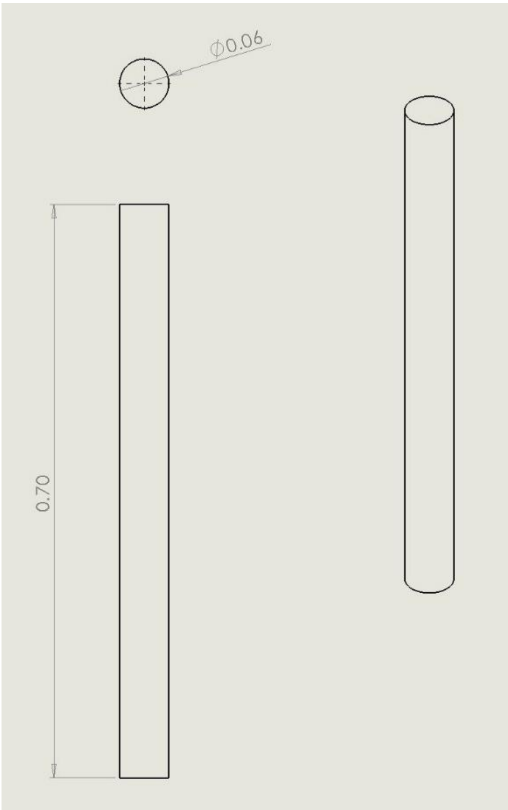
Bottom Body



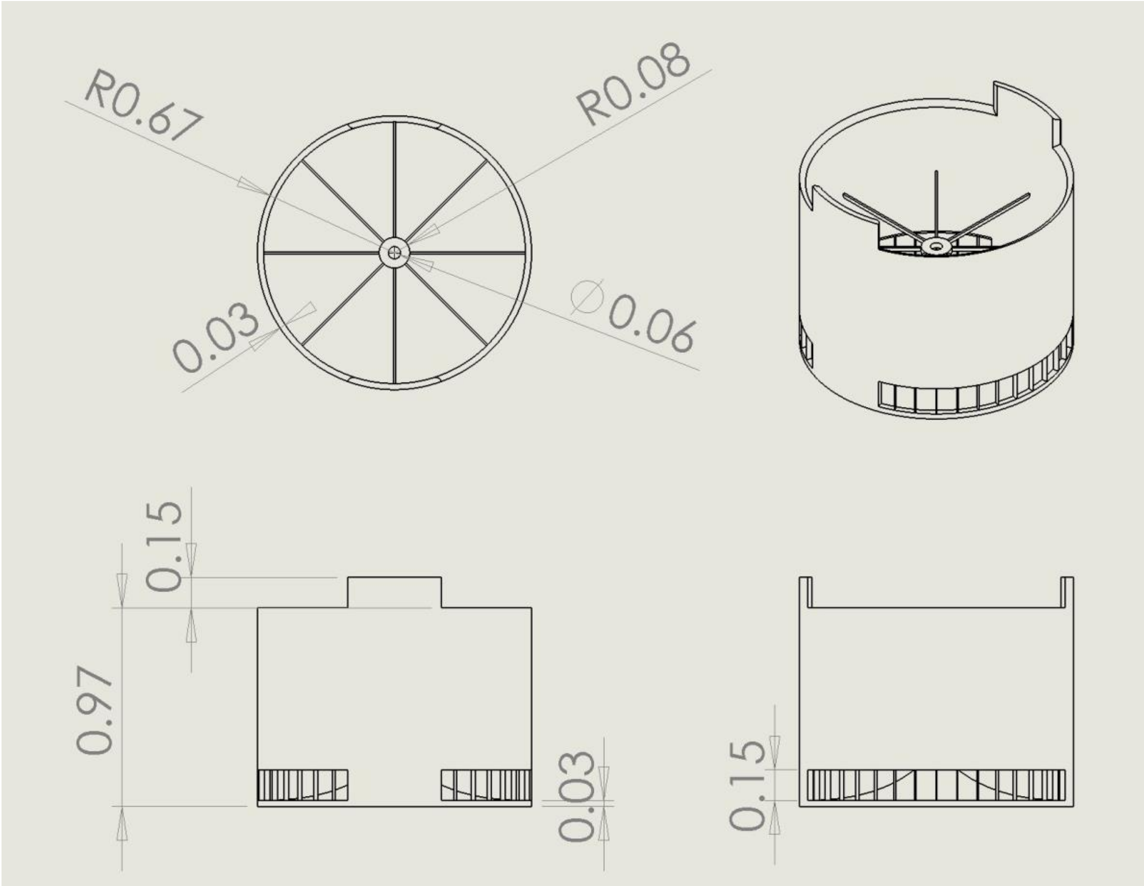
Cockpit



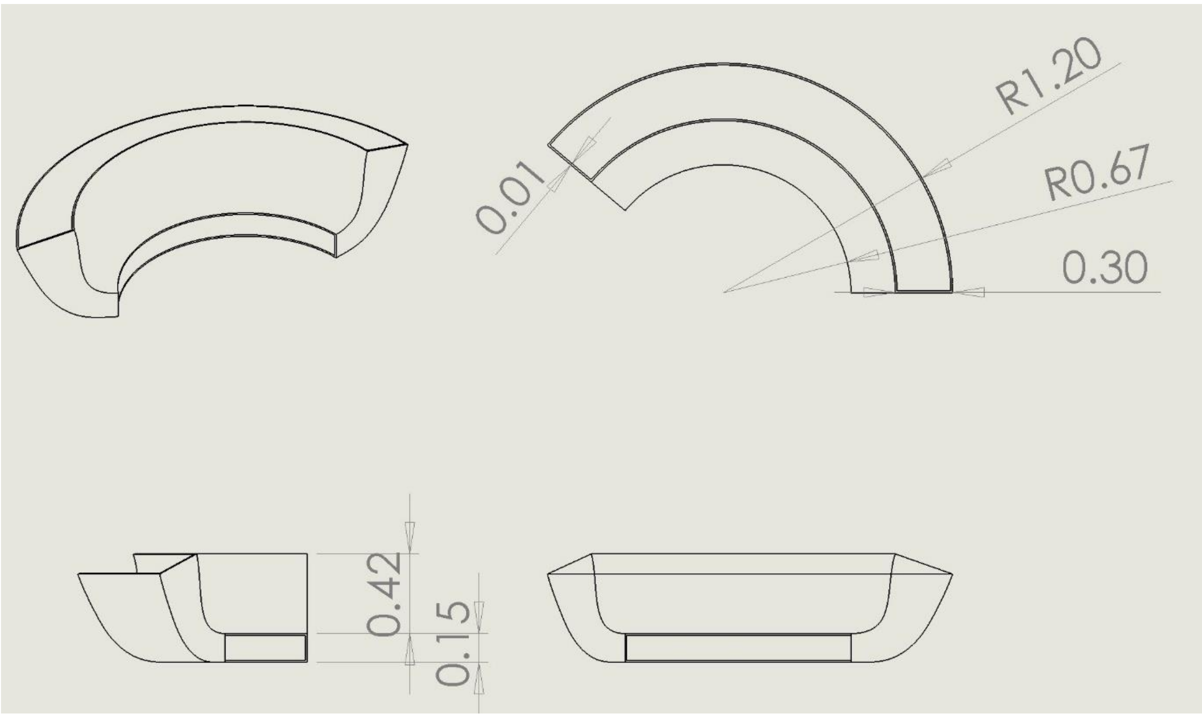
Wind Shield



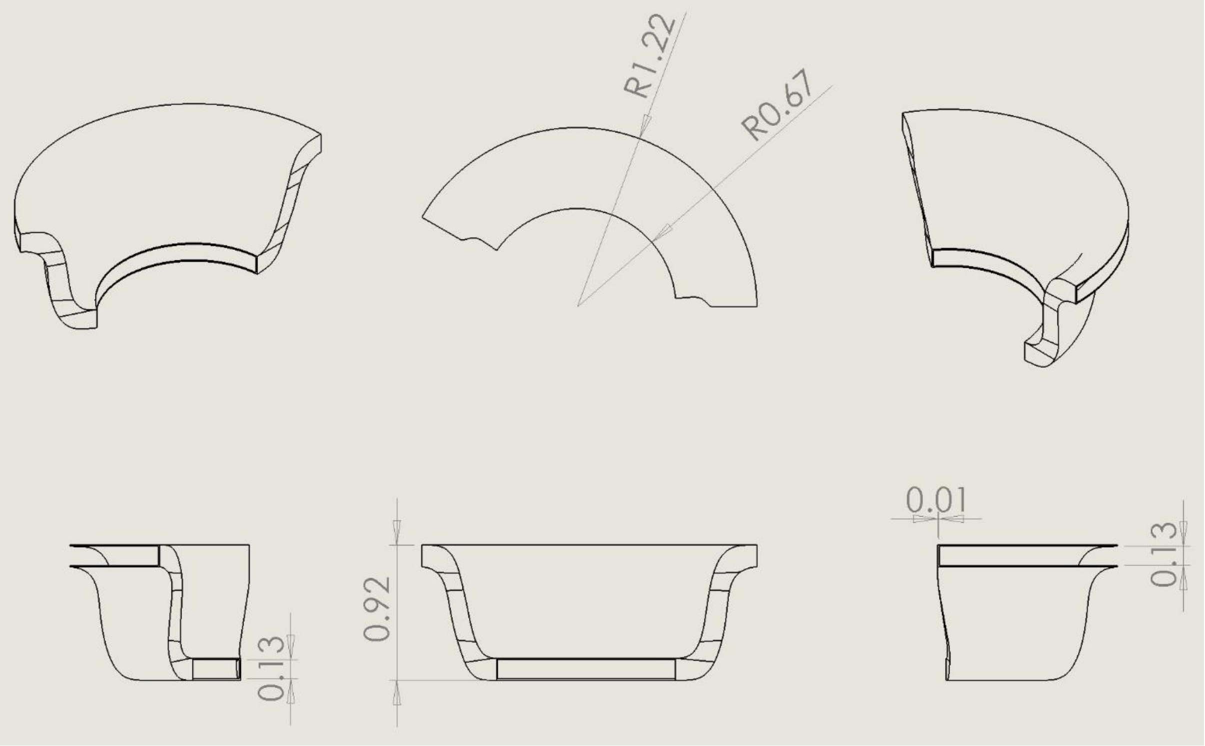
Turbine Rod



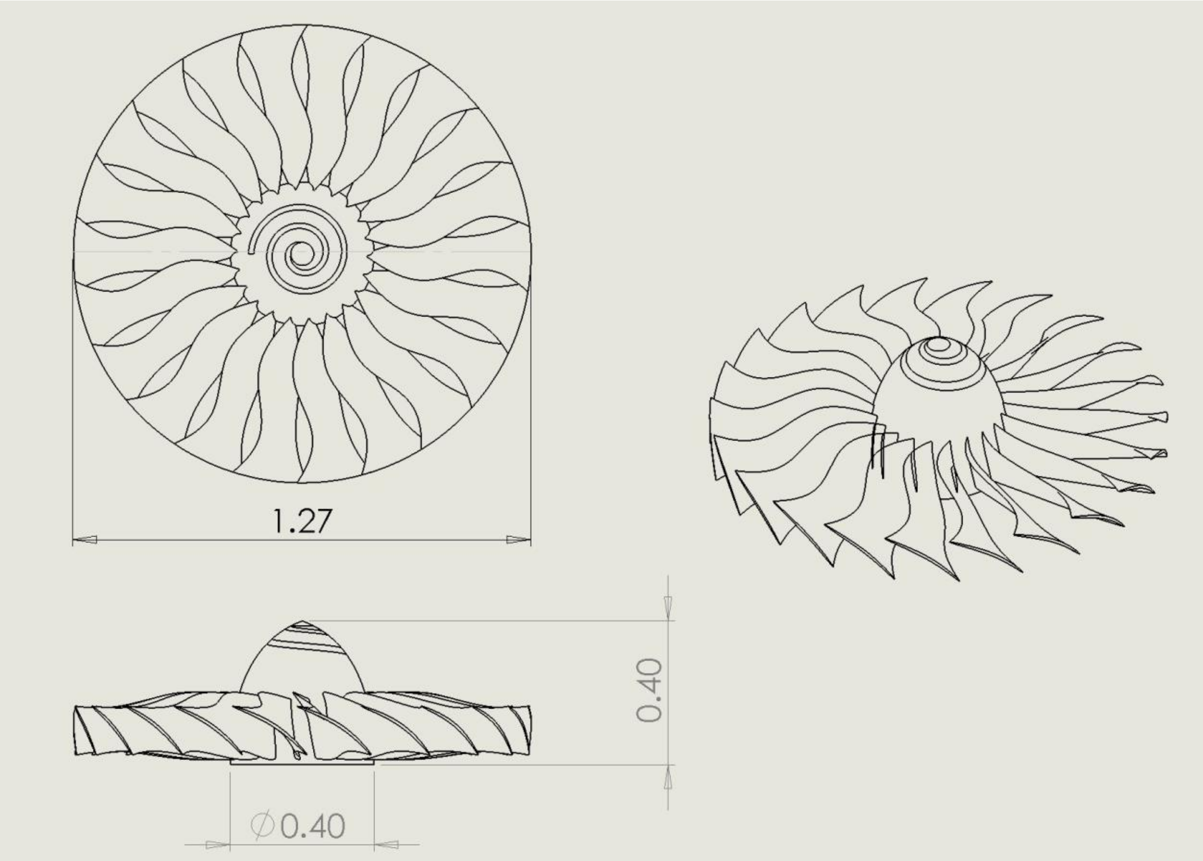
Turbine Casing



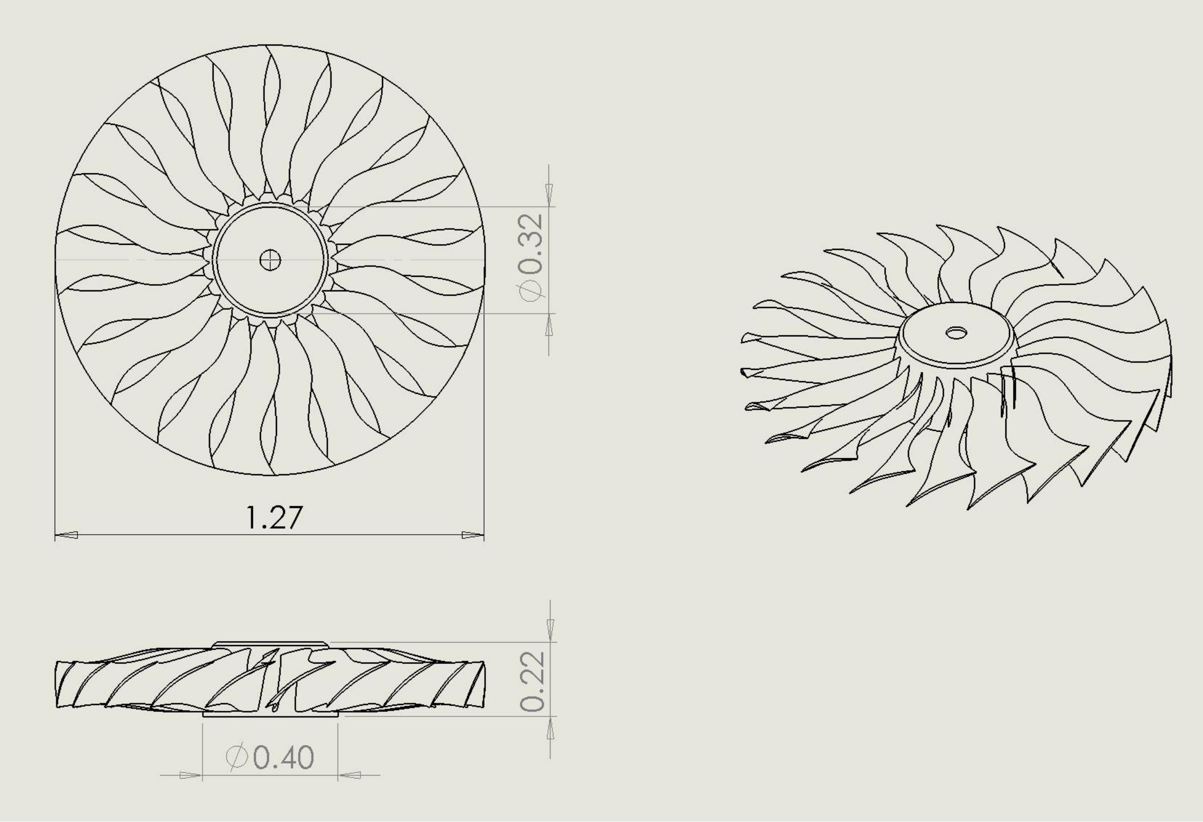
Air Inlet Path



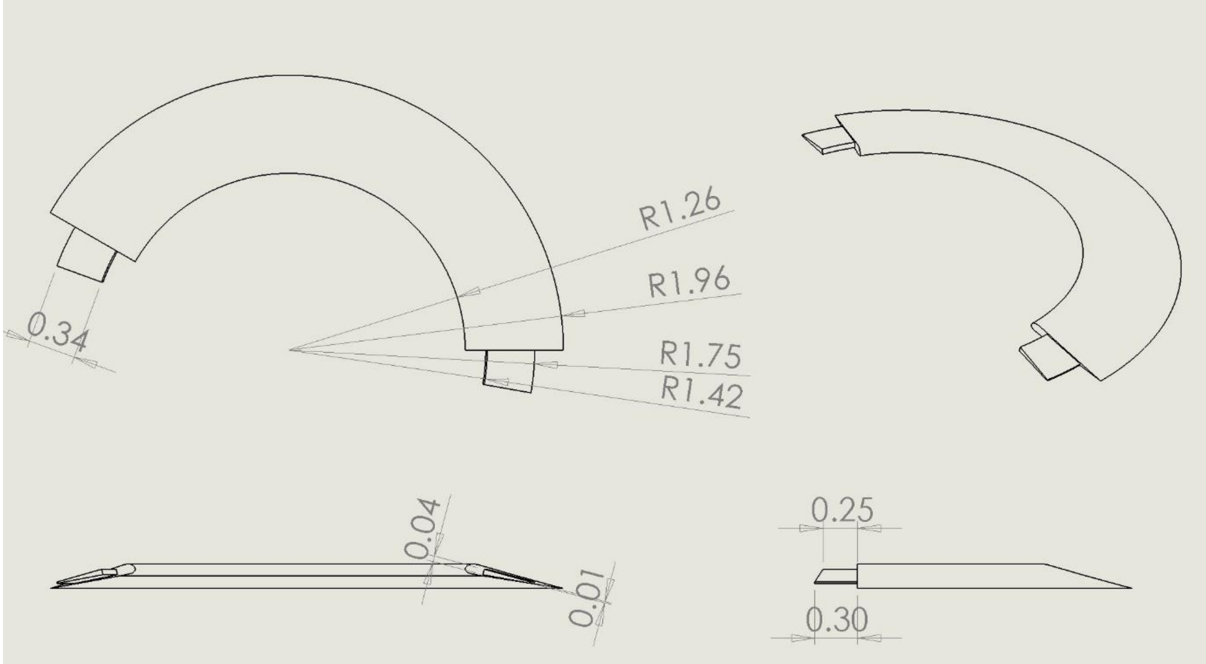
Air Outlet Path



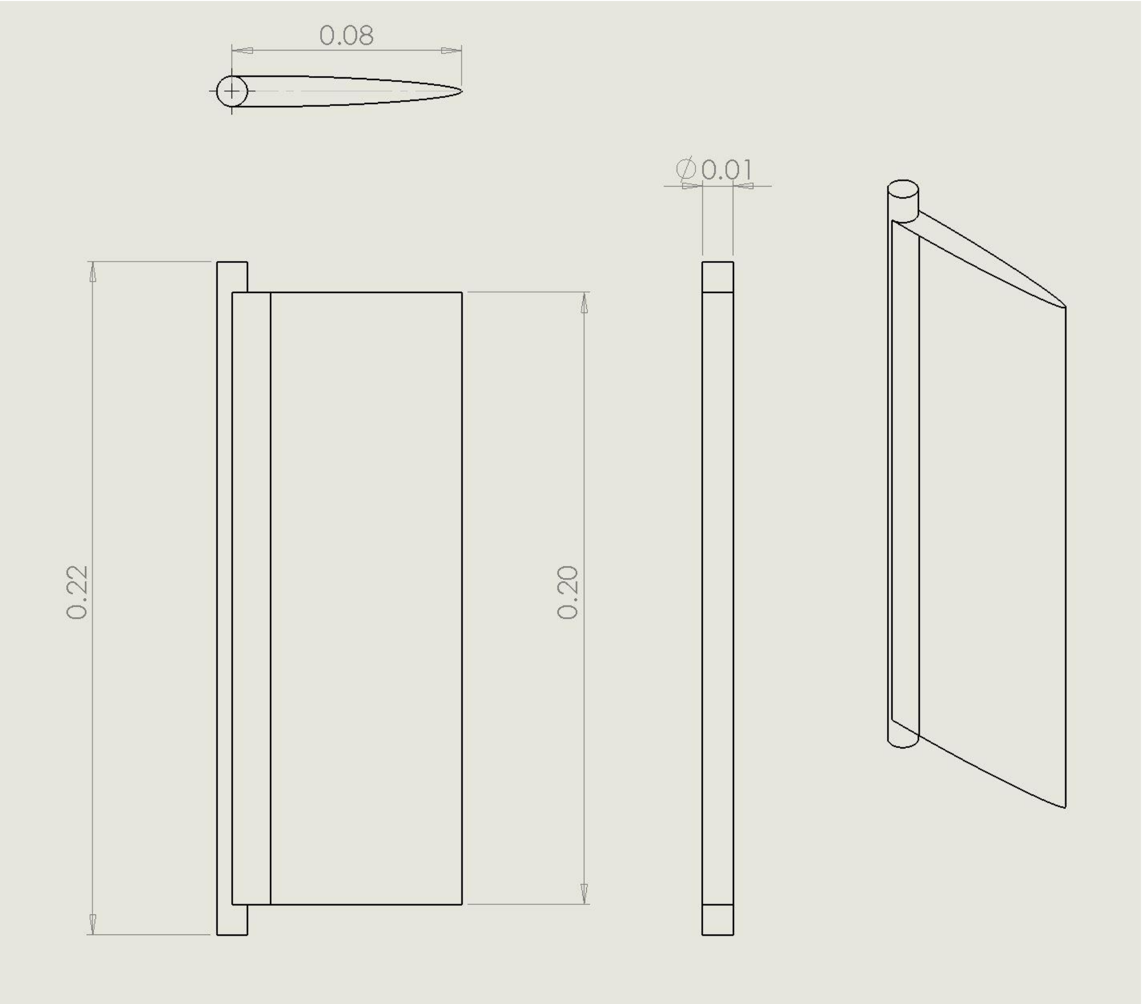
Turbine 1



Turbine 2



Aerofoil



Air Blade

Appendix C: Material's Properties

TYPICAL PROPERTIES of ACRYLIC PMMA		
ASTM or UL test	**Property**	**Acrylic**
	PHYSICAL	
D792	Density (lb/in³) (g/cm³)	0.043 1.18
D570	Water Absorption, 24 hrs (%)	0.3
	MECHANICAL	
D638	Tensile Strength (psi)	8,000 - 11,000
D638	Tensile Modulus (psi)	350,000 - 500,000
D638	Tensile Elongation at Break (%)	2
D790	Flexural Strength (psi)	12,000 - 17,000
D790	Flexural Modulus (psi)	350,000 - 500,000
D695	Compressive Strength (psi)	11,000 - 19,000
D695	Compressive Modulus (psi)	-
D785	Hardness, Rockwell	M80 - M100
