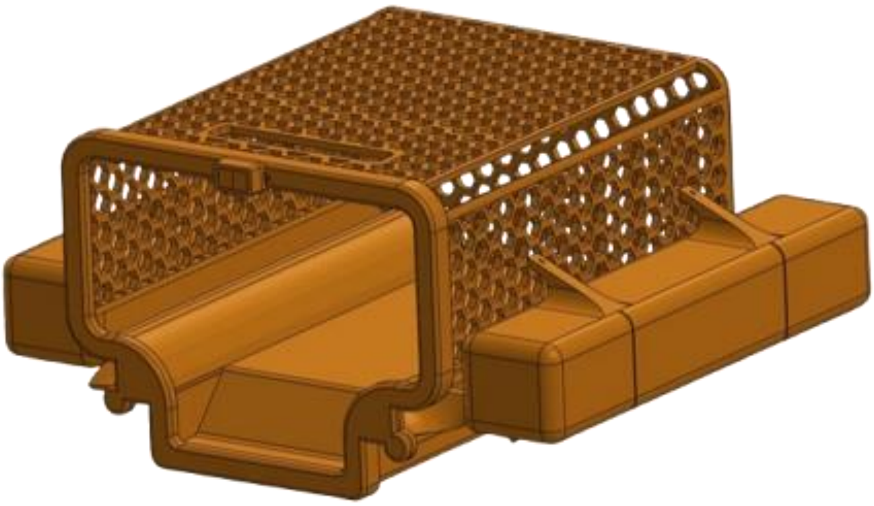
DESN2000 – Design Engineering 2

Final Report – 40%

T11A – Group 2



Executive summary

Plastic pollution is a serious and growing problem, affecting marine life, entire ecosystems and even our own food supply. With this problem in mind, our team was challenged to design Cleanup for Coastlines, an innovative, autonomous water drone used to clean our waterways and protect marine life from waste pollution. This project supports UN Sustainable Development Goal #14: Life Below Water, emphasizing the required support in keeping our oceans clean.

The objective of this report is to document the development process, design solutions and technical aspects of Cleanup for Coastlines. It aims to provide a comprehensive overview of how the team approached the problem and what choices were made to design our solution. The report also highlights the challenges that the authors as a team faced while looking for a robust solution to an ever-growing problem.

The topics covered in this report are design concept, technical analysis and the process of developing and finalising design using CAD software. Emphasis of the report is placed on technical analysis of power transmission of the product and sensor selection for autonomous aspect of the solution.

The final design of Cleanup for Coastline successfully addresses the core challenge, efficiently remove waste from water bodies. Through collaborative efforts of our team, the authors were able to design an innovative solution to the posing problem. Our autonomous system with the use of advanced sensors like GPS, LiDAR and more, enables the drone to continuously collect waste and make our oceans clean. The authors developed a solution that not only addresses the environmental problem but also demonstrates sustainability and practical application.

Team Statement

Student Name / zID	Individual Contribution

Ishbel Wood – z5479039 - z5479039@ad.unsw.edu.au	• Introduction
	  ○ Overview and reflection of the design process
	  ○ Structure and organization of the report
	• Description on Final Design Concept
	  ○ Detail final concept, key features and components
	  ○ Practicality and feasibility of design
	• Document Formatting and language check

Benas Vaiciulis – z5457896 - z5457896@ad.unsw.edu.au	• Executive Summary
	• Introduction
	  ○ Background and significance
	  ○ Design relevance
	• Technical Analysis
	  ○ Sensor selection
	  ○ Sensor Pseudocode

Luke Scard – z5479533 - z5479533@ad.unsw.edu.au	• Technical Analysis
	  ○ Buoyancy investigation
	  ○ Weight investigation
	• Cost analysis
	• Conclusion
	• Bill of materials
	• Document Formatting and language check

Marcus Gatt – z5418365 - z5418365@ad.unsw.edu.au	• Technical Analysis
	  ○ Sensor Analysis
	  ○ Sensor justification
	  ○ Circuit diagram
	  ○ Pseudocode
	• Conclusion
	• Document Formatting and language check

