Hydro-foiling Jet-Ski: A Design for Production

Master Thesis

Hendrik Viljoen

22490254

School of Engineering, University of Western Australia

Supervisor: Thomas Bräunl

School of Engineering, University of Western Australia

Co- Supervisor: Pierre Louis Constant

School of Engineering, University of Western Australia

School of Engineering Western Australia

University of Western Australia

Word Count: 7614

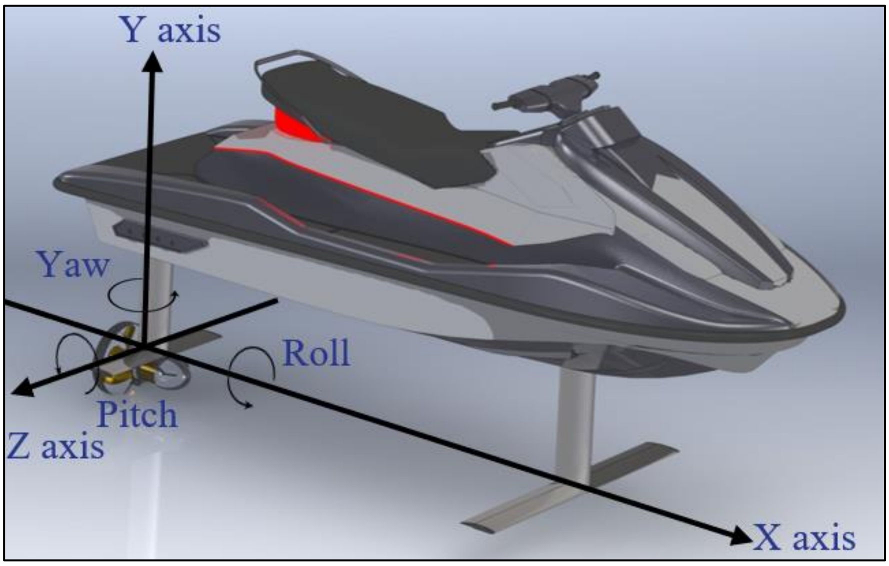
Submitted: 29/05/2023

Abstract

With a global shift towards clean energy, a demand for electrically powered vehicles has created opportunities for innovation. Yet to make a dominant entry to the personalised watercraft market, emerging innovations of electrically powered watercraft are being tested by several start-up companies. This paper presents a design iteration of an electrically driven, hydro-foiling personal watercraft, that will allow the product to become marketable by ensuring its fabrication and assembly is scalable. Employing a philosophy of form follows function, the design solution; a chassis that incorporates all the functionality and strength of the craft, resolves issues identified with the current model. The design incorporates existing products into an assembly with minimal modifications and custom-made parts. This chassis will be easily assembled and mounted to an exterior body yet to be designed, allowing freedom of aesthetical and ergonomic design choice of the final product.

Glossary

Essential to the interpretation of this work is a global coordinate system often referenced in a Cartesian coordinate system of (X,Y,Z) while the control of the system is referred to in terms of pitch, yaw and roll as defined below.



Term	Definition
Hydro-Ski	Hydro-foiling Jet-Ski
FEA	Finite Element Analysis
FVA	Finite Volume Analysis
COM	Centre of Mass
HDPE	High-Density Polyethylene

Contents

Abstract 2
Glossary 2
Table of Figures 4
1 Introduction 6
2 Current Design 6
2.1 Issues 7
2.1.1 Cavitation Altitude & Pitching Control 7
2.1.2 Differential Thrust 8
3 Existing Products 8
3.1 Moth sailboat 8
3.2 Candela C7 foiling boat 9
4 Problem Statement 11
4.1 Objectives 11
5 Chassis Material Selection 12
6 Force Analysis 13
6.1 Thrust Force Analysis 14
6.2 Lift Force Analysis 15
7 Insert Design 17
7.1 Constraints 17
7.2 Dimensions 17
8 Strength Analysis 18
9 Commercially available products 20
9.1 Maytech Fully Waterproof MTI120116 18.8KW 20
9.2 Lithium Phosphate Iron Batten Battery 20
9.3 Hydrofoils supplier - WASZP 20
10 Design Solutions 22
10.1 Front Foil control 22
10.2 Centralised Thrust 24
10.3 Rear Foil Control Surfaces Actuation 25
10.4 Gantry 27
10.5 Steering connection 27
10.6 Battery mounts 28
10.7 Complete Assembly 28
11 Balancing 29
12 Conclusion 30
12.1 Final Design 30

12.2 Limitations 33
12.2.1 Components to be added 33
12.2.2 Rudder design 33
12.2.3 Sealing/waterproofing 33
12.2.4 Payload 33
13 Appendix A 34
13.1 Retracting mechanism (externally designed) 34
13.2 First Draft of Chassis 35
13.3 Displacement plot 35
13.4 WAZSP Foil Assemblies Invoice 36
14 References 37

Table of Figures

Figure 1a – Hydro-Ski successfully foiling above the water, Figure 1b rear foil assembly 6
Figure 2 Cavitation caused when pitching 7
Figure 3 Positioning of two motors creates a moment if thrust force is unbalanced. 8
Figure 4 - Moth Sailboat control diagram, adapted from (Ponte et al., 2022) 9
Figure 5 - Candela's C7 foiling boat (Candela) 10
Figure 6 - Aerial footage of the C7 making a left banked turn (Candela) 10
Figure 7 Scope outline 11
Figure 8 - Free body diagram of dominant forces acting on vessel while foiling 13
Figure 9 Shigleys Mechanical Engineering Design Failure Selection flowchart (Budynas, 2018) 13
Figure 10 - FVA maximum pressure differential of 125.5 kPa. $d = 2$m, $\alpha = 5$ degrees, $\beta = 2.5$ degrees. 15
Figure 11 - Rear foil lift force, 110 iterations until stabilisation at 353 Newtons 16
Figure 12 - Front foil lift force, 110 iterations until stabilisation at 3972 Newtons 16
Figure 13 - 110 until stabilisation at 5270 Newtons 16
Figure 14 Base dimensions of Hydro-Ski 17
Figure 15 Finite Element Analysis of forces acting on HDPE chassis while foiling 18
Figure 16 – Detailed view of largest Von-Mises Stresses acting on body, concentrated at the rear and lower bearing. 19
Figure 17 Front foil assembly details 22
Figure 18 Front foil transparent view 23
Figure 19 Exploded Motor Assembly 24
Figure 20 WAZSP rear foil alterations 25
Figure 21 WASZP retrofitting details 25
Figure 22 Mechanical link to servo motors 26
Figure 23 Full rear foil assembly 26
Figure 24 Gantry to secure rudder and accommodate retracting mechanism 27
Figure 25 Steering Assembly 27
Figure 26 Battery assembly mount (dimensions in milometers) 28
Figure 27 Complete assembly of subassemblies 28
Figure 28 Centre of Mass analysis 29
Figure 29 Chassis with foils retracted 31
Figure 30 Concept sketch of chassis within exterior body 32

Figure 31 Hydro-Ski concept 32
Figure 32 Sketch of possible rudder solution 33
Figure 33 Retracting Mechanism 34
Figure 34 First draft 35
Figure 35 Displacement plot 35
Figure 36 Quote from KA Sailing for foil assemblies 36

1 Introduction

In 2013, Oceanomatics, Tromes Design and The University of Western Australia started work on developing one of the first electrically driven Jet-Ski's. The project has proven to be no small task, presenting numerous challenges, most significantly being battery life. This led to a hydrofoil adaption in 2019, successfully increasing efficiency and extending ride time. This added a great deal of complexity to the system, including maintaining height at various speeds and turning while foiling above the water, often causing instability. Since then, solutions to these issues have been studied and implemented through various approaches with some success. Most notably, an automated stabilisation software. Presently the project has proven the working concept, achieving stable lift over short distances, see figure 1. To progress, there are a few key issues to be resolved that will require a complete redesign of the Hydro-foiling, Jet-Ski (Hydro-Ski).

2 Current Design

The vessel is essentially constructed from mounting the top half of an old Seadoo PWC Jet-Ski hull to a commercial windsurfing board which acts as the structural frame of the vessel see figure 1 a. Within this, waterproof casing houses both the batteries and the control unit which are fastened with straps. A wire steering assembly connects the handlebars to a metal gantry, which holds the rudder in place with a sleeve-pin connection. Attached directly to the rudder is the rear foil, which includes two servo-actuated ailerons providing roll and pitch control while two MP56115 motors rated at 5kW under 48V, secured at the outer ends provide thrust, see figure 1 b. The front foil connects through the paddle ski, locked in place by a simple padlock while foiling.

Figure 1a – Hydro-Ski successfully foiling above the water, Figure 1b rear foil assembly

This design proved the working concept of an electrically powered, foiling craft effectively, allowing the testing and development of the automated stabilisation software developed by Pierre-Louis Francois Constant. Though work continues to improve on the current prototype, there are a number of mechanical issues that will require redesign.

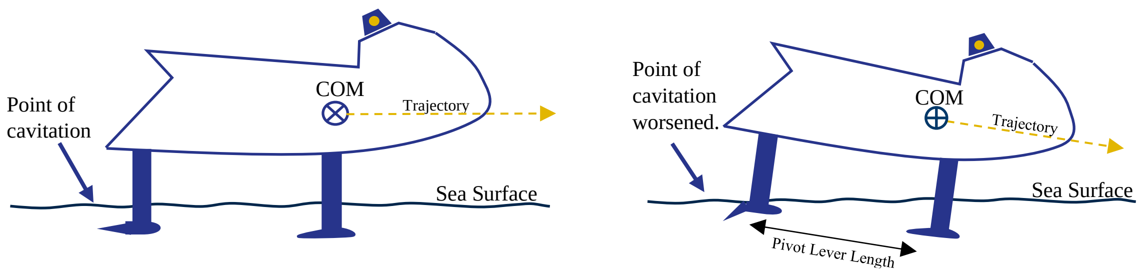
2.1 Issues

2.1.1 Cavitation Altitude & Pitching Control

Occasionally, while foiling, riders have noted the motors cavitating when the rear foil rises too close to the surface. This results in a sudden drop in thrust with damaging effects to the motor while interfering with the automated control system. Naturally riders have tried to counteract this by manually overriding the automated system and pitching the crat down to reduce altitude, however this was found to worsen the situation. To understand this phenomenon and the constraints surrounding the control of altitude, it is necessary to briefly analyse the control of the current design.

While foiling, the craft has three degrees of freedom; yaw, pitch, and roll $(\Omega, \varphi, \theta)$. Controlled by three inputs, rudder (manual), left aileron (actuated), right aileron (actuated). Its trajectory is controlled while it translates linearly along a 'line', meaning its position in space is time dependant with no ability to translate instantaneously. The centre of mass of the craft is positioned slightly behind the front foil, as such, the front foil provides most of the lift force, while the aft foil provides control of pitch and roll. During foiling, the pivot point of the craft sits at its centre of mass located above the junction of the front foils' mast and wing as seen in figure 2. Outlined in his paper, "Production of a real time controller for automated stabilisation of an electric foiling personal watercraft" (Constant, 2023). Pierre notes that dynamic instability in the transverse plane is the more complicated issue, analogous to an inverted pendulum as it is inherently unstable and "requires constant actuation to remain balanced" (Constant, 2023), and is the reason for the development automated stabilisation software. In the longitudinal plane, though less complicated, as it is more stable, the current design requires the use of the rear control surfaces to adjust the pitch of the craft. Having the pivot point so far from its point of action the rear ailerons effectively have a large lever as depicted in figure 2 b. Meaning a smaller force is needed from the deflecting control surfaces to change the pitch of the craft.

Figure 2 Cavitation caused when pitching



Initially considered advantageous due to the small size of the current control surfaces and their attaching servos, this is the root cause of the cavitation issue, as once cavitation starts to occur, it's too late to decrease altitude. The reason for this.

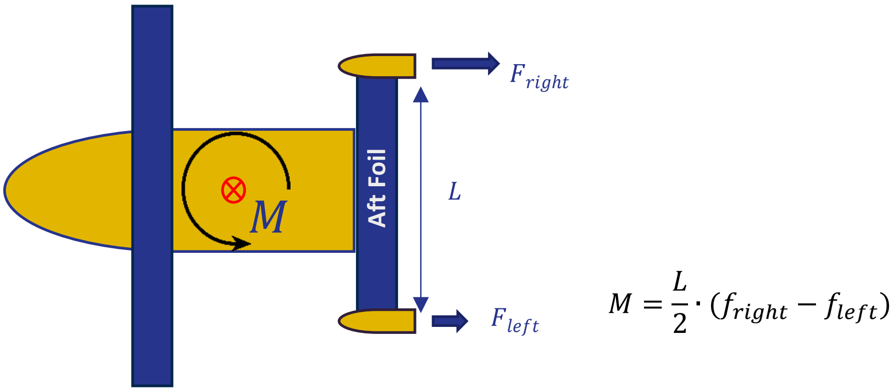
- To decrease altitude, the pitch of the craft needs to be adjusted downward, achieved by the ailerons retracting down, deflecting water and increasing lift force that raises the rear foil higher.
- Being time dependant, its trajectory is changed before it is able to reduce its target altitude, thus as the craft attempts to adjust its pitch, the rear foil approaches the surface of the water and the cavitation is worsened.

Once cavitation takes full effect, the only means of recovery is a complete stall, whereby the craft stops foiling completely. This is believed to be a major factor that limits the duration of foiling, limiting it to shorter distances. As this problem is related to the distribution of forces acting on the vessel, it cannot be solved by improving the automated stabilisation software, rather it will require mechanical redesign.

2.1.2 Differential Thrust

The two thrusters are positioned at the outer ends of the rear foil, this was based on availability of products at the time. However, it has caused substantial problems to both balancing, user safety and the steering system having several mechanical failures. In the event of thrust imbalance, whereby one of the motors is not receiving power the force generated is multiplied by the length of the foil, like a lever depicted in figure 3. This is then transmitted through the steering system to the handle, the resultant force is so significant that riders have noted that "it feels as if though the rudder hit something" – Josh Kirkham, UWA master student, often being uncontrollable.

Figure 3 Positioning of two motors creates a moment if thrust force is unbalanced.



This issue is of significant functional and safety concern and must be addressed in the next design iteration of the Hydro-Ski.