D256	IZOD Notched Impact (ft-lb/in)	0.3
	THERMAL	
D696	Coefficient of Linear Thermal Expansion (x 10^{-5} in./in./°F)	5 - 9
D648	Heat Deflection Temp (°F / °C) at 264 psi	150-210 / 65-100
D3418	Melting Temp (°F / °C)	265-285 / 130-140
-	Max Operating Temp (°F / °C)	150-200 / 65-93
C177	Thermal Conductivity (BTU-in/ft²-hr-°F) (x 10^{-4} cal/cm-sec-°C)	3.9 1.2
UL94	Flammability Rating	-
	ELECTRICAL	
D149	Dielectric Strength (V/mil) short time, 1/8" thick	400
D150	Dielectric Constant at 60 Hz	4.0
D150	Dissipation Factor at 60 Hz	0.05
	OPTICAL	
-	Light Transmission, minimum (%)	92
-	Refractive Index	1.48-1.50

Plexiglass Properties [13]

Dry and Wet Carbon Fibre [14]

Appendix D: Types of Solar Cells

As the world moves towards more green engineering, more environmentally friendly products are anticipated. New technologies are being produced as alternatives to fossil fuel to power our devices, with the advantage of zero carbon emissions. Solar cells are green energy sources, which can recharge and power various machinery. Different solar cells have different applications, as they vary in efficiency and power outputs.