Zhewei Zhao – z5454744 - z5454744@ad.unsw.edu.au	• Description on Final Design Concept
	  ○ Existing solutions comparison
	• CAD model and Mechanical Part Drawings
	  ○ Floaties models
	  ○ Drawings of floaties, Front Panel, Propeller
	  ○ Assembly drawing

Katie Waller – z5480296 - z5480296@ad.unsw.edu.au	• Technical Analysis

	○ Applying course principals to analyse power transmission ○ Overall design of the power transmission system, stating assumptions ○ Justification and selection of drive choices ○ Selection of all transmission elements • Document Formatting and language check
Dave Cooper – z5478494 - z5478494@ad.unsw.edu.au	• Design development and modelling the physical unit ○ All components bar floaties • Technical drawings ○ Main unit ○ Electronics Cover

1. Introduction

1.1 Background Information and Significance

Despite current global efforts, it is estimated that between 75 and 199 metric tonnes of plastic are currently present in our oceans. The amount of plastic waste entering aquatic ecosystems could nearly triple from 9 - 14 million tonnes per year in 2016 to a projected 23 - 37 million tonnes per year by 2040 [1]. This shows how significant the problem of plastic pollution is, especially for our marine life.

Every year, about 100,000 marine mammals die due to plastic waste [2]. 81 out of 123 marine mammal species are known to have ingested plastic waste [2], which means it eventually ends up in the human food chain, posing serious health risks.

Tackling this pressing issue is essential for the long-term health of our oceans, public well-being, and economic stability. The Cleanup for Coastlines project is our answer to this challenge, supporting UN Sustainable Development Goal (SDG) #14: Life Below Water. This goal calls for the protection and sustainable use of our oceans and marine resources. By developing an autonomous water drone that can effectively remove floating waste, the authors hope to help protect marine ecosystems, reduce plastic pollution, and contribute to a cleaner, healthier world.

1.2 Design Relevance

Our problem directly aligns with the project brief provided at the beginning of the course. The final design of CFC is a mechanical system with integrated electrical components, creating a unique and innovative mechatronics solution for plastic waste removal from water bodies. The solution includes the use of sensors for navigation and obstacle avoidance, which is essential for an autonomous drone, use of motors and batteries for controlling the velocity and direction of the drone. The emphasis of the project is on sustainability and marine conservation, which directly aligns with the aim of Sustainable Development Goal #14.

1.3 Design process

Project CFC's team continually adapted their design to accommodate any new discoveries and corrections in calculations which allowed the best possible unit to be created. Extensive research was performed to find the best options for each component, taking into consideration the cost of each option, its life-span, weight, reliability, effectiveness in underwater environments and suitability to the specific constraints of the setting of Sydney harbour. For each decision, it was also needed to consider its effect on the other components of the design as well, which made communication a crucial aspect of the design process.

See Appendix F for the details of how the design changed from the original, to the presentation concept, and then to the final design as it will go through all the adjustments and all the justification as to why these were made.

1.4 Structure and organization

This report will explore the key components, novelty and feasibility of the final design concept. The following will be an in-depth exploration of both the power transmission system and the sensor selection, where it will justify and analyse the selections of different elements and decisions. Next in the report will be the overview of the CAD model and mechanical part drawings, including bill of materials, exploded views and assembly views. Finally, the conclusion will draw conclusions on the feasibility of the design, discuss if the SDG is properly addressed and outline any future work to be undertaken. The Acknowledgements, References and Appendix can also be found at the end of this report.