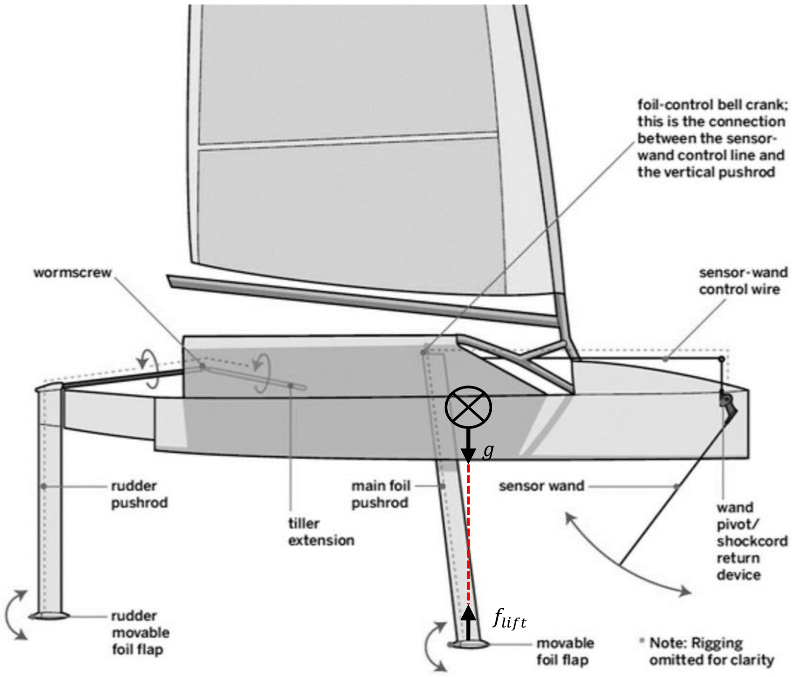
3 Existing Products

3.1 Moth sailboat

Hydro-foiling is not an altogether new concept, attempts by engineers all over the world date back to the early 20th century. However, recent material advancements have seen hydrofoils develop immensely within sailing sports for its superior efficiency (Abbasov & Orekhov, 2019). A quick comparison of the world record top speeds of a non-foiling craft and foiling craft shows the superiority of hydrofoils, with the non-foiling 'Vestas Sailrocket 2' reaching 47.2 knots in 2012 while in the same year the foiling 'Hydrotere' reached 55.5 knots (Bourgeon et al., 2013). Thus, literature and scientific advancements is largely centred around the sailing industry, which can be drawn on for design inspirations and solutions to the next Hydro-Ski design. Of the many foiling sailboats, the Moth sailboat provides dimensions of approximately the same size as that of the Hydro-Ski and has been analysed with respect to altitude and pitch control (Findlay & Turnock, 2008).

The Moth sailboat is a high-performance, foiling vessel designed for racing, it is known for its exceptional speed and manoeuvrability. Common to most foiling sailboats, the Moth incorporates a clever design of a mechanical system that controls the altitude without input from a sailor see figure 4 (Ponte et al., 2022).

Figure 4 - Moth Sailboat control diagram, adapted from (Ponte et al., 2022)



This is achieved through a mechanical linkage from a wand, that rests on the surface of the water up through a series of mechanisms to a control surface 'movable foil flap', allowing the vessel to maintain height while foiling (Destuynder & Fabre, 2018). Unlike the current design, the lift force is increased or decreased in line with its centre of mass, meaning no moments are created in the longitudinal plane. Separating altitude control from pitch control, a key issue with the current Hydro-Ski design.

3.2 Candela C7 foiling boat

Useful the as the literature on sailboats might be, it is not sufficient to cover issues related to thrust of the vessel. Being one of the first electrically driven PWC, there is not much in the way of publicly available information regarding the technology behind the design of powered hydro-foiling craft. Nonetheless, not being a direct competitor, a Swedish start-up, (Candela), has successfully developed a hydro-foiling boat which has been analysed regarding thrust control. Their latest model, the C7 shown in figure 5, is capable of a range of 50 nautical miles and a top speed of 30 knots. Making it the most accomplished high powered, electrically driven, foiling craft.

Figure 5 - Candela's C7 foiling boat (Candela)

The key difference to this design and the UWA's current design is that there are no ailerons. Instead, by using hydraulic actuators, the entire foil's pitch is adjusted, changing the angle of attack of the foil. By changing the angle of attack of the front foil independently on either side of the front wing, the unbalanced lift force across the wing allows the vessel to enter a banked turn. Demonstrated in figure 6, is aerial footage of the C7 making a wide, left banked turn. Here by close inspection, it is evident that the thrust is perfectly perpendicular to the bow of the boat, while the vessel makes a wide left turn indicated by its wake.

Figure 6 - Aerial footage of the C7 making a left banked turn (Candela)

Though it has a vastly different control system, the centralised thrust provides a solution to the current differential thrust issue experienced by the Hydro-Ski. By increasing the size of the motor, the two motors can be replaced with a single, larger motor, allowing the thrust force to be positioned centrally. Thus, making the it impossible for differential thrust forces to occur, significantly improving safety and functionality to both the vessel and users.

4 Problem Statement

As the current design of the Hydro-Ski was constructed with the aim of proving the working principal of electrically-powered, hydro-foiling, many of its components resulted from what was available, economic reproducibility was not a factor considered in design choice.The primary stakeholders, Oceanomatics in conjunction with The University of Western Australia are ready to invest in the next iteration of the Hydro-Ski, the intention is to produce a final design iteration that will enable scalable production while resolving these final remaining mechanical issues.

4.1 Objectives

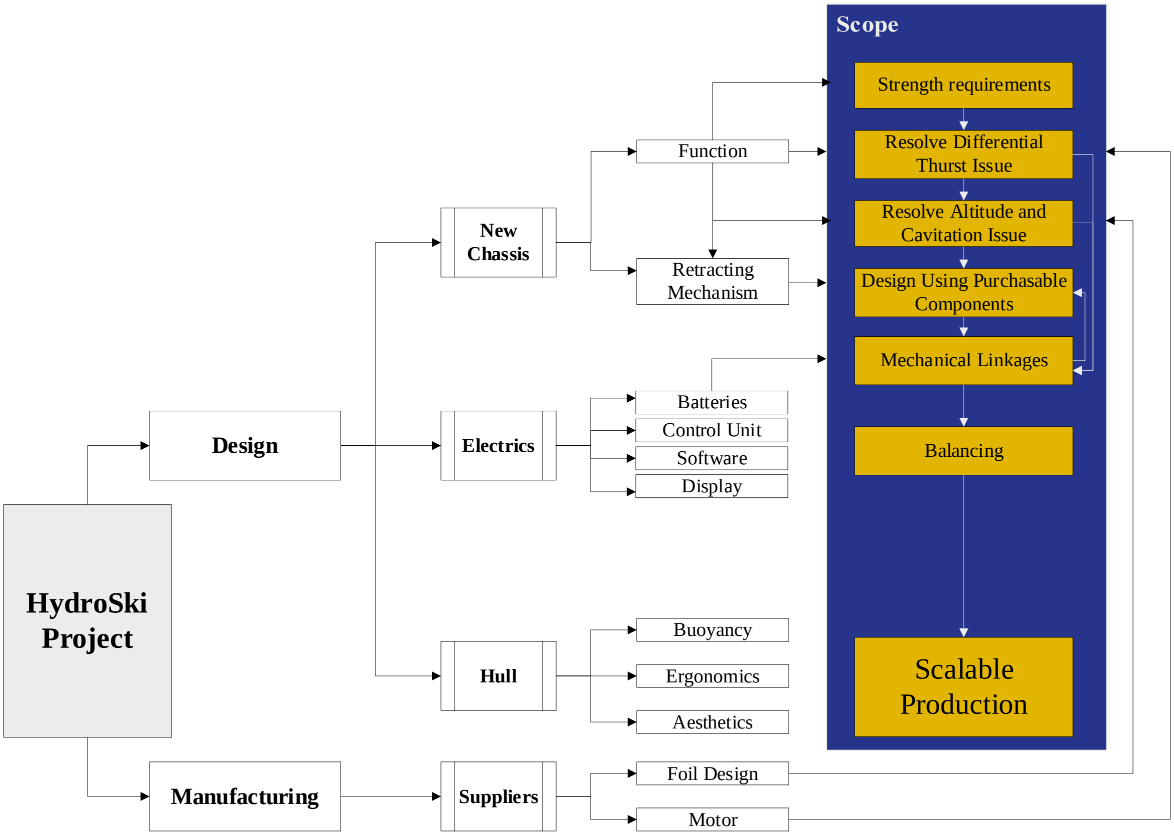
The aim is to design a chassis that encompasses the functionality and strength of the Hyrdo-Ski while foiling. This chassis will be easily be mounted to the exterior body, that will provide the buoyancy, seating, handle as well as the overall aesthetics of the final product. By outsourcing components, the total size of the future production facility will reduce in both scale and cost.

Objectives that will ensure functionality and strength of the Hydro-Ski.

- Design & strength analysis chassis.
- Resolution of altitude/pitching control.
- Resolution of differential thrust issue.
- Integrate commercially available components.
- Mechanical linkages, servos to control surfaces, rudder to steering.
- Balancing, centre of lift & centre of mass.

Outlined below is the scope of this work and its logical relation to the overall Hydro-Ski project.

Figure 7 Scope outline



Here it should be noted that work has already begun on a retracting mechanism, see appendix 13.1, that will enable to raising/lowering of the foils to be automated and must be considered in the design.

5 Chassis Material Selection

Common materials used for small boats and watercraft include fibre reinforced plastic (FRP), aluminium alloy (5052), wood and high-density polyethylene (HDPE). The material used for the construction of the Hydro-Ski was selected on the criteria summarised in table 1.

Table 1 Material properties summary (Shinoda & Bathurst, 2004)

Material	Manufacturability	Corrosion Resistance	Youngs Modulus (GPa)	Specific Gravity (sg)	Cost estimate ($AUD)/kg
FRP	Moderately easy – requires mold preparation	Good corrosion resistance but can degrade over time if not maintained	200	1.4	2.5-5
Aluminium (5052)	Moderately hard, requires in house	Excellent corrosion resistance	68	2.7	3-6
Wood	Requires craftmanship	Susceptible to rod and decay if not maintained	18	0.7	1.5-5
HDPE	Easy	Excellent corrosion resistance	0.028	0.96	1.2-3

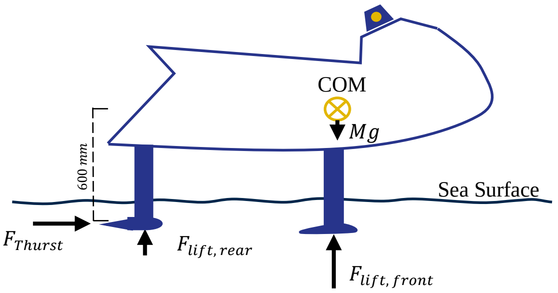
Manufacturability is a significant design criterion for this project, wood and aluminium was excluded as the labour cost of wood craftmanship would be too significant, furthermore though aluminium is easy to manufacture, its common form is extruded plates or bars, which would require further in house work adding to total production cost (Chiang et al., 2014). Though FRP had a much higher Youngs Modulus, its construction is mold based, and would be harder to integrate into a two-part design whereby the chassis can easily be mounted to the exterior body. Not being easily weldable or drilled into is a significant issue for this design, encouraging further investment to HDPE as the solution. One of the primary stakeholders, Oceanomatics Pty Ltd, have existing relations with a CNC HDPE manufacturer, able of producing any two-dimensional shapes from sheets of HDPE 40 mm thick. Particularly useful is HDPE ability to be welded, ensuring proper sealing of the parts, meaning that manufacturing of the chassis would be as simple as sending two dimensional drawings of the design and welding them together on site (Shakir Abbood et al.; Shinoda & Bathurst, 2004).

A major concern was its relatively low Youngs Modulus of 28 MPa, though the client was invested in the selection of HDPE for is convenient producibility, it was agreed that a proper strength analysis would be conducted on the chassis before verifying its structural integrity.

6 Force Analysis

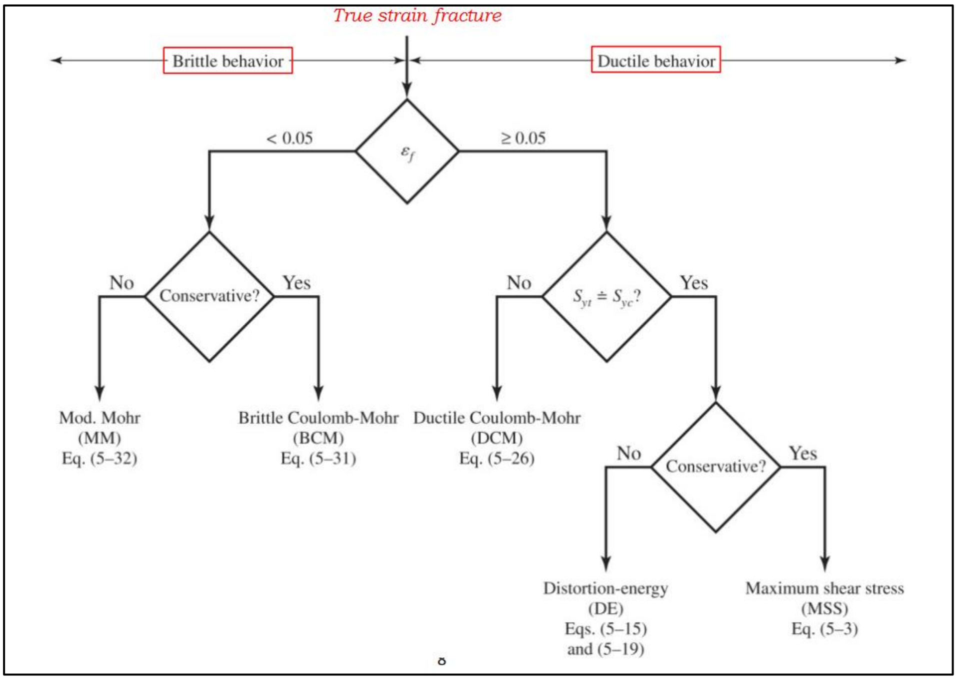
To ensure the structural integrity of the chassis, was to the largest forces acting on the vessel must be determined. The dominant forces present while foiling include three main components, thrust through the rudder, lift from the front foil and lift from the rear foil. Both lift forces act axially in the vertical (y-direction) while the thrust force creates a torsional moment on the bearing connection as it is acting along the x plane at a distance of approximately 600mm from the centre of mass depicted in figure 8.

Figure 8 - Free body diagram of dominant forces acting on vessel while foiling



Due to the material properties of HDPE, the Von Mises – Yield Strength failure criterion has been selected as HDPE is a ductile material following Shigleys approach to ductile failure theory.

Figure 9 Shigleys Mechanical Engineering Design Failure Selection flowchart (Budynas, 2018)



Allowing an analysis that will account for all shear, axial and torsional forces created from the three dominant forces acting vessel, thrust, lift and gravity.

6.1 Thrust Force Analysis

An estimate for thrust force is given by simple momentum theory, as a worse case corresponds to maximum force, it is acceptable to neglect losses due to turbulence, heat and noise. Allowing momentum imparted to the water to equal momentum transferred to the vessel.

Hence considering the mass flow through the propellor, static thrust force is given by:

$$F_{Thrust} = \dot{m} \cdot [v_e - v_o]$$

Where $\dot{m}$ is the mass flow rate, v_e is velocity at exit and v_o is the entrance velocity.

Substituting for mass flow rate,

$$\dot{m} = \rho \cdot \pi \cdot r^2 \cdot v_p$$

Where ρ is density of water, r is the radius of the propellor and v_p is velocity at the propellor.

Assuming:

1. Incompressible flow:

$$v_e = v_p$$

2. No current, entrance to propellor is considered at a point far enough away for no disturbance (low pressure):

$$v_o = 0$$

$$F_{Thrust} = \rho \cdot \pi \cdot r^2 \cdot v_e^2$$

3. An estimated top speed of 20 knots and a standard propellor diameter of 15cm

Yields the following constants and resulting thrust force of 1.875 kN.