Types of solar cells:

Solar cells are also known as 'Photovoltaic Cells,' as they convert light energy (photons) to electrical energy (voltage), by using a thin layer of a semi-conducting material (silicon), The thin layer is differently charged at the top and bottom 'plates,' and is encased between two thin glass sheets or polymer resin for protection [27].

During daylight, these cells are exposed to sun energy and absorb their photons, energising the electrons within the semi-conductor material. These electrons will contain enough energy to move between the differently charged sides of the semi-conductor material inducing a Direct Current (DC). Different types of solar cells differ in electrical output, depending on the materials used to produce them. However, a more important factor is the molecular alignment of silicon molecules, such that better alignment produces a better photovoltaic effect.

- Monocrystalline Solar Cells:

These cells are also known as single-crystalline silicon. They have a unique shape with a dark uniform colour. They are made from silicon ingots, which start off as cylinders, and are then carved to produce silicon wafers, giving them a rounded edge. The following lists the advantages [29] of this type of cell, which make it the most favoured type:

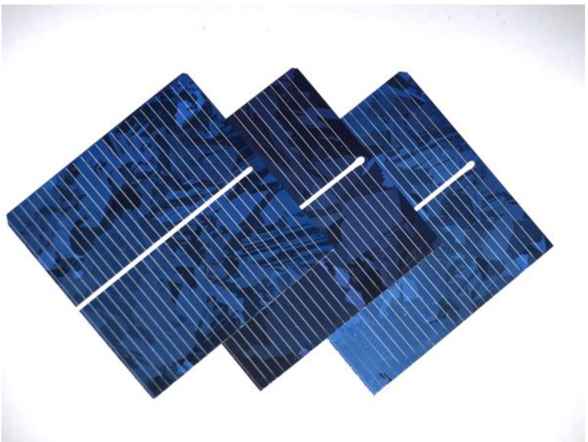
- They have the highest efficiency rates (up to 20.1%) due to the highest silicon grade that is used as an ingredient.
- They are space efficient: due to their high output, they require the least amount of space to produce the same power as any other type of solar cell.
- They have the longest lifespan, such that manufacturers include a 25-year warranty due to their high durability.
- They perform better than all types of similarly rated solar cells at low light conditions.

Monocrystalline Solar cell [28]

- Polycrystalline Solar Cells:

These are also called multi-crystalline silicon cells, and are produced by melting raw silicon and pouring it into square moulds, which is then cooled to perfectly-shaped square wafers. This causes them to be cheaper than monocrystalline, with a lower efficiency of 13-18% [27]. However, they possess the following advantages [29]:

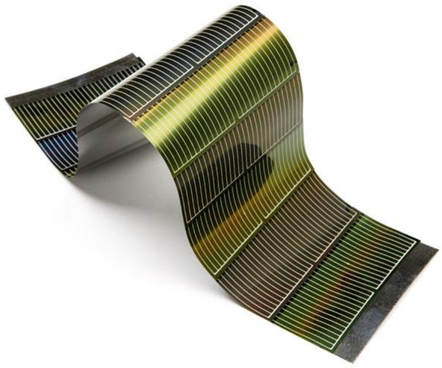
- Their production process is simpler and cheaper, producing less waste than monocrystalline solar cells.
- Although they have lower heat tolerance than monocrystalline solar cells, it is deemed insignificant when comparing price difference.



Polycrystalline Solar Cells [30]

- Thin-Film Solar Cells:

This type of solar cells is even cheaper than the previously mentioned ones. They are manufactured by placing more than one semi-conductor or photovoltaic material onto a substrate. They are very easy to produce, thus have a great production scale. Moreover, they are flexible, and allowing for a large range of usage. However, they consume large spaces, and so, are unsuitable for most applications [31].