2. Description on final design concept

2.1 Final design concept

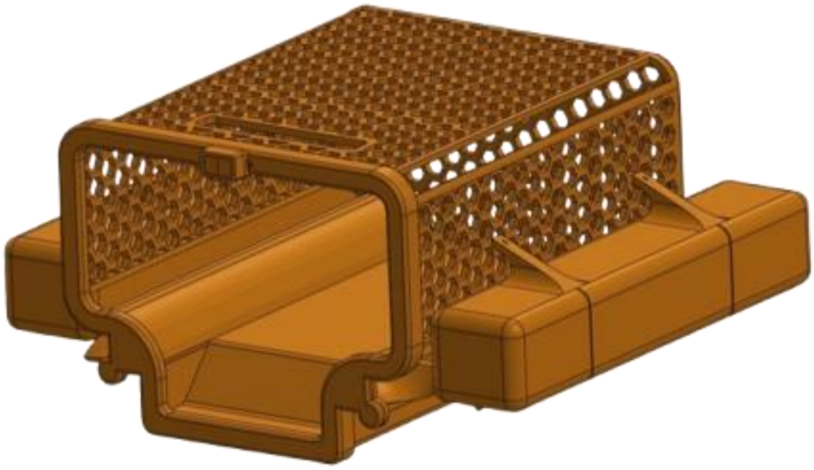


Figure 1 – Assembled final design

The final design, depicted in Figure 1 for CFC is made up of multiple components explored below.

2.1.1 Body

The body is the frame for the entire unit, connecting all the components together and housing them cohesively and compactly, allowing for easier storage.

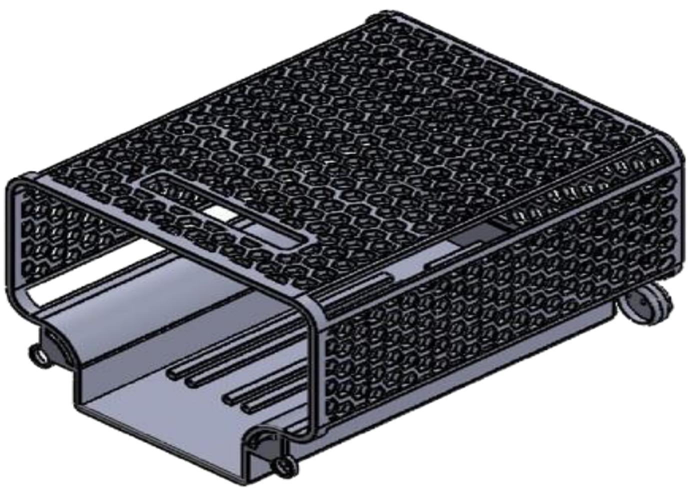


Figure 2 – Main body unit

It houses the electronics and batteries in its lowest section, which then gets covered by the electronics cover 'E-cover', sliding in to create a watertight seal. With the angular front, it acts as a scooper to help filter the rubbish towards the top. The electronics section, shown below in Figure 3, is strategically placed at the lowest section of the unit as it provides greater stability as it is moving, minimizing the impact of winds or waves to capsize the unit and turn it upside down.

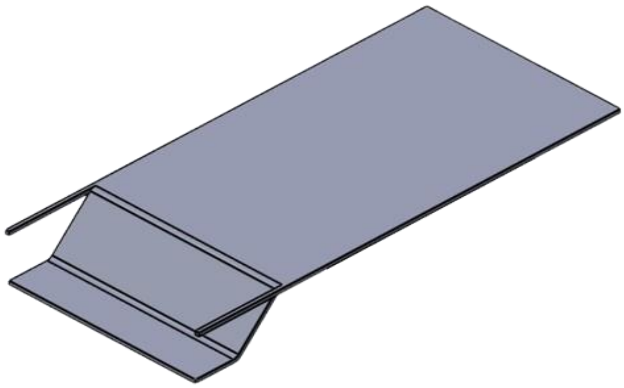


Figure 3 – Electronics cover

Apart from the walls and sides that are housing the electronics and need to be completely sealed, the unit's frame is made up of an open hexagonal pattern. This design allows the water to pass through the storage volume, minimizing the impact of the ocean's forces or currents, while still being a solid housing unit and not letting the rubbish float around without a set boundary. The hexagon shape has the most sides for a tessellating shape, allowing the least amount of surface area while maintaining integrity and preserving its shape. The lowered surface area is optimal for lowering drag of the unit as it is moving through the water and minimizing the ocean perpendicular forces.

The unit's frame is quite buoyant as it is made of HDPT. See 3.1.5 for more details on the buoyancy of the unit.

2.1.2 Electronics & sensors

A range of sensors were required for the movement of the CFC unit, both to navigate where to go and to avoid obstacles. An Ublox NEO-M8N GPS will be used for the location, and to navigate movement, a combination of the MPU-9250 IMU for the orientation of the unit and a TF02-Pro LiDAR for obstacle detection is the best choice. A Raspberry Pi is the brains of all the sensors and ties them all together. See 3.2 for more details of the sensors and electronics working together.