Table 2 Thrust force constants

Parameter	Value	Unit
Thrust Force (F_{Thurst})	1875	N
Density (ρ)	1000	Kg/m^3
Propellor radius (r)	0.075	m
Velocity (v_e)	10.3	m/s

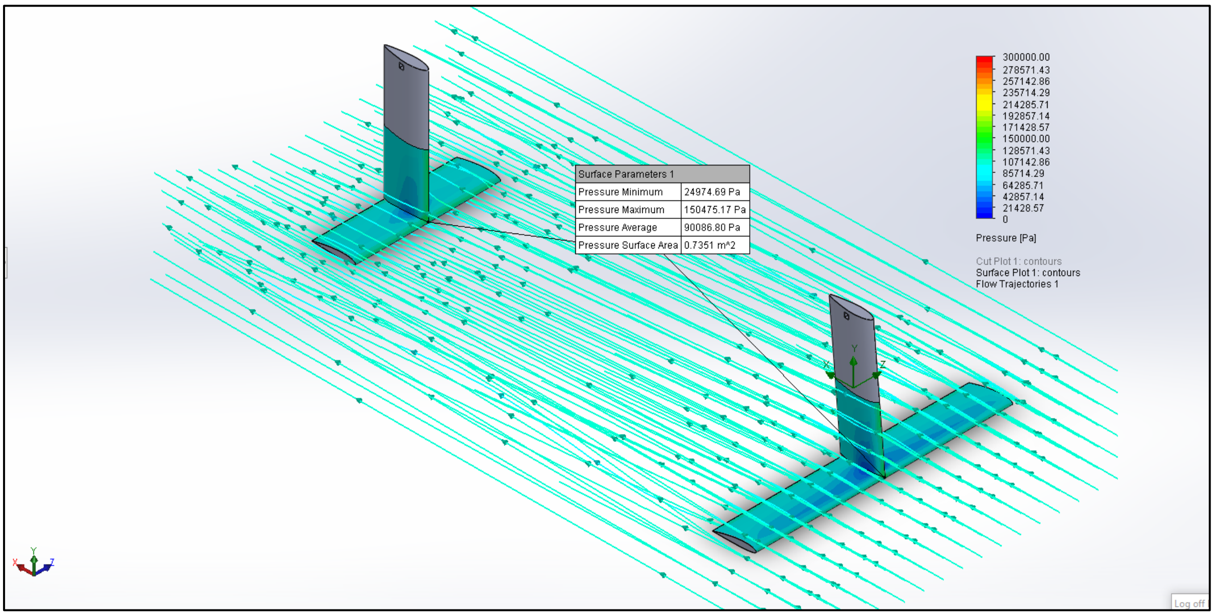
6.2 Lift Force Analysis

To determine lift force, the foils have been modeled with a simplified closed surface geometry in order to conduct FVA flow analysis on SolidWorks see figure 10. The front foil length of 1.17m, rear foil length of 0.66m and mast length of 0.6m was based on the dimensions of the current design. While the foil profile is based on the NACA 2415 profile (Genc et al., 2012) which closely resembled that of commercially available foiling products discussed later in section 9. Using an iterative process, the optimal parameters of distance between foils (d), front foil angle of attack (α), rear foil angle of attack (β) were determined. whereby the distance between foils and angle of attack was adjusted to arrive the optimum result of a load carrying capacity of 530kg, parameters are summarised in table 3 while resulting lift forces are summarised in table 4.

Table 3 Finite volume analysis parameters

Parameter	Value	Unit
Distance between foils (d)	2	meters
Front Foil angle of attack (α)	5	degrees
Rear Foil angle of attack (β)	2.5	degrees

Figure 10 - FVA maximum pressure differential of 125.5 kPa. $d = 2$m, $\alpha = 5$ degrees, $\beta = 2.5$ degrees.



Naturally this pressure differential only represents the maxima and mina pressures experienced on the foils at an elemental point and is thus not indicative of the force over the entire surface area of the foil.

The total resultant lift force averaged over the entire surface of the foils varied significantly with each iteration. Thus, it was necessary to run multiple iterations until the simulation stabilised as depicted in figures 11 to 13. Final results were obtained when the averaged resulting lift force varied less than 1.5% of total load.

Figure 11 - Rear foil lift force, 110 iterations until stabilisation at 353 Newtons

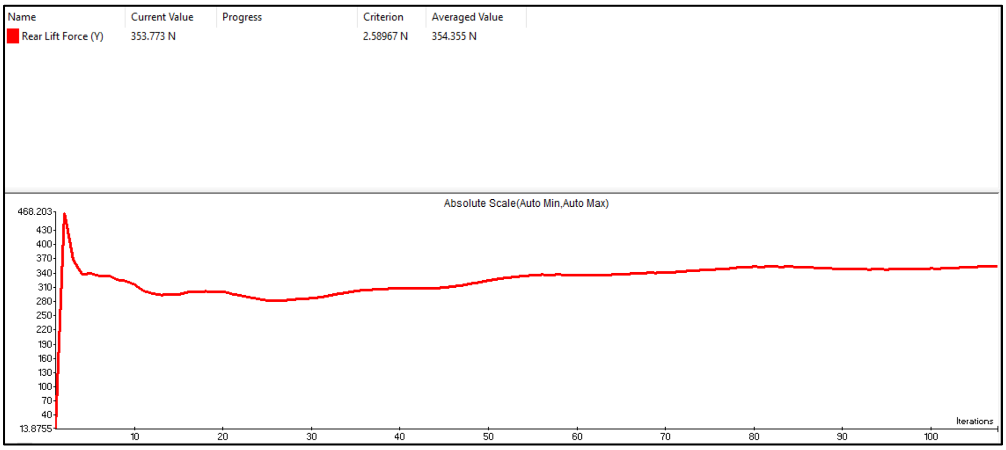


Figure 12 - Front foil lift force, 110 iterations until stabilisation at 3972 Newtons

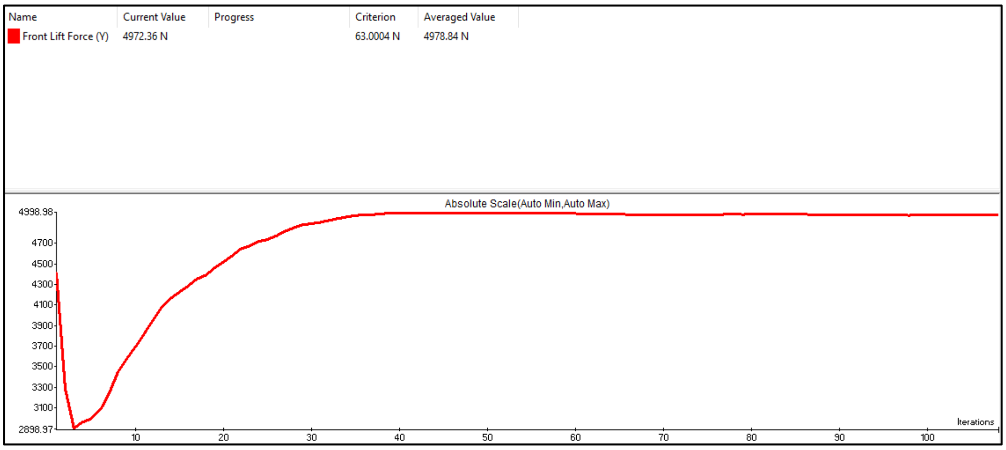
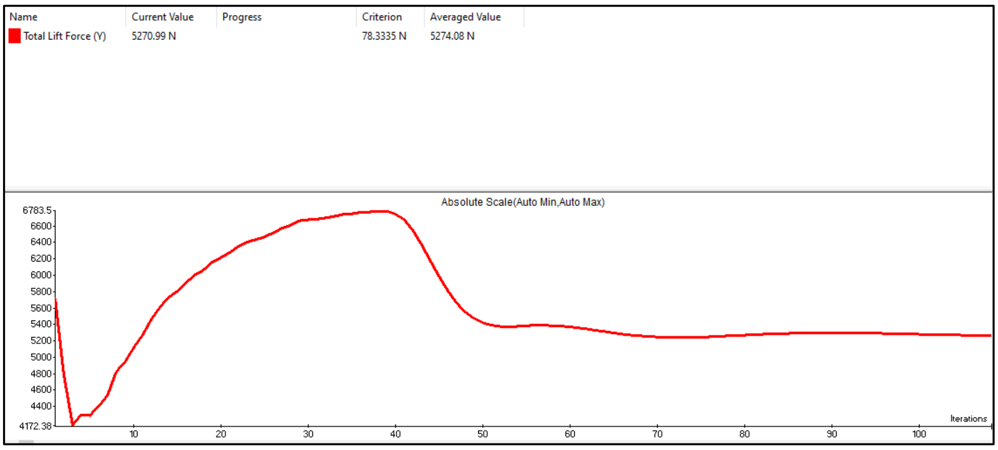


Figure 13 - 110 until stabilisation at 5270 Newtons



Thus, forces present at maximum velocity of 20 knots are summarised in table 4.

Table 4 Summary of lift forces acting on the vessel, obtain from iterative calculations of averaged force over entire wing.

Force	**Value**	**Unit**
Rear Lift	354	Newtons
Front Lift	4978	Newtons
Total Lift	5274	Newtons

Note that the sum of the rear foil lift and front foil lift do not necessarily sum to the total lift calculated. As seen in figure 13 the total lift force from both foils rises significantly, nearly asymptotes, drops and then stabalises at a lower value. This could be explained by the complex turbulent effect the front foil might have on the rear foil. As such, each iterative stabilising averaged force calculation was conducted independently for the front, rear, and total force, yielding small variations to each result. Separate values for rear and front foil lift are useful for balancing in section 11.

7 Insert Design

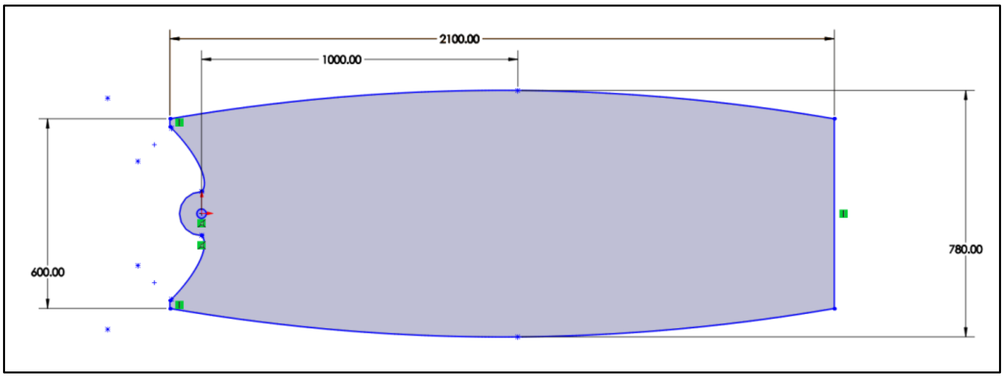
7.1 Constraints

As the chassis will be constructed from welding 4mm sheets of HDPE, the geometry must be simple in the y direction (height) and cannot accommodate significant slopes. The total length of the Hydro-Ski cannot exceed 4m in length, to ensure its transportability on common trailers, with a rough goal of 3.5m. Discussions with the client highlighted that the height of the chassis must be as limited as possible allowing the side profile (in the x-y plane) to be kept to a minimum reducing the effects of cross winds on the stability of the craft. It must also be large enough to house all electrical components including batteries, control unit, cooling system and foil retracting mechanisms. To ensure waterproofing, it is desired for the hull bottom to be completely sealed, whereby the body of the Hydro-Ski may be mounted and welded to the top. Lastly the chassis must accommodate a bearing for the rudder that will allow a 120-degree turning radius. Following several presentations of initial designs see appendix 13.2, the following base was selected.

7.2 Dimensions

Figure 14 shows fixed dimensions, total length, back width, maximum total width and point of maximum width along its length, while curvature may be changed to accommodate the mounting of the body yet to be designed.

Figure 14 Base dimensions of Hydro-Ski



Significant changes from initial drawings include accommodating the front foil within the insert design. Initially it was desired to exclude the front foil, as this will extend directly into the water creating a potential leak point. As the project progressed it was noted that water proofing will be required regardless due to the addition of a front control surface (see section 10.1), thus proper seals would be required at the foils exit point. Thus, a section was added to guide the front foil mast, held in place by a locking pin connection, raised and lowered by retracting mechanism (see section 13.1).

8 Strength Analysis

Once the base design of the chassis was finalised, a finite element analysis was conducted in SolidWorks to verify the strength of the HDPE chassis, from section 5 the design criterion required that the maximum Von Mises stress must be less than the yield strength of HDPE (21.9 MPa),(Shinoda & Bathurst, 2004).

Figure 15 Finite Element Analysis of forces acting on HDPE chassis while foiling

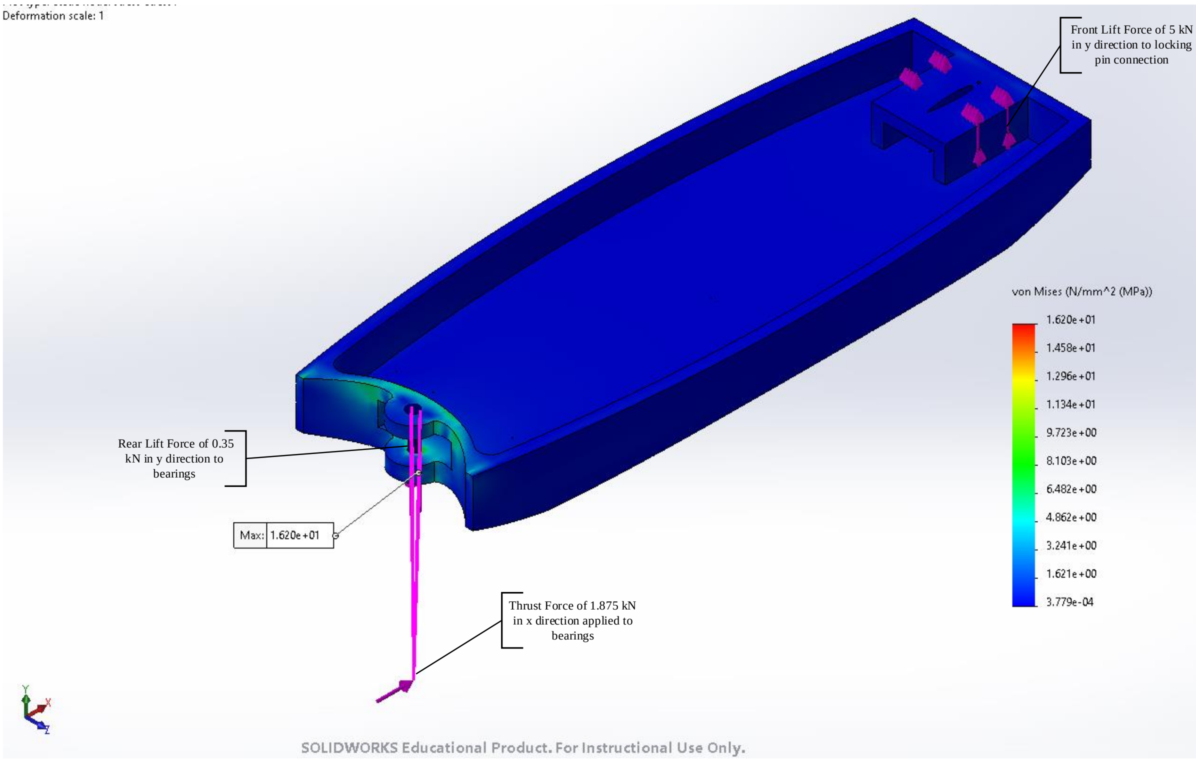
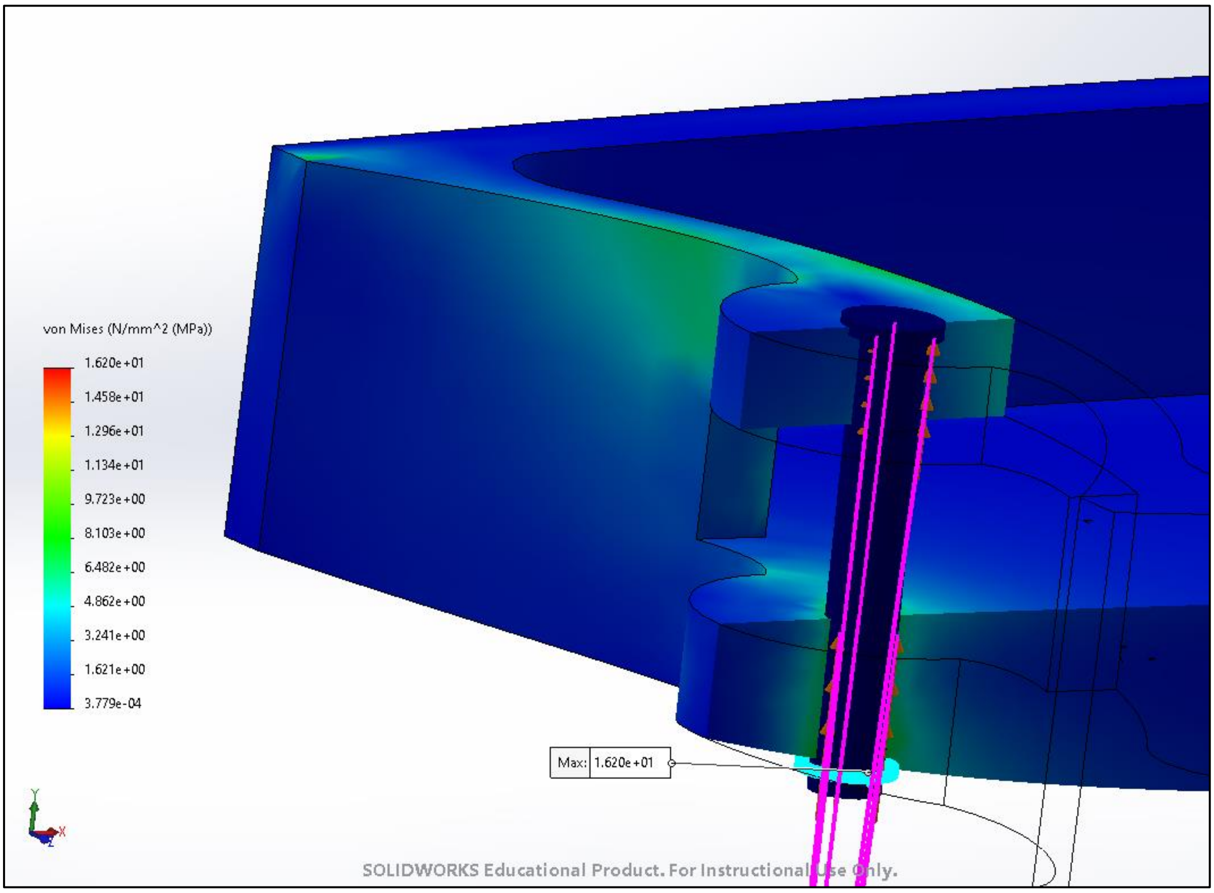