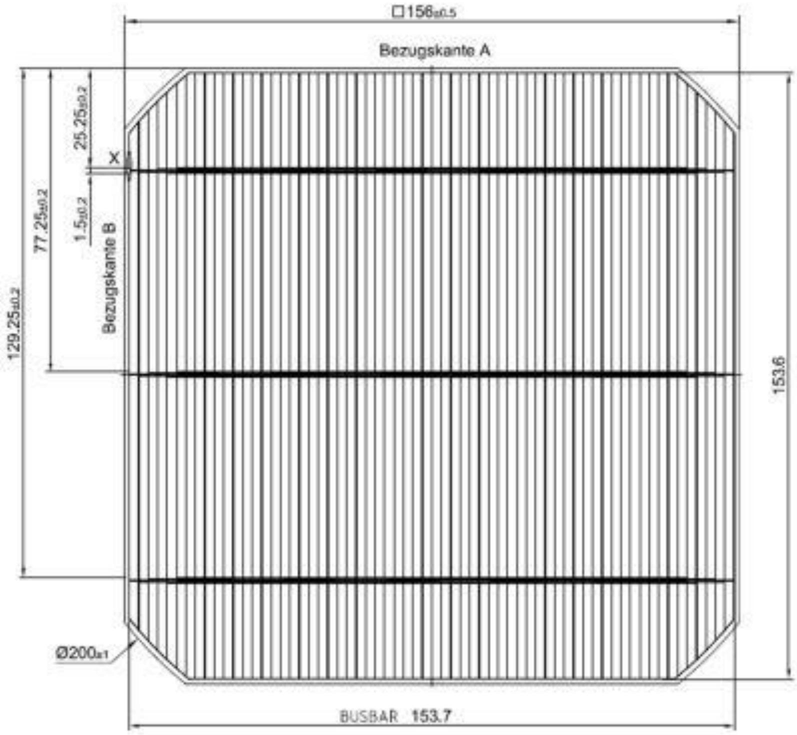
Thin-Film Solar Cell [32]

- Amorphous Solar Cells:

This type of solar cells is the cheapest to produce: instead of using silicon crystals for production, silicon is deposited in very thin layers on the backing substrate. The thin silicone layer allows the cells to be flexible. However, their low efficiency of 7-9% causes them to require approximately twice the area of any other solar cells to produce the same output [27].

Amorphous Solar Cell [33]

Appendix E: Solar Cell dimensions



Monocrystalline Solar Cell Layout [43, 44]

Appendix F: Lift Force and the Angle of Attack

The lift force is the force that will lift the object off the ground. Factors that contribute to lifting an aircraft include wing design, air speed, viscosity, and angle of attack.

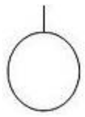
The angle of attack normally expresses the angle between the wing chord line and the flight path [48]. For the purposes of this project, it determines the angle of the wing chord line and the direction of wind flow, which is horizontal. It also considers the ratio of lift and drag forces acting on the wing. Taking the wind velocity to be constant, a greater angle of attack produces a greater lift force. However, this is true to a certain extent: when the aerofoil reaches the 'Critical angle of attack,' the drag forces will equal or exceed the lift force, thus stalling the craft [49].

Another phenomenon that plays a huge role in lift is known as the boundary layer [50]. The layer of fluid that is the closest to the surface of an object is nearly stationary (some consider it stationary). It is created due to the tendency of fluids to stick to a surface (Coanda Effect). Due to Bernoulli's effect, mass continuity equation, and the geometry of an aerofoil, the windspeed on top of the wing will be moving faster than the wind below the wing. Faster wind speeds result in lower pressure: thus, the wind below the wing produces greater pressure, and pushes the wing upwards, creating lift. Due to research done in the first term (2^{nd} of Dec 2016) and the research paper [51], which talks about NACA 632-215 Aerofoil (The aerofoils used in this project have similar profile), the optimum angle of attack was found to be 11^{o}.

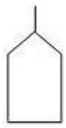
Appendix G: Fault Tree Analysis

Flow Tree Analysis Symbols

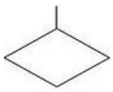
Event Symbols:



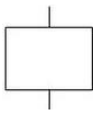
Basin Event: Failure in an element of system component



External Event: A normal event which is expected to occur

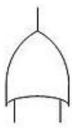


Undeveloped Event: An event which has insufficient information

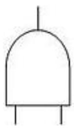


Intermediate Event: Connects basic events to end result

Gate Symbols:



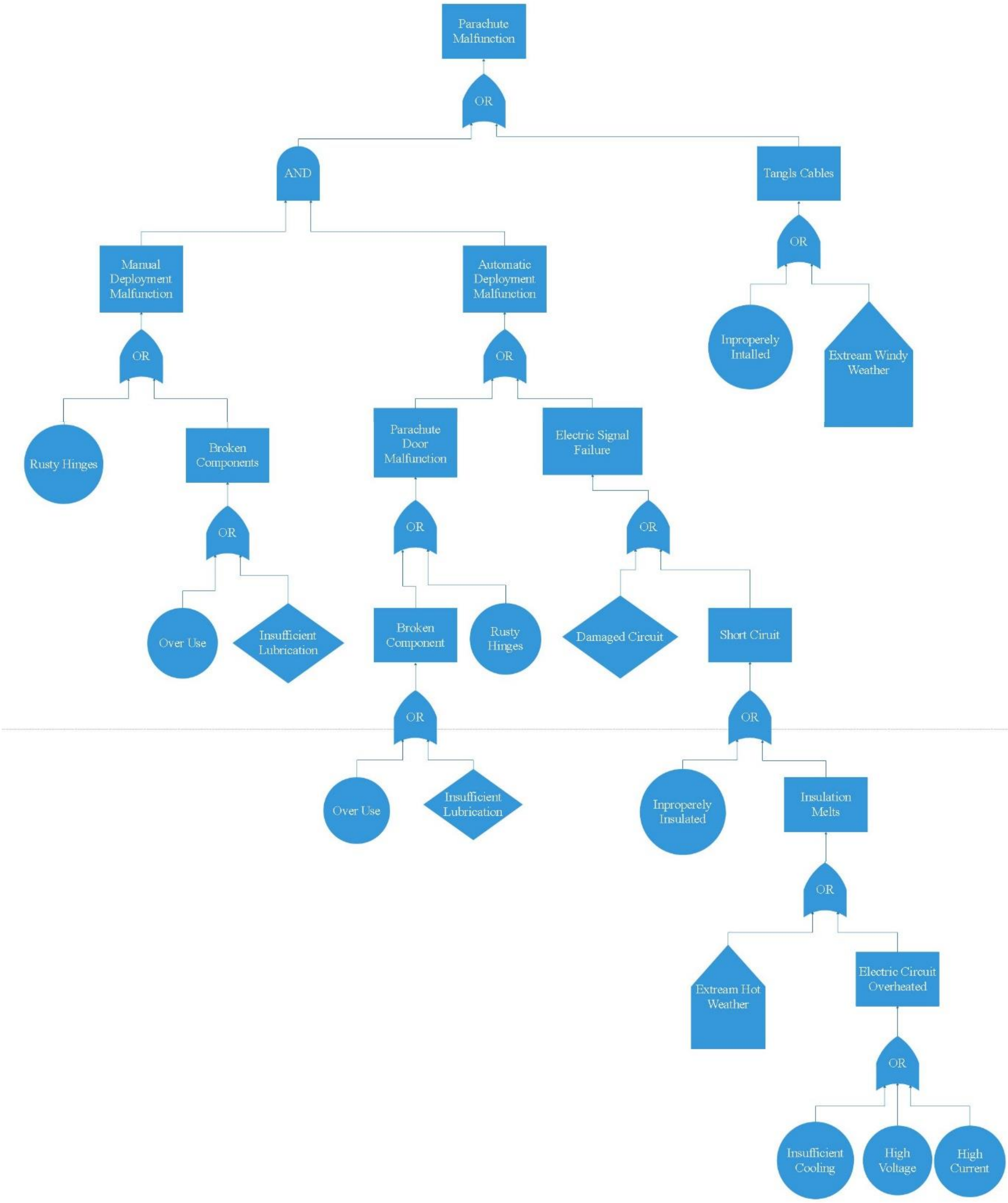
OR Gate: Output occurs if any of the input occurs



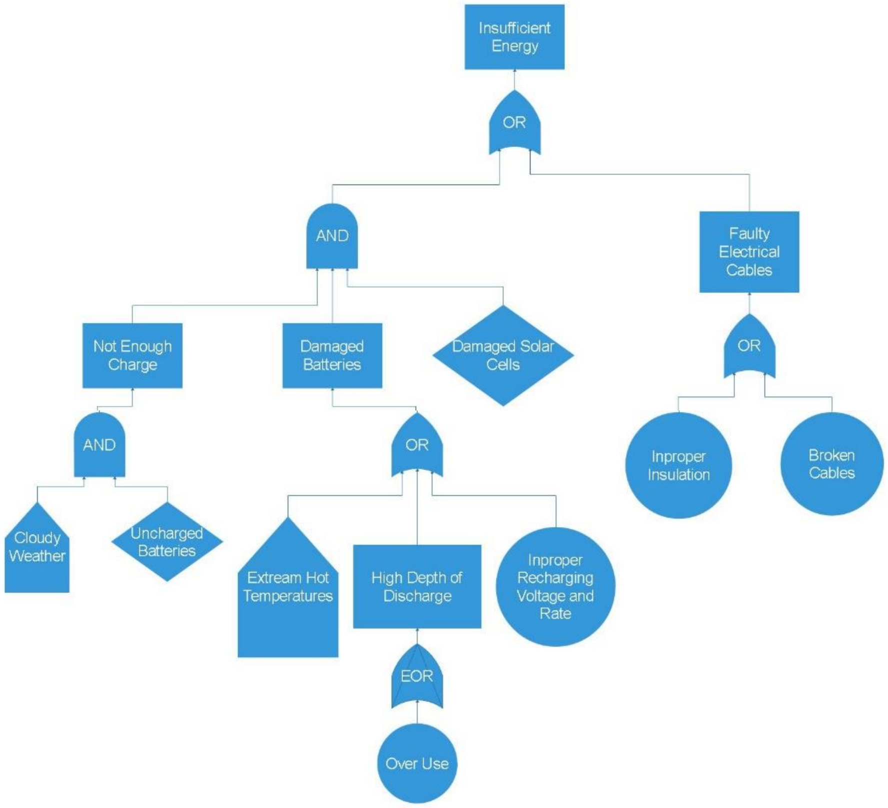
AND Gate: Output occurs if all the inputs occur