Most of the sensors and electronics are all fully operational from within the electronics compartment, but the LiDAR need visuals and so are connected by a wire running through the front panel, through a small hole on the front to have a complete view from the front of the unit.

2.1.3 Front cover and Netting

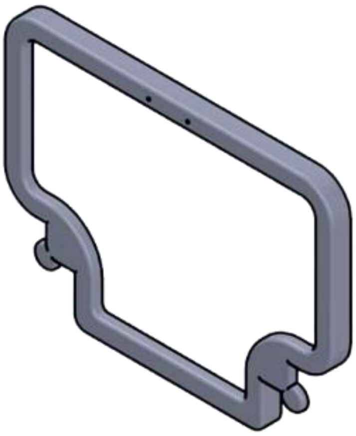


Figure 4: Front cover

The unit has a multipurpose front cover, displayed in Figure 4, which locks the E-cover in place for extra security, ensuring that no water to leak in through the bottom but also has a hook about the interior of the front cover which is used to hook the netting which is the main catchment component of the unit. The netting can be easily removed if full of the trash it has collected and replaced quickly to minimize handling time and due to its smaller mesh, it can catch and collect smaller components that would pass through the hexagonal grating.

The front cover also provides extra material to guard the main unit against unwanted impact. Due to the front cover's ease to be removed, if it was damaged, it is easier and cheaper to replace than an entire unit.

2.1.4 Floaties

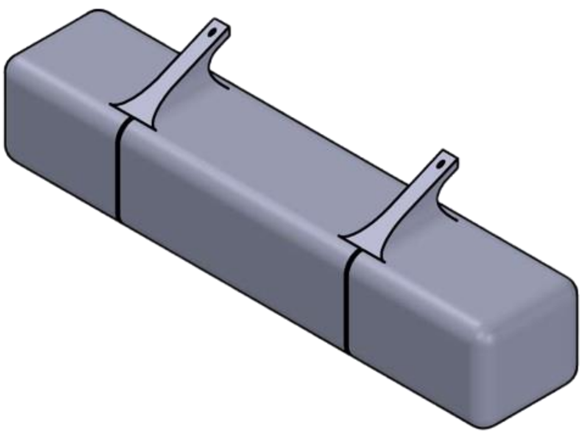


Figure 5 –The Floatie Design

To combat the weight of the unit, the hollow 'floaties' made from HDPT on either side of the unit help to keep the unit buoyant and afloat as it collects the rubbish and stay at an optimal height for collecting the rubbish on the water surface. These floaties are designed to be easily attachable at different levels for different floating levels and are brightly coloured to ward of fish.

2.1.5 Propellers

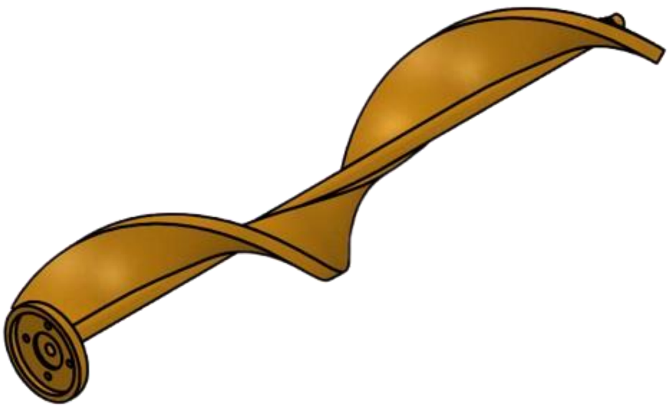


Figure 6 – The Propeller Design

The propulsion system, mirroring that of a tugboat with its propeller design, allows for greater thrust in low-speed applications as it runs at a relatively slow speed. The dual propellers and control system allow movement through the water but also allow the unit to turn without the need for a rudder that would increase opportunities for noise and disruption, which is undesirable.