Figure 15 depicts the results from forces calculated in section 6, 1.875 kN thrust force in the x direction at a distance of 600mm, 0.35 kN lift from the rear foil in the y direction and 5kN of lift from the front foil also in the y direction. As predicted, although the lift force from the front foil is much larger, the effect of the moment acting on the bearings from the rudder has the most significant effect as it acts over a smaller surface area.

SolidWorks shows a maximum Von-Mises Stress of 16.2 MPa found, dangerously close to the yield strength of HDPE, however it should be kept in mind this is acting at a finite element, as shown in figure 16, the contact point with the bearing. Small local deformation is not of great structural concern and can easily be solved with a proper installation of the bearing connection.

Figure 16 – Detailed view of largest Von-Mises Stresses acting on body, concentrated at the rear and lower bearing.



As shown the majority of the remaining stresses are concentrated around the rear wall supporting the bearing connection, depicted in a turquoise to green colour indicating a Von-Mises Stress of around 6.4MPa.

Resulting in a safety factor S of:

$$S = \frac{Yeild\ \ Strength}{Max\ operating\ condition} = \frac{21.9}{6.4} = 3.4$$

For a maximum velocity of 20 knots, and load of 500kg (total weight).

As assumed, FEA modelling confirmed that the maximum stress on the chassis is concentrated around the bearing connection as shown in figure 16. In this design the chassis supports the bearing pin at its top and bottom, maximising the second moment of area of the chassis under bending and achieves a satisfactory safety factor of 3.4. Any alterations to this connections (as suggested in the limitations, see section 12.2.2) will have to be verified with a FEA analysis on the bearing forces interacting with the chassis.

9 Commercially available products

As outlined in section 4 figure 8, commercially available products are necessary for the scaled manufacturing of the end product, thus the selection of parts to be purchased occurred in conjunction with the new design. The selection process of electrical components was not included in this scope, the selected components are outlined below.

9.1 Maytech Fully Waterproof MTI120116 18.8KW

Single Powerful Brushless In runner Motor for Electric Surfboard/RC Boat/Jetski' (Maytech, 2023).

Table 5 - Maytech 18.8kW Motor Specifications & Details (Maytech, 2023)

Supplier	Maytch Australia	
Model Number	MT120116-100	
Max Power (kW)	18.8	
Peak Current (A)	220	
RPM (max)	10000	
Max Torque @60% (N*M)	22.6	
Efficiency (%)	88	
Weight (kg)	4.6	
Quote (x1) – ($AUD)	1,790.90	

9.2 Lithium Phosphate Iron Batten Battery

20 × lithium phosphate batteries sourced from (DHGate, 2023), China suitable for marine application.

Table 6 - DHGate 138 AH Batten Battery (DHGate, 2023)

Supplier	DHGate (China)	
Model Number	Lifepo4	
Nominal Voltage (V)	3.2	
Capacity	138 AH	
Length	960 ±1.0mm	
Width	90 ±1.0mm	
Thickness	13.5 ±0.5mm	
Weight (kg)	2.63	
Quote (x20) – ($AUD)	1,908.13	

9.3 Hydrofoils supplier - WASZP

Oceanomatics already had an existing relationship with an Australian sailboat manufacturer, WASZP, who were contacted to source foil assemblies separately (Sailing, 2023). The following parts were sourced and quoted see appendix 14.4. The front foil assembly would require minimal retrofitting, however significant changes need to be retrofitted to the rear foil assemble to accommodate the motor and rear control surfaces, as outlined in section 10.2-10.3.

The same vertical foil assembly will be used for the front and the rear foil, the connection to the horizontal foils is design to allow adjustment of connection angle from zero (perpendicular) to eight degrees (from vertical). Note this is not the angle of attack of the horizontal foil profile, rather the angle at which the mast will penetrate the water.

Table 7 - Mast Assembly details

Supplier	WAZSP – KA Sailing	
Model Number	WZFFVX	
Height (mm)	795	
Length (mm)	160	
Width (mm)	30	
Penetrating angle (degrees)	0 - 8	
Material	Aluminium	
Quote (x2) – ($AUD)	863.43	

Table 8 - Front foil assembly details

Supplier	WAZSP – KA Sailing	
Model Number	WZFFH84X	
Height (mm)	20	
Length (mm)	155	
Width (mm)	1170	
Control Surface	Single bearing	
Material	Aluminium	
Quote (x1) – ($AUD)	415.79	

Table 9 - Rear foil assembly details

Supplier	WAZSP – KA Sailing	
Model Number	WZFFH62X	
Height (mm)	20	
Length (mm)	155	
Width (mm)	660	
Control Surface	Single bearing	
Material	Aluminium	
Quote (x1) – ($AUD)	260.00	

Note these quotes are only valid until 17/04/2023 and have been provided for the purpose of cost estimates.

10 Design Solutions

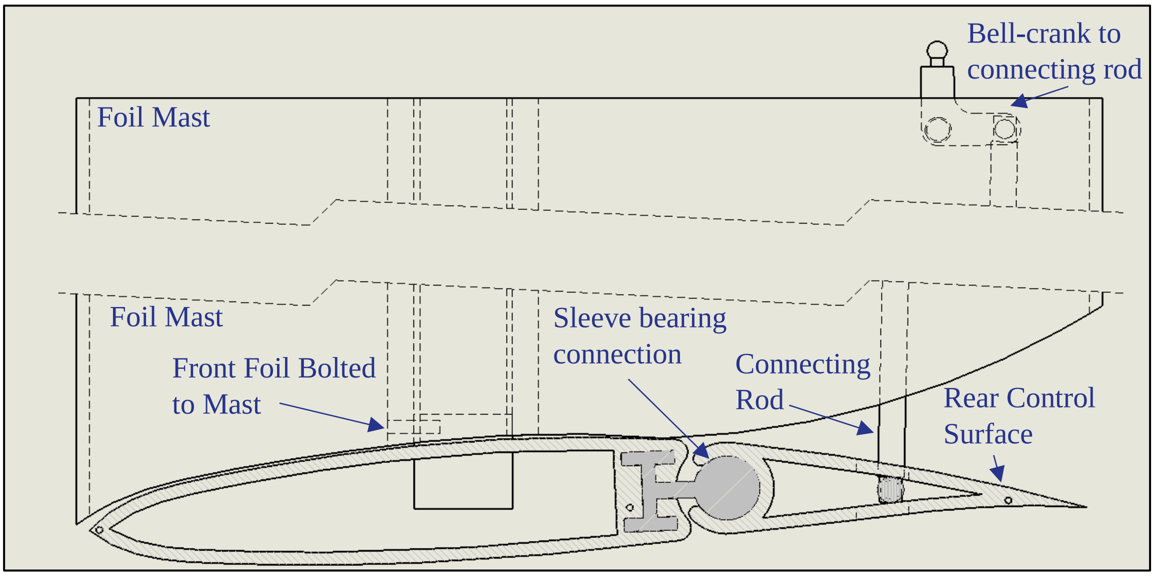
10.1 Front Foil control

As previously discussed in section 3.2, a solution to the pitching cavitation issue might be obtained by adding an additional control surface to the front foil. This will allow any adjustment of altitude to be separated from a change in pitch, as the resultant force from the control surface acting on the front foil is in line with the centre of mass of the craft, thereby not creating an additional moment which would otherwise alter the pitch of the craft. Minimal modifications are needed to the WASZP horizontal foil (WZFFH84X) while the front vertical foil (WZFFVX) can remain as is. To ensure compatibility and full function, a SolidWorks model of these foils have been constructed.

Note* that though these designs are original creations on SolidWorks, they were modelled directly from a patented design with minimal alterations, as such, they should not to be reproduced and must be purchased directly from a supplier and then modified to fit the craft.

The front part of the horizontal foil is bolted to the mast, while the rear is separated and connected with a sleeve bearing see figure 17, creating the front control surface. The foils are constructed of aluminium, while the bearing is likely a hard polymer, like Teflon, providing minimal friction, especially in a wet environment.

Figure 17 Front foil assembly details



Within the rear control surface, a rod has been added to reduce the deflection of the front control surface. It connects to the lower end of a connecting rod (running up the interior of the mast) with a pin connection, this allows the control surface to be rotated around its sleeve bearing with vertical movement of the connecting rod. At the top end of the connecting rod, a bell crank converts reciprocating to oscillating motion, this is where a servo motor will be attached. Thus, the pitch of the front control surface may be actuated from the top of the foil mast, not requiring any electrical components to be submerged. As the horizontal foil assembly (including control surface), vertical foil assembly (including connecting rod and bell crank) will be purchased from WASZP, no significant alterations are required.

Figure 18 Front foil transparent view

10.2 Centralised Thrust

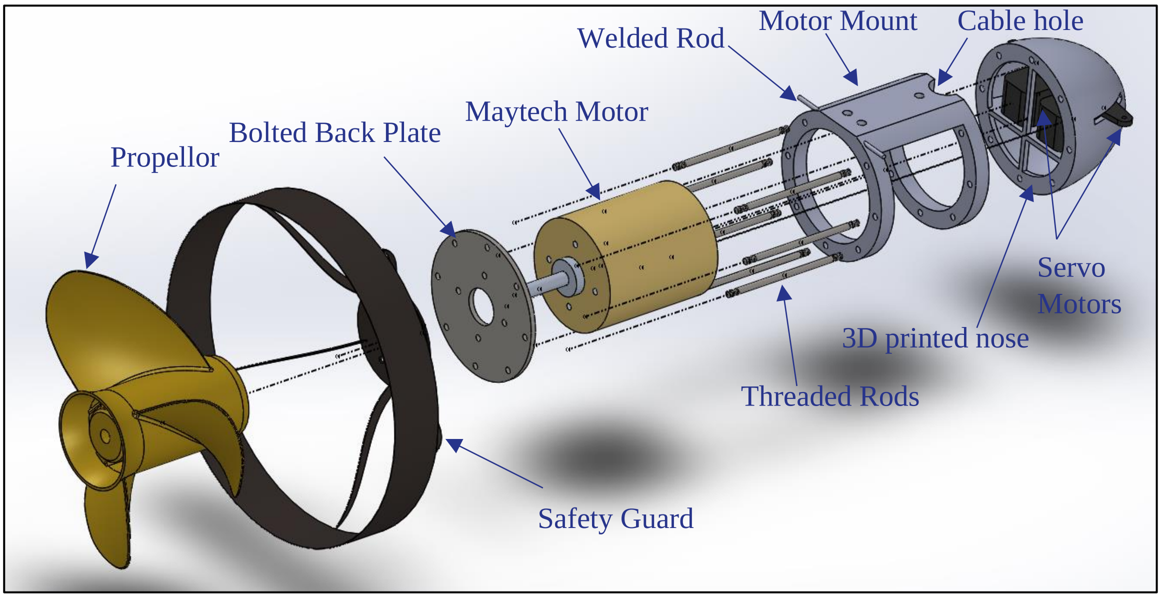
The differential thrust issue explored in section 2.1.2, is easily resolved from learnings outlined in section 3.2, whereby simply replacing the two motors on the outer ends with a centrally located motor removes the possibility of differential thrust. It will however, require a significant alteration to the commercially available rear foil from WAZSP see section 9.

The 18.8 kW motor purchased from Maytech is not offered with a front mounted adaption, meaning it can only be mounted from the rear where its shaft is, thus a mounting needed to be constructed to hold the motor in place. Due to the significant forces involved, high strength was required without inhibiting convective cooling, as the motor is not water-cooled, but is fully water proof. Electric cables deliver power to the motor from the front end (opposite to the shaft), as such a protective nose cone was envisioned. Due to the large size of the motor, this nose cone provided a useful space to house two servo motors for the actuation of the rear control surfaces later detailed in section 10.3.

The final design is depicted in figure 19, an aluminium motor mount, encases the Maytech motor and connects directly to the bottom of the rear horizontal foil. This motor mount has been designed to allow water to flow past the motor for convective cooling, however this meant that it was prone to bending stress through the mount connecting to the foil due to the axial thrust force of the motor. This has been resolved by the use of a bolted back plate and threaded rods, which bear the axial load from the motor. A small cable hole needs to be machined to allow electrical power to be delivered to the motor and servo motors. Two steel rods need to be welded to the motor mount to attach a bell crank (part of the rear control surfaces actuation mechanism, see section 10.3).

The nose will not bear any significant load, allowing it to be 3D printed from a hard polymer and will house two servo motors that will actuate the rear control surfaces. At the rear, a safety guard mounts to the back plate, with a propellor yet to be sourced.