Exclusive OR Gate: Output occurs if exactly one input occurs

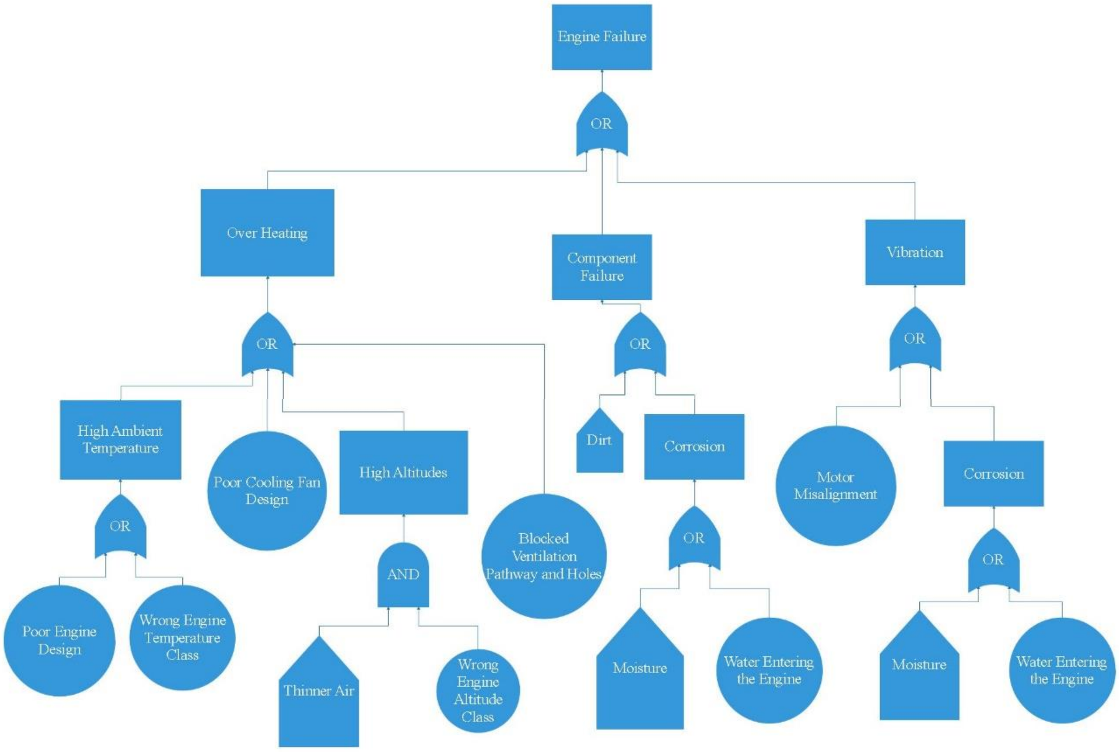
- Parachute Failure:



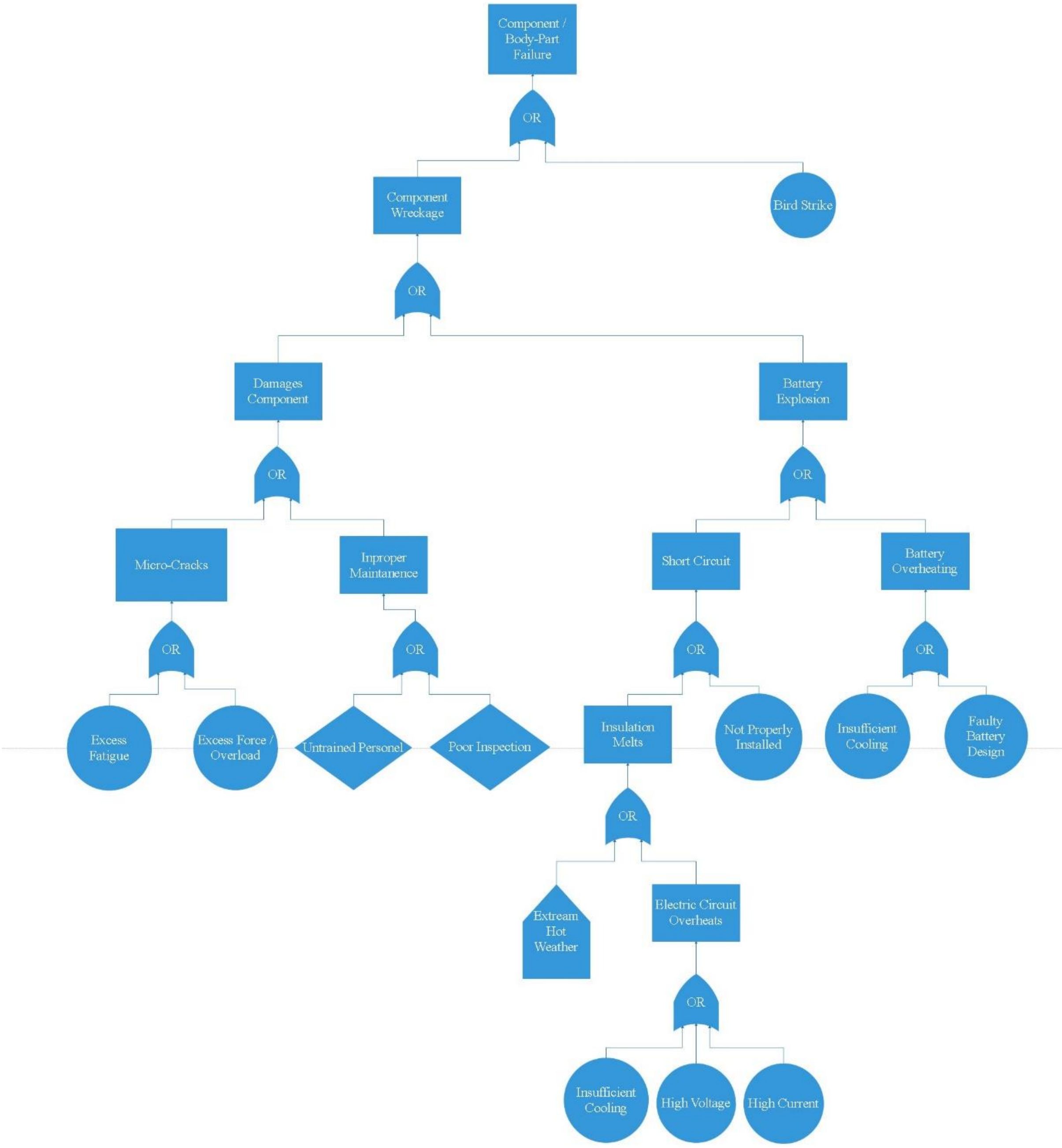
- Insufficient Energy:



- Engine Failure:



- Component / Body-Part Failure:



Appendix H: Cross-Section of Final model