Following on from that, this design of propellers is optimal for minimal disruptions as it is quieter when in use. Additionally, it would be less harmful for a fish that get caught in it, gets thrown straight out opposed to other harsher propeller designs.

Due to its spiral shape, it has less turbulence around the blade allowing the design to reach greater efficiency (75%- 85%), see Appendix D, and the length of the propeller minimises impacts of rough or flowing waters, allowing for consistent movement.

2.2 Existing Solutions

Table 1: Existing solutions on the market

No.	Existing solution	Description
1	Interceptor- The Ocean Cleanup [3]	Upscale Machine
2	Waste Shark- Ran Marine Technology [7]	Autonomous Surface Vessel
3	Seabin [9]	Fix point water filter

When considering SDG14, there are few existing solutions in the market as linked in Table : The Interceptor, Waste Shark, Seabin and Bubble Barrier.

Figure 1: Existing Interceptor Design

The Interceptor, as seen in Figure 1 7, was developed by The Ocean Cleanup. It is solar-powered and designed to extract plastic waste from channels before it reaches the ocean. The Interceptor has a larger storage, resulting in higher waste capacity. For instance, System 03's second extraction, 18,360 kg, covering deck after sweeping an area of 480 square kilometres [6]. The organization also developed different solutions for various environmental conditions.

While operating this machine requires workers and technicians, it leads to higher operation cost (A single interceptor currently costs €700,000).

Figure 2: Existing 'Waste shark' Design

Waste shark, an autonomous surface vessel (ASV), developed by Ran Marine Technology, functions as an aquatic drone collecting floating waste. With similar appearance and design parameters (Figure 2), the Waste shark is available in various models [7].

With different models and accessories, it still requires manual operation (via remote control) which would increase potential costs. The price tag starts about $23,600 [8].

Figure 9: Existing 'Sea bin' Design

Seabin, a floating machine designed to filter waster. It is installed in dockyards and harbors, filtering water until full and being cleaned manually. The filtration system of Seabin could handle microplastics that up to 2 mm, as well as oil, as seen in Figure 9. The autonomous filtration process could gather waste up to 20kg per day.

Despite being installed at various waste points, the Seabin still has limitations such as reduced capability of general floating waste (large plastic). Additionally, without the design of mobility, the efficiency varies from different environments where it is deployed.

In conclusion, the existing solutions provide various approaches associated with SDG14, and each offers unique advantages such as higher waste capacity or greater precision. However, the overall cost is also key to the SDG and project feasibility, the 'CFC bucket' provides cost-effective and less complexity for deployment and manufacturing while maintaining great efficiency and convenience in waste collection and recycling.

2.3 Design Practicality and Feasibility

Cleanup For Coastlines addresses the conservation component of the SDG #14 statement "Conserve and sustainably use the oceans, seas and marine resources for sustainable development" through the aim to remove rubbish from water bodies and clean coastlines. It achieves this through the mechatronic system made up of many sensors, electronics and control algorithms, see 2.1 for a more detailed breakdown of the systems.

As seen in 2.2, the alternative options are very expensive, starting around $23,000 but from the cost calculations seen in Appendix E, Project CFC's unit is less than $6000 making it a much more affordable option at almost a quarter of the price. Due to the project being a global initiative, the target stakeholders are national, state and local governments due to their keep oceans clean, protect wildlife and improve the community environment. CFC's unit is a device that would be well within the budget of these governments, but they are also designed for long life and minimal maintenance. By buying many of these different units and placing them at different locations, coastlines would be able to be cleaned and monitored easily by the governments for a very economic price considering the competitors.

Some risks that were identified in the brainstorming stages was the potential risk that this device could pose to wildlife, such as its automatic collection of wildlife alongside the rubbish in its path. To prevent this, much consideration of the sensors and the pseudocode was done with this in mind and can be read fully in section 3.2.1.2. Another risk was that passing wildlife would get caught in the propellers which strongly affected the choice of propellers which can be read in depth in 2.1.5.

The device shall comply with relevant regulations on safety and engineering standards.
Since the robot is autonomous, it will need to comply with AS ISO 31000 – Risk Management Guidelines. Whilst there are no explicitly stated guidelines for autonomous systems, it states that risk management must be an integral part of the robot design, such as to avoid risks associated with collision. This is achieved using our sensor system to detect obstacles and avoid them whilst navigating.