Figure 19 Exploded Motor Assembly

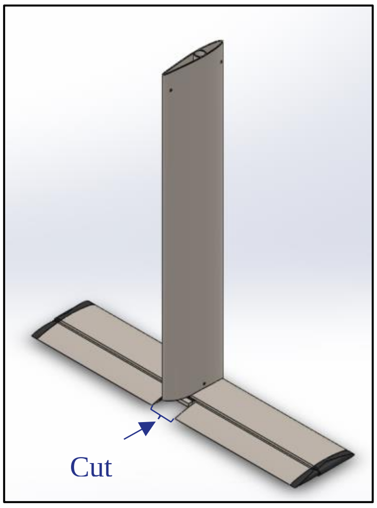


Note* it is essential to bolt both the backplate/motor mount and the nose/motor mount, such that each threaded rod will have four nuts, (two on each side of front and rear connections). Else, the threaded rods will not distribute the thrust force around the motor mount, concentrating forces through to top of the mount where it connects to the rear foil and will likely fail.

10.3 Rear Foil Control Surfaces Actuation

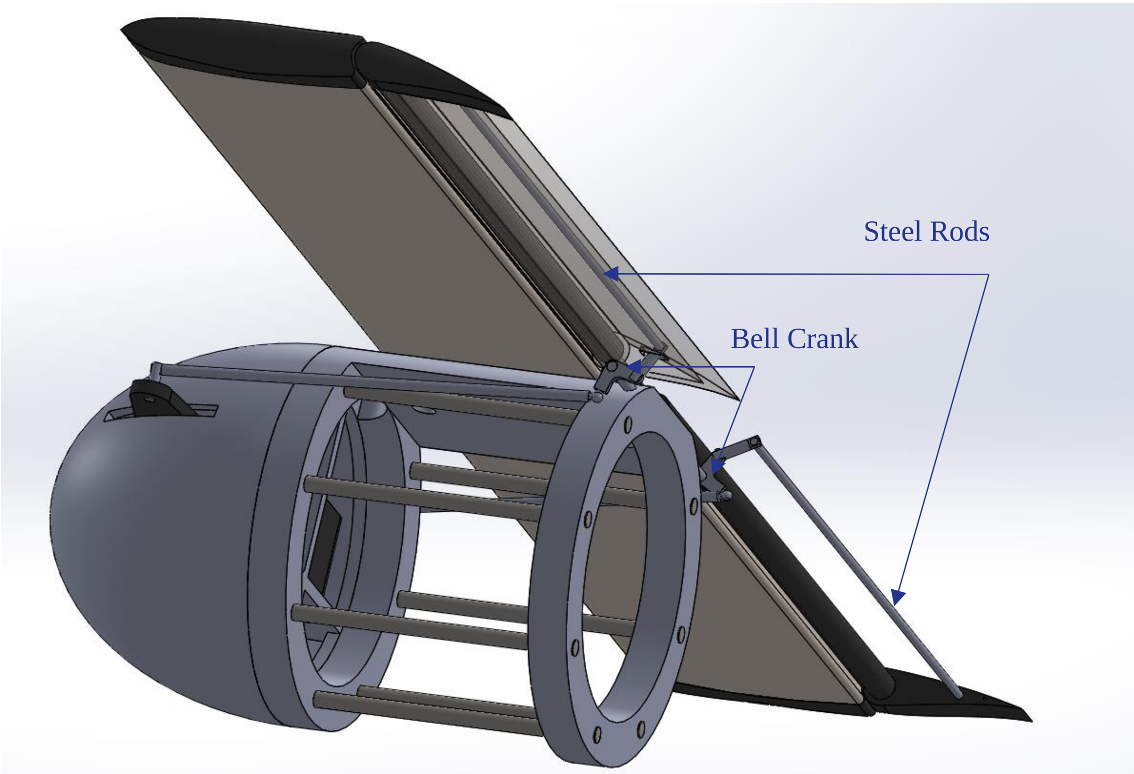
Alterations needed from the purchased Maytech WZFFH62X foil include modifications to the rear foil control surface, allowing independent movement of the two rear control surfaces and to accommodate the new motor as seen in figure 20, cut size is 60mm.

Figure 20 WAZSP rear foil alterations



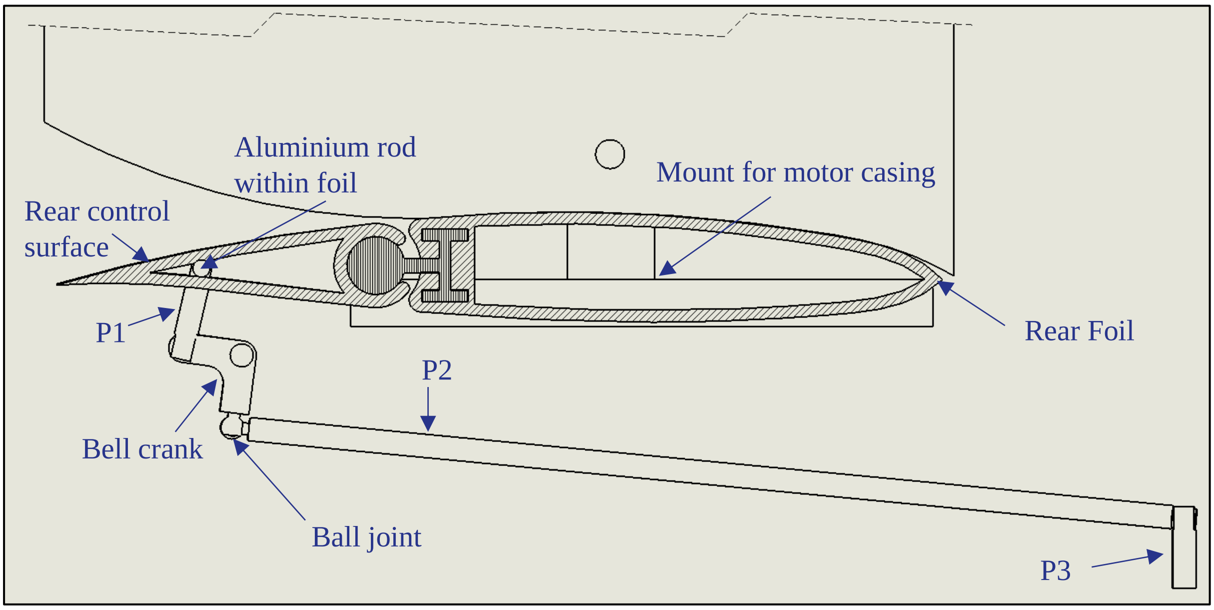
To ensure independent drive of two rear control surfaces, two steel rods need to be mounted to the rear control surface in the interior of the WZFFH62X foil as depicted in figure 21.

Figure 21 WASZP retrofitting details



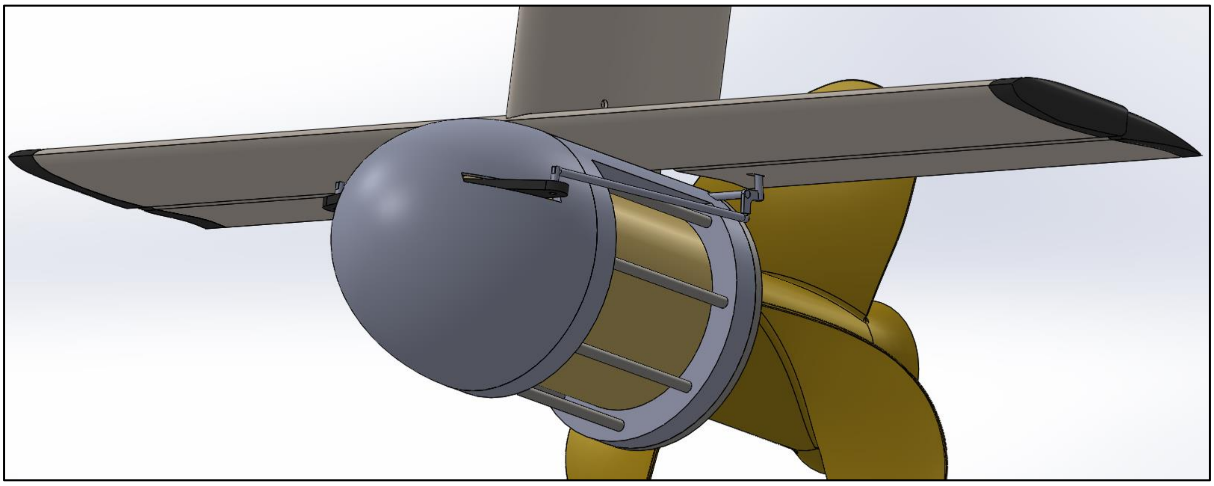
For actuation, a connection from the servo motors to the rear control surfaces needs to be implemented. Two bell cranks are mounted to the rods welded to the motor casing, transferring motion from the servo motors to the rear control surfaces, independently.

Figure 22 Mechanical link to servo motors



The mechanical assembly is composed of three additional connecting rods for each side, the longer middle rod, P2 will require a ball joint at one end to accommodate an extra degree of freedom and allow the rotary movement. P1 has two pin connections at 90 degrees from each other, one attaching to an aluminium rod within the foil and one to the bell crank. P3 are simple pin connection to the other end of P2 and has a bearing at its connection with the servo motor.

Figure 23 Full rear foil assembly

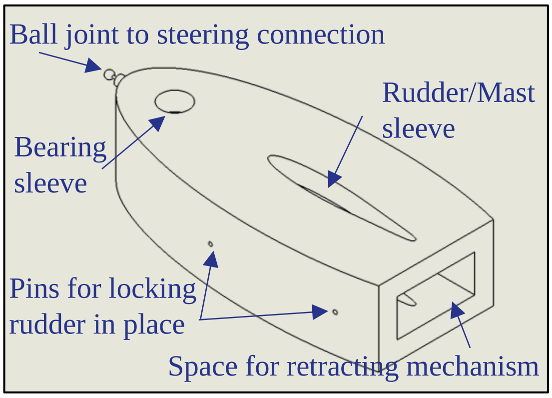


In a similar manner to the front foil actuation, oscillating motion of the servo motor will result in reciprocating motion of the rear control surfaces. The notable difference here however being that the two rear control surfaces may be actuated independently, allowing the opposing forces to create a moment about the x axis, allowing the craft to control roll.

10.4 Gantry

To accommodate the retracting mechanism to be implemented, see section 4.1, the rear foil mast (acting as the rudder) must be encased in a double-plated, walled gantry. As this part will be exterior to the body shape yet to be designed, aesthetics matter. Thus, a basic construct has been designed, however will require further artistic styling.

Figure 24 Gantry to secure rudder and accommodate retracting mechanism

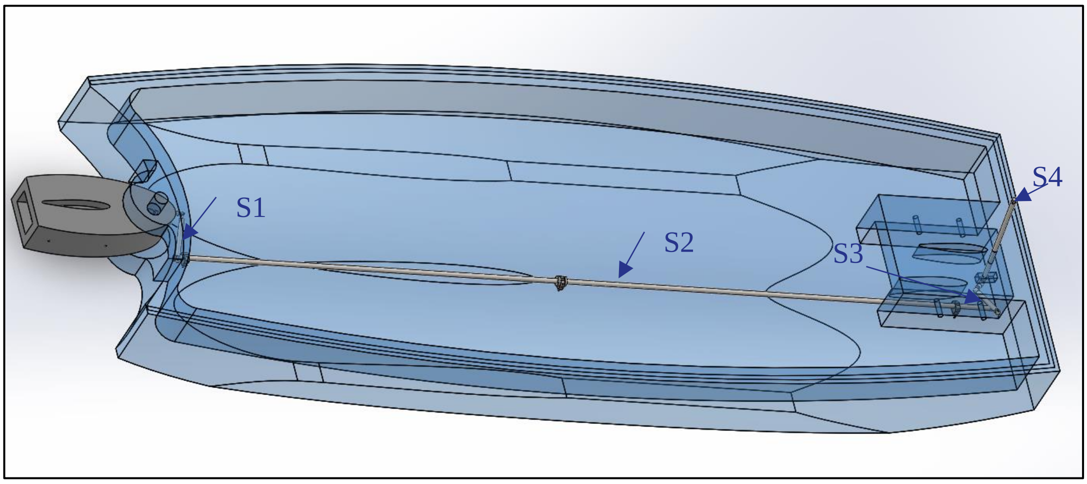


A pin with a ball-joint is connected at the front of the gantry connecting the steering linkage as depicted in section 10.5. A hole will allow a bearing sleeve to be inserted connecting the gantry to the chassis. The mast of the rudder assembly will be able to slide up and down the sleeve cut in the gantry through the use of a retracting mechanism and locked in place with pins while foiling or fully retracted.

10.5 Steering connection

The pervious design incorporated a wire steering assembly; however, it was noted in the past that it often failed mechanically, breaking at connections where the wire was forced to bend around corners. In this design a solid shaft steering linkage was attempted as shown in figure 25.

Figure 25 Steering Assembly

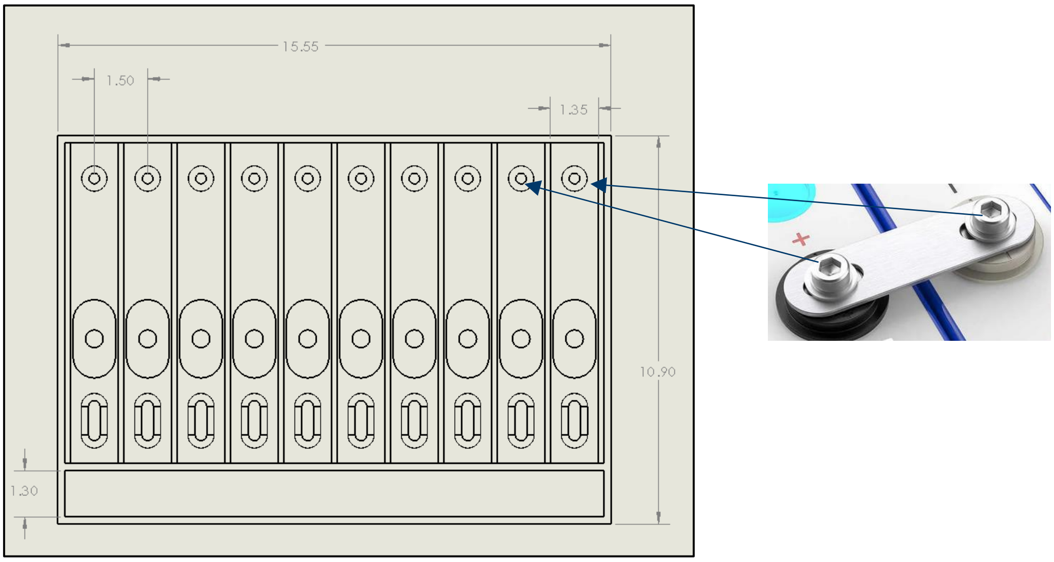


The steering assembly is comprised of four connections, S4 mounts directly to the handlebar to be purchased, as the handle bar is rotated, its rotation is transferred into liner motion of S3, rotation of S2, linear motion of S1 and finally rotation of the gantry about the bearing axis. Though this design has added strength, including the gantry, it will be a five-bar mechanism. This not only increases complexity, but also friction in each pin or ball joint, and warrants further investigation to design a simpler steering connection, that will be able to bear the loads from the rudder.

10.6 Battery mounts

The selected batteries are optimal for adding additional batteries in series, increasing voltage to a desired output, voltage and capacity was determined outside of the scope to be 64 volts, meaning 20 3.2-volt batteries will be required. As the configuration of the batteries will heavily impact balancing of the vessel, two assemblies of 10 batteries were envisioned, and detailed in figure 26.

Figure 26 Battery assembly mount (dimensions in milometers)

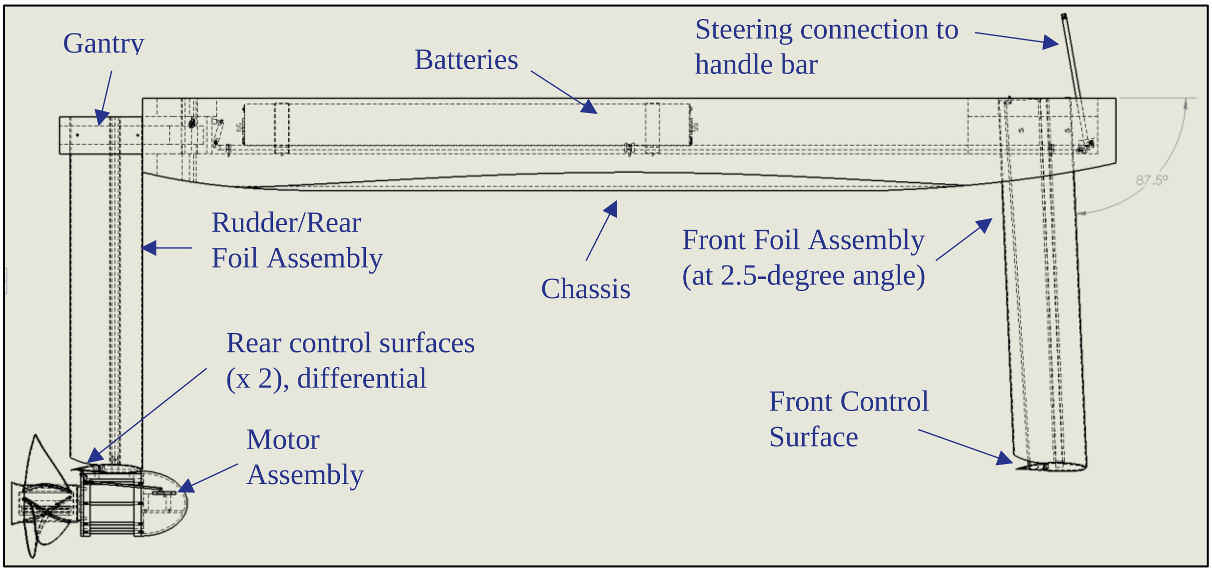


These drawings detail the mounting specifications, to connect these in series, the batteries are assembled (+ - + - …e.c.t.), and simply connected with aluminium connectors as per figure 26.

10.7 Complete Assembly

Assembling the new motor – rear foil assembly, front foil assembly and batteries the final design starts to come together. As the rear vertical foil also acts as a rudder it sits perpendicular to the vessel, while the front vertical foil sists at an angle of 2.5 degrees from vertical, giving it greater hydrodynamic stability and shifting the centre of lift forward slightly.

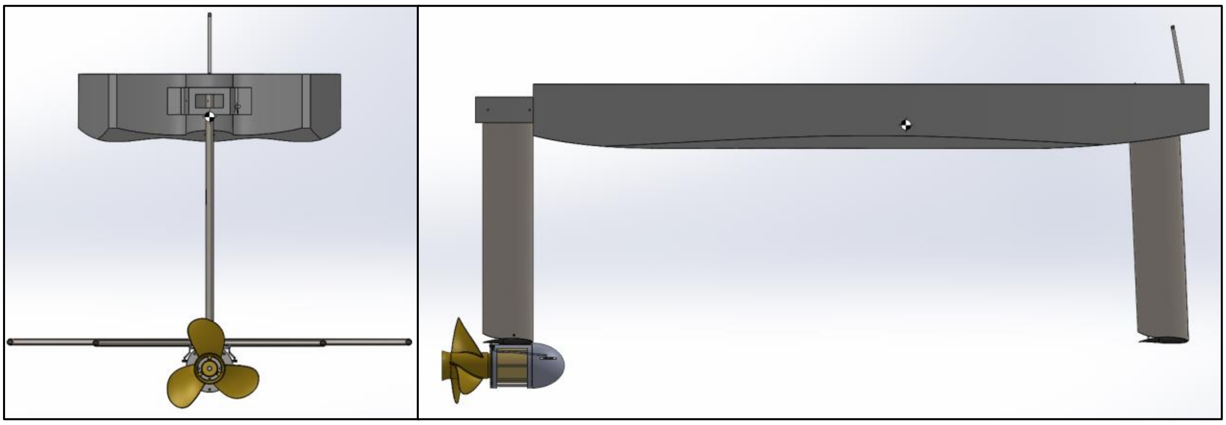
Figure 27 Complete assembly of subassemblies



11 Balancing

With the exception of the steering assembly, (in which case it was necessary to build around the centreline of the protruding foils), across the longitudinal plane (x-y plane), symmetry in design has ensured that the centre of mass sits centrally along the longitudinal axis. However, in the transverse direction, lift forces of both foils and gravitational forces of the chassis, exterior body (yet to be designed) and the rider need to be balanced. Using a SolidWorks Mass analysis software package, the centre of mass can be determined, shown in figure 28. With a total mass including all components, of 319 kilograms.

Figure 28 Centre of Mass analysis



The centre of mass in the transverse plane sits colinearly with the axis of lift produced from the foils, as long as the seat for the rider and the exterior body follows the same principal, stability in the transverse plane will be ensured. This would mean that the resting position (going straight) would require differential actuation of the rear control surfaces (creating a moment in the x direction to cause the craft to roll). In the longitudinal plane however the location of the centre of mass will be dynamic, as the lift produced from the foils is a function of velocity. This will be accounted for in a similar fashion as that of the current design where the automated stabilisation software pitches the craft to maintain stability. Nonetheless, from section 6.2 it is evident that the majority of the lift force will be derived from the front foil (at a velocity of 20 knots, about 5kN of lift from the front foil and 0.3kN from the rear). Roughly this means the rear will support about 30 kilograms while the front supports 500 kilograms. Thus, the centre of mass needs to be shifted significantly forward, this can be done in two fashions.

1. Move the front foil further back
2. Ensure the rider sits far forward as well as the weight from the exterior body which will protrude over the edge of the front foil by about 1.5 meters, see concept sketch in section 12.1, figure 31 for reference.

The real solution is likely a combination of both that will factor in the weight from the exterior body and the rider, with a simple function as follows. With the aim to have the global centre of mass (COM) be in line with the front foil, let x_1 be the distance between the centre of mass of the chassis (C), x_2 the distance between the rider (R) and x_3 the distance between the centre of mass of the exterior body (B) all with reference to the location of the front foil.

$$\sum_{x} x_1 \cdot C + x_2 \cdot R - x_3 \cdot B = 0$$

Noting that here it is assumed the centre of mass of the chassis and the rider are behind the location of the front foil while the centre of mass of the exterior body was assumed to sit in front of the font foil.

Thus, to accommodate constraints by the weight and positioning of the rider and exterior body, x_1 was reduced as far as possible by shifting the location of the batteries, with the result of the centre of mass sitting 710mm from the front foil. If this distance needs to be further reduced it must be done by shortening the chassis in total length and moving the front foil further back, possibly allowing the rider to sit in front of the front foil. However, this has not been progressed as it will depend on the weight of the external body, yet to be determined.

12 Conclusion

12.1 Final Design

The final design has met the design objectives of strength, provided by the chassis design, resolution of the pitching/altitude control (causing cavitation) has been achieved by the redesign of the front foil assembly with an additional control surface, while the differential thrust issue (causing instability) was resolved by redesigning the motor and rear foil assembly. All forces that contributed to the analysis of strength and balancing have been verified through Solid-Work packages including, flow simulation and force analysis, which incorporate finite element analysis for computation.

Actuation of the new assemblies has been considered as a part of this scope and are detailed with mechanical linkages. Space for electrical components and balancing of lift and weight force, ensure that this chassis will provide all the functionality of the foiling craft. An attempt was made to ensure the final design was holistic, in the sense that components complement each other, with their function. For example, in the rear foil assembly, the additional space created by the larger motor was used to house servo motors for the actuation of the rear control surfaces.

Finally, this design will allow for scalable manufacturing, the chassis body can be constructed from CNC HDPE cut outs, a motor has been sourced from Maytech and both of the new foil assemblies can be purchased from sailboat supplier, WASZP, retrofitted to accommodate means of actuation.

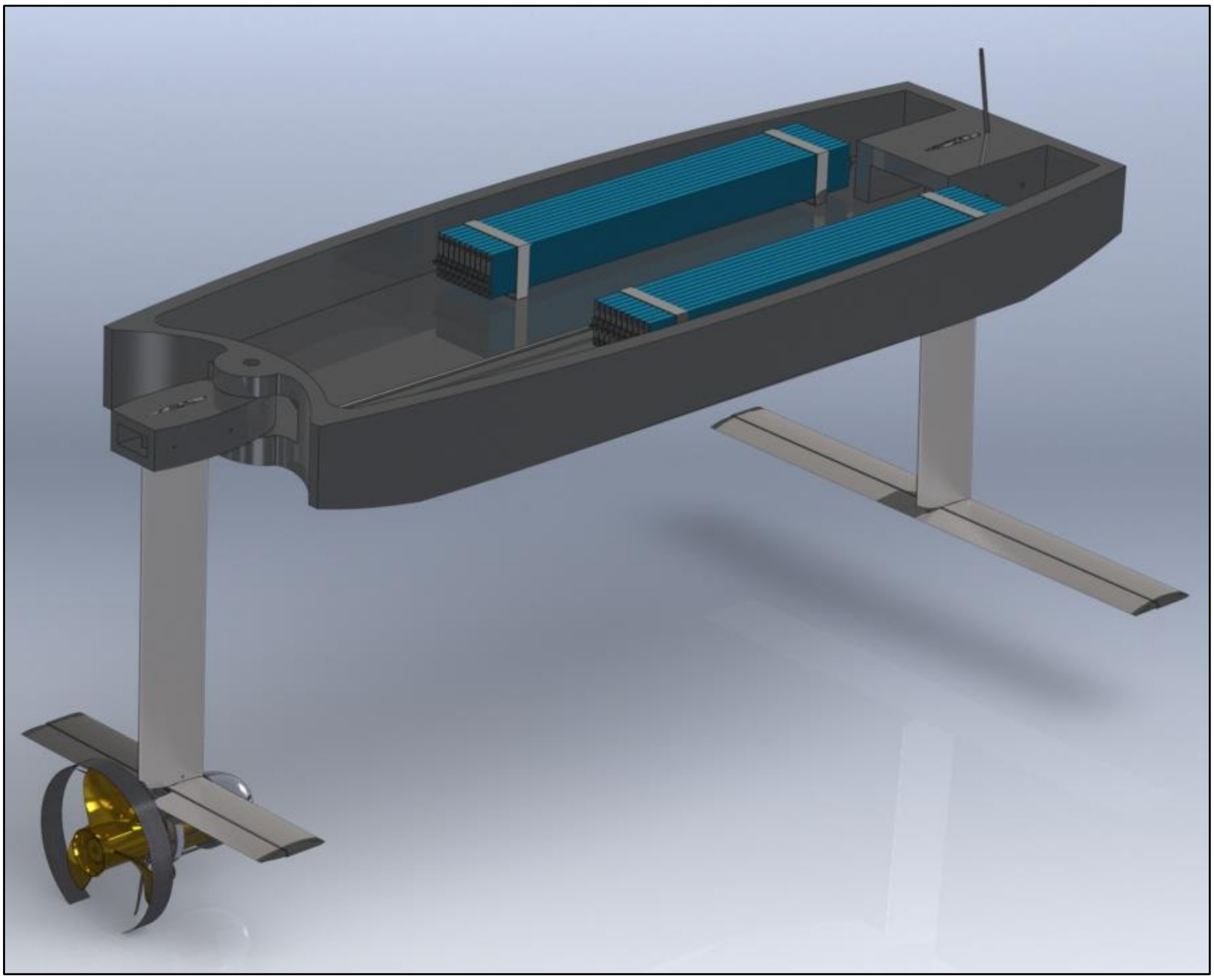
Table 10 Chassis final dimensions & specifications

Dimension	Value	Unit
Length	2280	mm
Height (foil extended)	1005	mm
Height (foils subtracted)	950	mm
Width	1200	mm
Centre of mass (from front foil)	710	Mm

Table 11 Design Specifications

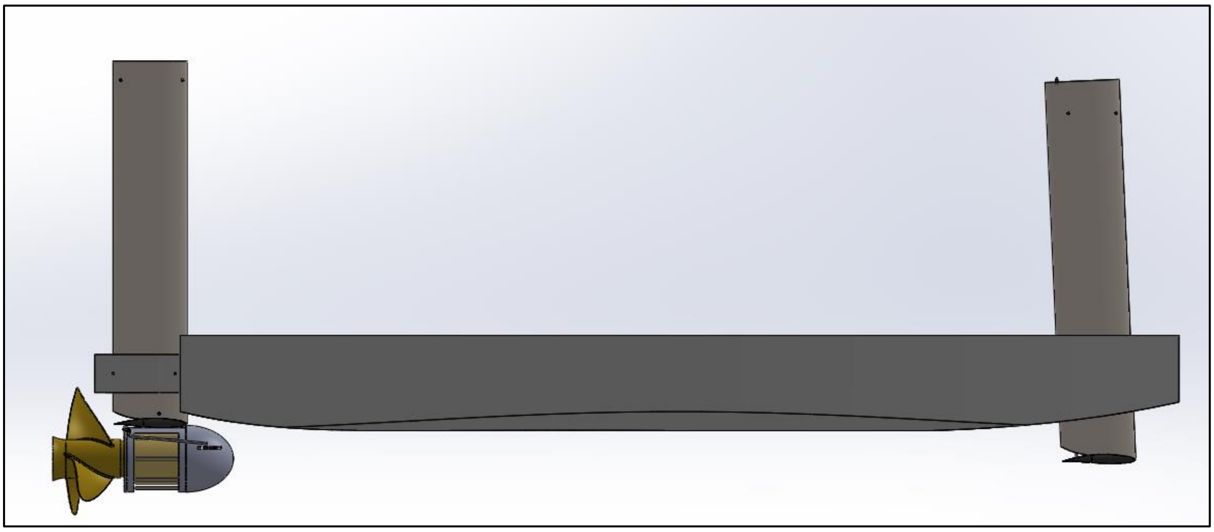
Specifications	Value	Unit
Weight (excluding submerged components & exterior body)	300	kg
Lift capacity (while foiling @ 20 knots)	538	kg
Payload (excluding exterior body)	238	kg
Design speed	20	knots

Table 12 Final chassis design, 3D render



The exterior body to be designed that will provide buoyancy (while not foiling), aesthetics, and ergonomics (seating and steering) will need to consider the retracted position of the foils as shown in figure 29.

Figure 29 Chassis with foils retracted



Below, are concept sketches to illustrate the size of the chassis and how it will fit within the exterior body which has been modelled off a standard size Yamaha Waverunner Jet-Ski .