Furthermore, to align with AS ISO 14001 Environmental Management Systems, particular design aspects and materials are chosen to be safe for the marine environment. For instance, the batteries are securely housed in their specialised compartment to prevent water exposure in the event of damage. This reduces the risk that toxic substances leech into the water.

3. Technical Design and Analysis

3.1 Power Transmission

3.1.1 - Power Required

To design the power system, initially it must be determined how much power is required. The following calculations will be based on the water in Sydney harbour, as our device is designed for operation in harbours and bays.

In Sydney harbour, the maximum current speed is around 1.5 m/s [16]. Therefore, for the robot to be able to move at reasonable speed whilst still opposing the current, it may be assumed that the maximum velocity of the robot will be 2 m/s. This speed will be used in the following Force calculation [12]:

$$F_{drag} = \frac{1}{2} \cdot\ c_d\ \cdot\ \rho\ \cdot\ v^2\ \cdot\ A$$

- $c_d =\ drag\ coefficient$
- $\rho = density\ of\ water$
- $v = movement\ velocity$
- $A = surface\ area\ of\ forward\ facing\ surface$

Following engineering standard procedure, a drag coefficient of 1.0 is to be used when no other reliable values can be obtained [15].

Additionally, in drag calculations, the average density of salt water to be 1025kg/m^3 will be used as this is the standard accepted value.

The final dimensions of the CFC bucket design frontal area are 0.5m x 0.372 m (including area of propellers), assuming frontal area as a rectangle. The buoyancy of this device will mean that only half of the fontal area will be submerged, hence the submerged area can be deduced using:

$$A_{Submurged}\ =\ \frac{1}{2}(0.5 \times 0.372)\ =\ 0.093\ m^2$$

Therefore, it's calculated that the drag force at maximum velocity is:

$$F_{drag\ max} = \frac{1}{2} \cdot\ 1\ \cdot\ 1025\ \cdot\ 2^2\ \cdot\ 0.093 = 190.65N$$

Now that the drag force for the robot moving at its maximum speed has been determined, several other factors must be considered. The design relies on a propeller. Small propellers are on a general basis, ~ 65% to ~80% efficient [17]. For the following calculations, let the reader assume from this point onwards that the uniquely designed propeller used on this robot will be ~75% efficient, as this specific design is optimised for efficiency.

To transfer power to the propeller from the battery, there are several available options.

3.1.2 - Motor Design Choice

Firstly, the types of motors that could be utilized within our robot will be contrasted in the following table:

Table 1: Comparison of Different Motor Options[12, 13, 14]

Type of Motor	Advantages	Disadvantages
DC Brushed Motor	Low Cost Medium Efficiency	Short lifetime as brushes wears out

	Reliable	Loud, due to brushes arcing
DC Unbrushed/Brushless Motor	High speed and efficiency Long lifetime Better suited to continuous cycles Less vibration	Medium cost due to added electronics Slightly heavier weight and size
AC Induction Motor	Higher torque No slip rings or brushes required Cheap to produce and maintain	Runs at a lower speed than synchronous Runs only at less than 1500 rpm
AC Synchronous Motor	High speed of rotation More effective than induction motors	Require additional starting method to rotate Excessive cost

After evaluating all the potential options on this front, it seems as if the DC unbrushed motor is most applicable for this scenario, due to its high efficiency, long lifetime, and reduced vibration which is important not to disrupt surrounding wildlife. Brushless DC motors have an average efficiency of ~ 85% - 90% [18]. In further calculations, the value of 90% will be used.

The specific DC brushless motor chosen for this AUV (Autonomous underwater vehicle) is this 2 hp Brushless DC Motor [20], as displayed in Figure 10:

Figure 10: ATO-D110BLD1500 Brushless DC Motor

This motor was chosen over other motors for several reasons. Because of the unique design of the propellers and the necessary speed output, a high torque motor is required. This motor is rated IP67, which means it is water resistant, as even though the motor will be in a watertight encasing, safety precautions should be taken in the case of an event that may lead to the casing cracking. This motor also has a 36V capacity and a high current rating, necessary due to the battery configuration discussed in section 3.1.3.