Figure 30 Concept sketch of chassis within exterior body

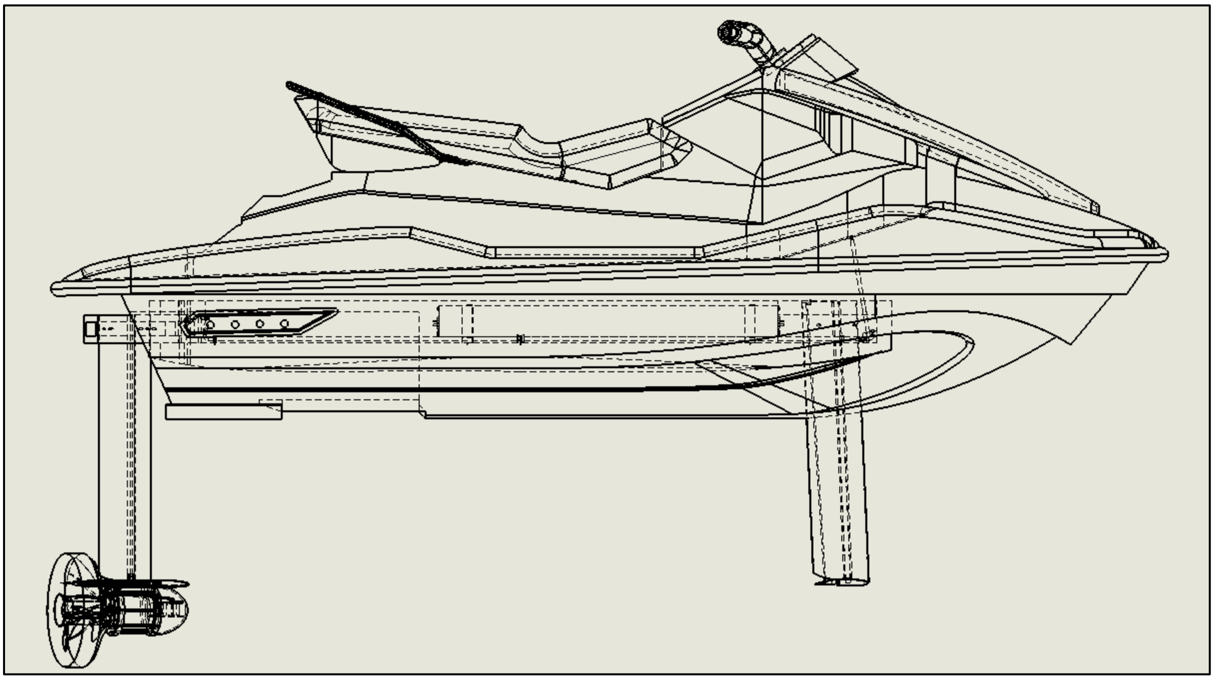


Figure 31 Hydro-Ski concept

12.2 Limitations

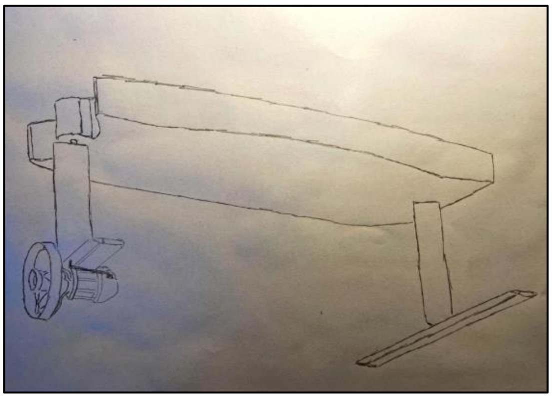
12.2.1 Components to be added

This design accounted for space needed for, electrical components such as the control unit, wiring, and cooling system to be mounted within the chassis and the retracting mechanism (shown in appendix 15.1). Actuation of the front control surface has not been specified as there is an ongoing discussion whether this is to operate in a similar fashion to that of foiling craft, with a mechanical wand design (as in figure 4 section 3.2) or if this will be integrated into the automated control system. Though features such as the propellor and safety guarding have been visualised, final components are yet to be sourced and will largely dependent on recommendation from Maytech. These components will be easily integrated as their rough dimensions have been accounted for throughout the design process of this chassis.

12.2.2 Rudder design

As previously mentioned, the rudder design will need to be altered, as the bearing for the rudder is in front of the thrust from the motor, the rudder will be forced from its central position causing instability. This issue was initially overlooked as in the previous design, the hydrodynamic force of the water keeps the rudder in place, however with a much larger motor, thrust force will be significantly increased, and must be further investigated and potentially redesigned to ensure safe operation. A possible solution is illustrated by shortening the rear vertical foil and welding a rod to the foil acting as a bearing.

Figure 32 Sketch of possible rudder solution



Note this was an initial sketch, excluded from further investigation due to the requirement of integrating the retracting mechanism, but solves the rudder and water proofing issue effectively.

12.2.3 Sealing/waterproofing

Evident from this design, is two sources of leaks, one at the connection with the front foil and one at the gantry connecting to the rudder. As previously discussed in section 10.1, the front foil retraction/extension needs to be properly sealed with a rubber seal around the shape of the foil. The rudder on the other hand has a large area to be covered, ideally this issue would be resolved with a redesign of the rudder as depicted in figure 32.

12.2.4 Payload

All finite volume analysis was conducted with the aim of determining maximum forces involved, to ensure structural strength. Thus, the payload indicated does not reflect capabilities at lower velocities. This does not mean that foiling at lower velocities at the maximum payload is not possible, it should be noted that at lower velocities the effective angle of attack can be increased or decreased through the control surfaces. This will require in depth analysis of lift force at various speeds and control surface position, to give accurate estimates of lift force generated.

13 Appendix A

13.1 Retracting mechanism (externally designed)

This was extremally and was requested to be considered in the implementation of the design.

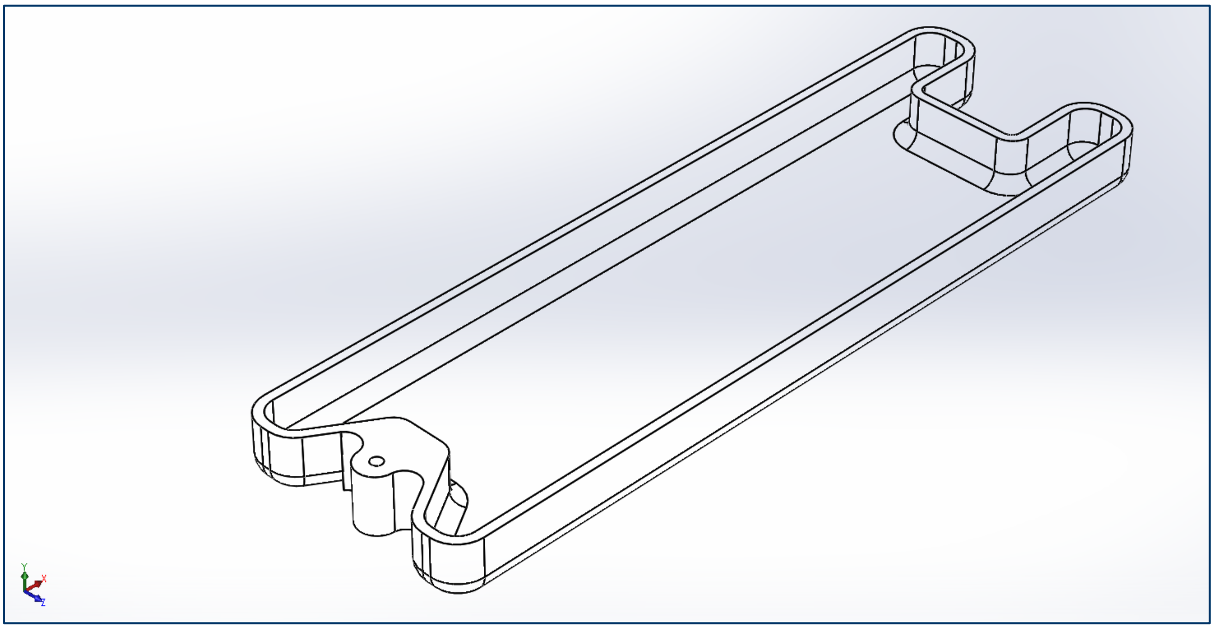
Figure 33 Retracting Mechanism

These gears can be 3D printed from a hard polymer with the exact same profile as that of the vertical foil (or mast). Friction provides the contact force that will enable the foils to be raised and lowered, however it should be mentioned, like a cone, some slipping will be required to achieve linear mortion due to the varying radius.

13.2 First Draft of Chassis

The first draft after discussion with the client.

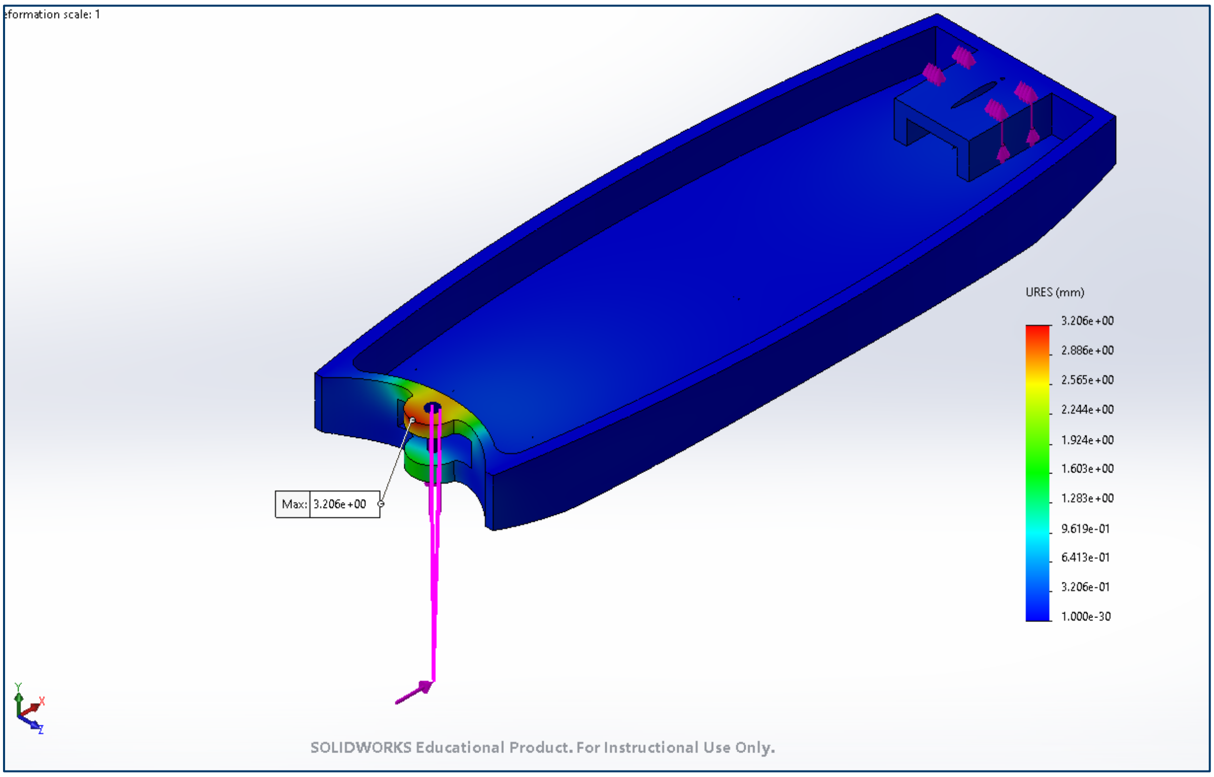
Figure 34 First draft



13.3 Displacement plot

Contour plot showing displacement due to maximum loading

Figure 35 Displacement plot



Red surfaces indicate a maximum displacement of around 3.2mm.

13.4 WAZSP Foil Assemblies Invoice

Figure 36 Quote from KA Sailing for foil assemblies

ABN: 39 053 749 116 Email: office@kasail.com Phone: +61 3 9585 3585

KA Sail Australia

KA Sail Australia, a division of Kingston Range Pty Ltd

Quote# 412538 ***Valid to 17/04/2023***

11 / 91-95 Tulip St
Cheltenham VIC 3192
Australia

Invoice To:
Pierre-Louis Constant

AUSTRALIA

Ship To:
Pierre-Louis Constant

AUSTRALIA

plc@oceanomatics.com.au

						Date
						27/03/2023
Part #	Name	Description	Qty.	Unit Price	Disc.	Total
WZFFH84X	RACING FOIL - CURRENT Fro...	RACING FOIL - CURRENT Front Foil Horizontal 84 S/Hand With cover	1	AU$ 593.98	30.0%	AU$ 415.79
WZFFVX	Front foil vertical assem...	Front foil vertical assembly S/Hand With cover Top bent / possibly missing top fittings	2	AU$ 863.43	50.0%	AU$ 863.43
WZFFH62X	Original Front foil horiz...	Original Front foil horizontal assy S/Hand, no tips	1	AU$ 260.00		AU$ 260.00
WZFFHTFL	Foil Front Horiz Tip Flap...	Foil Front Horiz Tip Flap Left	1	AU$ 15.45		AU$ 15.45
WZFFHTFR	Foil Front Horiz Tip Flap...	Foil Front Horiz Tip Flap R	1	AU$ 15.45		AU$ 15.45
WZFFHTML	Foil Front Horiz Tip Main...	Foil Front Horiz Tip Main Left	1	AU$ 52.73		AU$ 52.73
WZFFHTMR	Foil Front Horiz Tip Main...	Foil Front Horiz Tip Main R	1	AU$ 52.73		AU$ 52.73
				SALE AMOUNT		AU$ 1675.58
				FREIGHT & PACKING		AU$ 90.00
				GST		AU$ 176.56
				TOTAL AMOUNT		AU$ 1942.14
				TOTAL DUE		AU$ 1942.14

Preferred payment method is by credit card:
https://www.kasail.com/checkout/412538

or PayPal: https://www.kasail.com/paypal/checkout-cart/412538

For EFT/TT Payments, please inform us of the payment here:
https://www.kasail.com/cart/eftinfo/412538 to initiate your shipment.

Please send AU$ to this account only.

www.mach2boats.com

14 References

Abbasov, I. B., & Orekhov, V. V. (2019). Conceptual design of multifunctional hydrofoil vessel "Afalina". *Journal of Physics: Conference Series*, *1399*(4), 44020. https://doi.org/10.1088/1742-6596/1399/4/044020

Bourgeon, J.-M., Dyen, S., Moyon, D., Schmäh, D., Amacher, R., Colegrave, D., Calmon, M., Farhat, M., Fua, P., & Startchev, K. (2013). L'Hydroptère: A story of a dream. 21st HISWA International Symposium on Yacht Design and Yacht Construction,

Budynas, R. G. (2018). *Shigley's Mechanical Engineering Design*. McGraw-Hill Higher Education.

Candela. *Candela: The eclectric boat that goes 30 knots for 2 hours*. Retrieved 04/09/2022 from https://candela.com

Chiang, T.-Y., Ay-Su, A.-S., Tsai, L.-C., Sheu, H.-H., & Lu, C.-E. (2014). Corrosion resistance of 5052 Al-alloy with a Zirconia-rich conversion coating used in bipolar plates in PEMFCs. *International journal of electrochemical science*, *9*(11), 5850-5863.

Constant, P.-L. F. (2023). *Production of a real time controller for automated stabilisation of an electric foiling personal watercraft*.

Destuynder, P., & Fabre, C. (2018). On the Stability of Racing Sailing Boats with Foils. *Chinese annals of mathematics. Serie B*, *39*(3), 427-450. https://doi.org/10.1007/s11401-018-0076-6

DHGate. (2023). *138 AH Lithium Iron Battery*. https://www.dhgate.com/product/16pcs-3-2v-138ah-lifepo4-lithium-ion-battery/830937696.html

Findlay, M., & Turnock, S. (2008). Investigation of the effects of hydrofoil set-up on the performance of an international moth dinghy using a dynamic VPP.

Genc, M. S., Karasu, I., & Acikel, H. H. (2012). An experimental study on aerodynamics of NACA2415 aerofoil at low Re numbers. *Experimental thermal and fluid science*, *39*, 252-264. https://doi.org/10.1016/j.expthermflusci.2012.01.029

Maytech. (2023). *Maytech 18.8 kW motor*. https://maytech.cn/products/maytech-brushless-inrunner-motor-for-electric-surfboard-rc-boat-mti120116-200-sf?variant=31252460699753

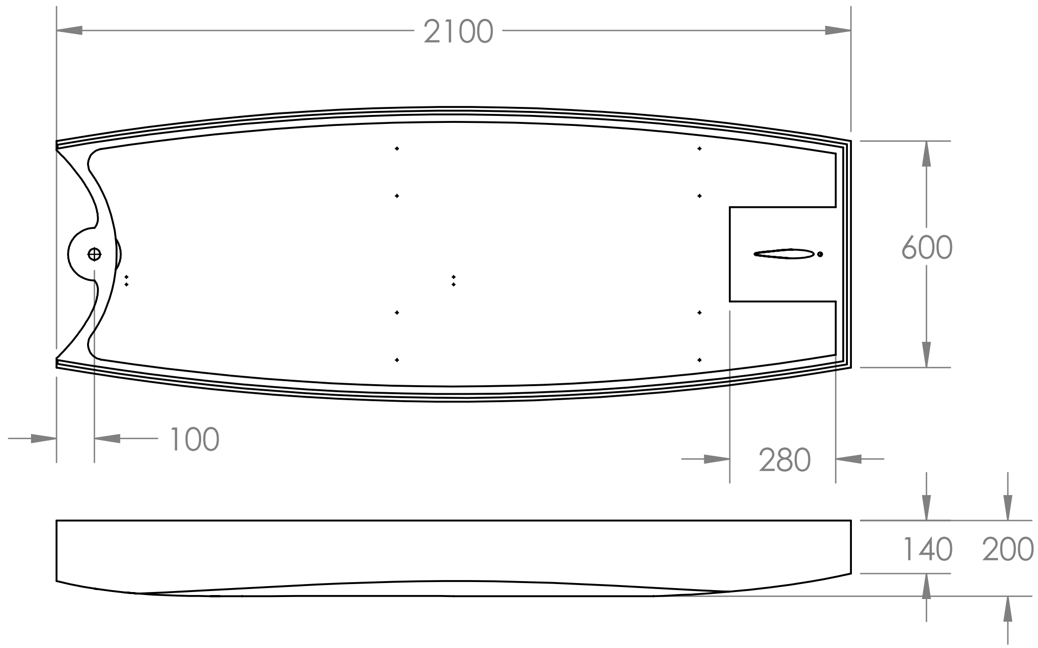
Ponte, R., Sutherland, L., & Garbatov, Y. (2022). Structural analysis of a 'Foiling Moth'sailing dinghy hydrofoil. *Trends in Maritime Technology and Engineering Volume 1*, 185-191.

Sailing, K. (2023). *WAZSP Product Page*. https://www.kasail.com/waszp/product

Shakir Abbood, I., Odaa, S. a., Hasan, K. F., & Jasim, M. A. (2021). Properties evaluation of fiber reinforced polymers and their constituent materials used in structures – A review.

Shinoda, M., & Bathurst, R. J. (2004). Lateral and axial deformation of PP, HDPE and PET geogrids under tensile load. *Geotextiles and Geomembranes*, *22*(4), 205-222.

15 Drawings



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: Rough TOLERANCES: LINEAR: +- 1mm ANGULAR: +- 1 degree	FINISH: Rough	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING — REVISION : 02

	NAME	SIGNATURE	DATE
DRAWN	Hendrik Viljoen		12/02/23
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Chassis

MATERIAL: HDPE

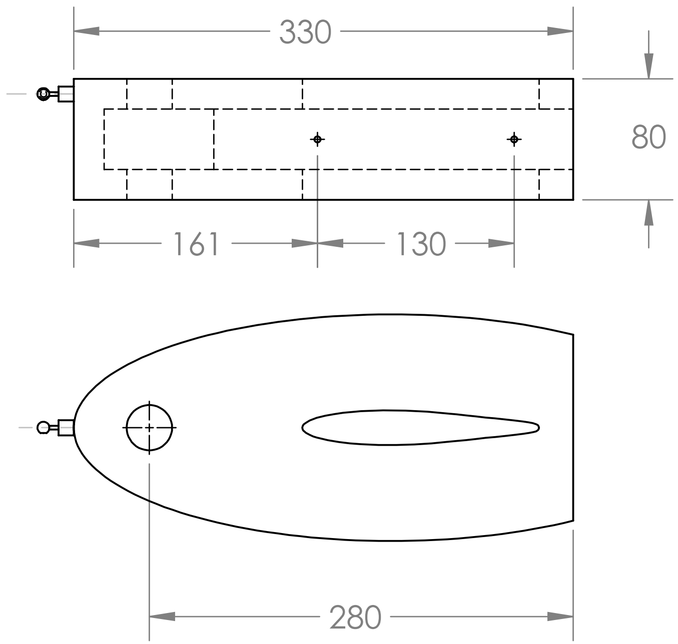
DWG NO. 101

A4

WEIGHT: 126 kg

SCALE:1:20

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: Rough
TOLERANCES:
LINEAR: +- 1mm
ANGULAR: +- 1 degree

FINISH: Rough

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 01

	NAME	SIGNATURE	DATE
DRAWN	Hendrik Viljoen		24/03/23
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Rear Mount

MATERIAL: Aluminium

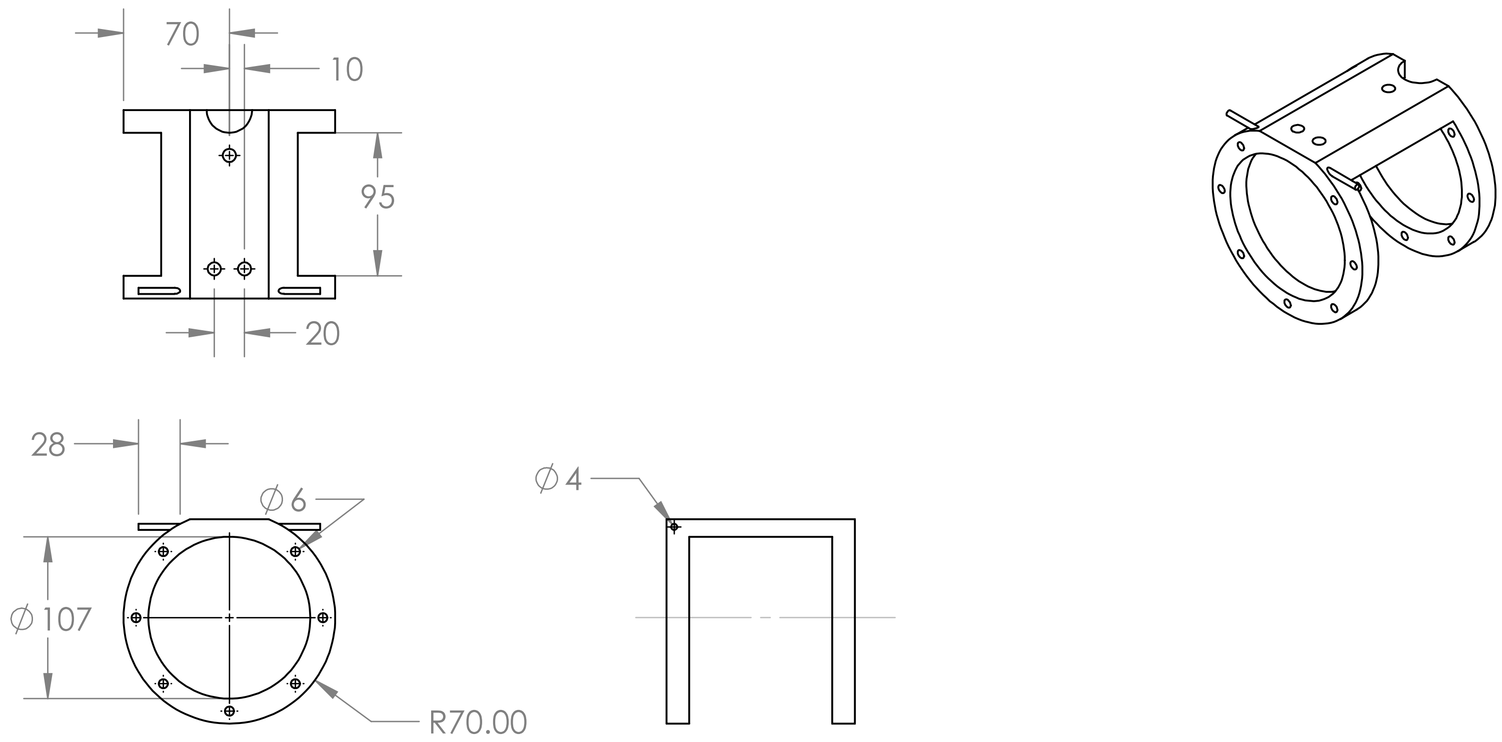
DWG NO. 102

A4

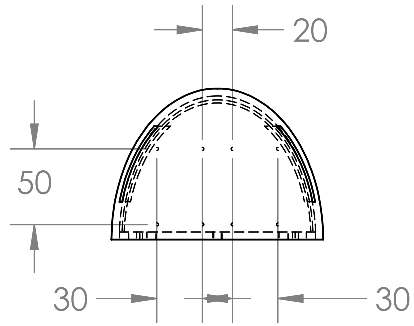
WEIGHT: 6.01 kg

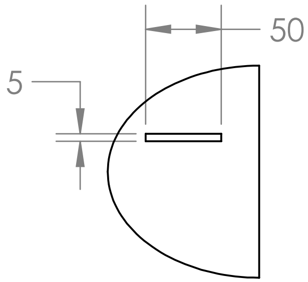
SCALE:1:5

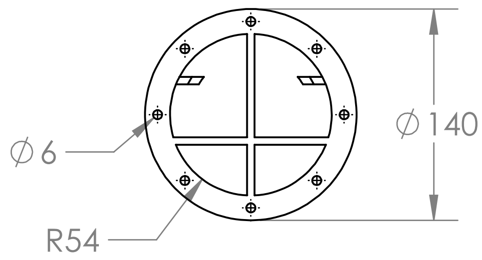
SHEET 1 OF 1



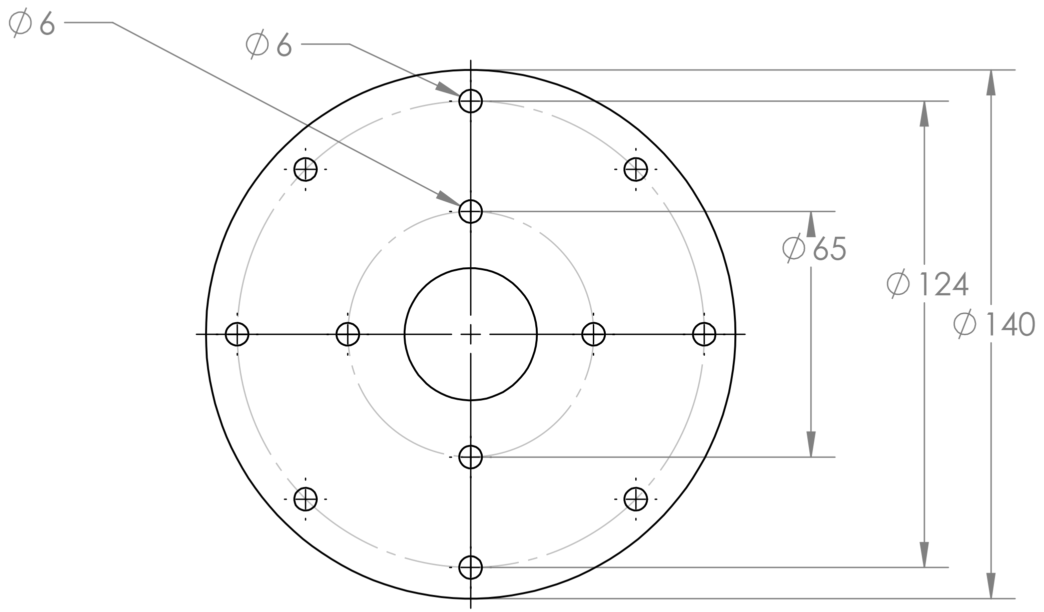
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: +- 1 MM ANGULAR: + - 1 DEGREE			FINISH: ROUGH		DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION 1
	NAME	SIGNATURE	DATE			TITLE: MOTOR MOUNT	
DRAWN	HENDRIK VILJOEN						
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: ALUMINIUM		DWG NO. 103	A4
				WEIGHT: 2.51 HG		SCALE:1:5	SHEET 1 OF 1



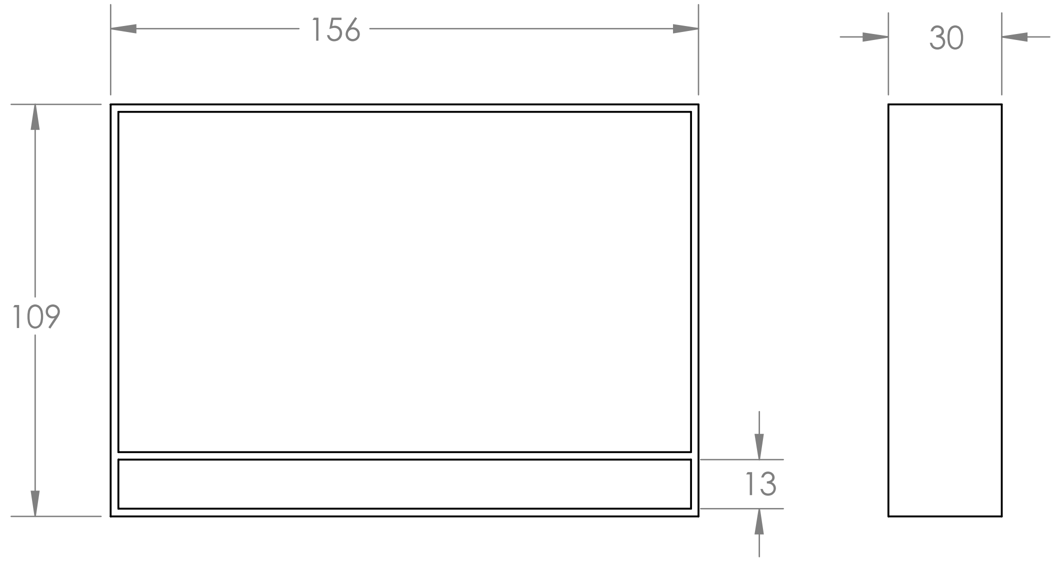




UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: +- 1mm ANGULAR: +- 1 degree			FINISH:ROUGH		DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE			TITLE:	NOSE
DRAWN	HENDRIK VILJOEN		30/03/23				
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL:		DWG NO. 104	A4
				WEIGHT:		SCALE:1:5	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: +- 1mm ANGULAR: +- 1 degree	FINISH: ROUGH			DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION 1
	NAME	SIGNATURE	DATE		TITLE:	BACK PLATE
DRAWN	HENDRIK VILJOEN					
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL: CARBON STEEL A830-1045	DWG NO. 105	A4
				WEIGHT: 0.51 kg	SCALE:1:2	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR: +- 1mm
ANGULAR: +- 1degree

FINISH: ROUGH

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 1

	NAME	SIGNATURE	DATE
DRAWN	HENDRIK VILJOEN		04/04/23
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: BATTERY BRACKET

MATERIAL: ALUMINIUM

DWG NO. 106

A4

WEIGHT:

SCALE:1:2

SHEET 1 OF 1