This DC motor has a high rpm load (3000-4200 range) and additionally has the necessary technology to correspond with the Raspberry Pi. This motor can be assumed to have an efficiency of ~90%, which will be used in further calculations.
Additionally, the shaft design of this motor is corrosion resistant and durable to withstand underwater conditions in its coupling between the motors and the propellers. When designing the coupling between the motors and the propellers, simplicity was key to ensure maximum energy transfer with minimal mechanical losses as with gear or belt drives. Thus, a direct drive system was chosen to lower maintenance and potential inefficiencies.

3.1.3 - Battery Configuration.

To determine the battery required, it must first be determined the power necessary, assuming ~90% efficiency of a standard lithium-ion battery. The power required to overcome the water resistance at the maximum velocity is:

$$P_{max} = \frac{F \times v}{\eta_{propeller} \times \eta_{motors} \times \eta_{batteries}}$$

$$P_{max} = \frac{190.65 \times 2}{0.75 \times 0.9 \times 0.9}$$

$$P_{max} = 627.65\, Watts/Hour$$

The total power required must additionally consider the power usage of the sensor components, which are 1.8Wh each, as well as the Raspberry Pi which requires 3.5Wh. Hence, the total power is:

$$P_{total} = 627.65 + 2.4 + 3.5$$

$$P_{total} = 633.55\, Watts/Hour$$

Lithium-ion batteries are the most suitable batteries in this application since they are highly efficient, lightweight and approved for use in marine applications.
The requirements that are essential for the battery to have are:

- The batteries must supply 36V to power motors adequately
- There must be voltage stability, i.e. the batteries need to maintain a steady output despite variable loads
- Power the vehicle at maximum power usage for a minimum of 2 hours
- Easily removable from unit for recharging, minimizing downtime
- Be able to handle vibration, temperature changes, and theoretically, even impact
- Must include safety features to prevent overcharging or overheating.

The battery that was selected based on these requirements is the Bosch Powertube 500 vertical battery [19], shown in Figure 11.

Figure 11: Bosch 500 Power-tube Battery

This battery meets the requirements in a unique sense since it is an E-bike battery, hence it has all the required qualities listed, such as being resilient to vibrations and potential impact, easy to remove for charging, and water resistant, as these are all similar functional requirements of an E-bike battery.

However, just one of these batteries alone has only 500Wh, so will not be enough to power the AUV for even 1 hour. To extend the battery life, the design choice was made to incorporate three of these batteries in parallel. Adding the batteries in series would increase the voltage supplied to the motors, and since the motors are rated for only 36 volts, adding the batteries in series may overheat and overload the motors.

This battery setup will be directly connected to a 36V voltage regulator, ensuring constant voltage delivery despite any variations in battery load.
This setup will also increase the capacity in Amp hours because the current of each battery is combined. The Bosch Powertube 500 is rated at 13.4-amp hours, so in parallel, the system will have 40.2 Ah.

This parallel battery configuration can power the AUV for a minimum of 2.5 hours, and in ideal conditions, where there is no current and the AUV is travelling at 0.5m/s the power required is 9.8Wh, hence the AUV can theoretically travel with no current for over 100 hours if necessary. This battery range will allow the robot to travel between 4 and 180km

3.1.4 - System compatibility

To find whether this current will overload our motors, first the torque required is calculated. Since there are 2 motors, referring to the drag force calculation, it's inferred that the thrust will only have to be 95.325 N per propeller. Hence, torque is calculated as:

$$\tau = \frac{T \times D}{2 \times \eta \times \pi}$$
$$\tau = \frac{90.325 \times 0.1}{2 \times 0.75 \times \pi}$$
$$\tau = 2.022\ Nm$$

The motor was chosen specifically to withstand a high torque and amp load, according to it's datasheet, the holding torque is 4.78 Nm, which will be sufficient, and additionally that the rated current is 52.08 A, which is higher than the system current of 40.2 A.

These high thrust DC Brushless motors will be controlled by a motor driver. It will be connected to directly connected to both the batteries and the Raspberry Pi. The Raspberry Pi will send a PWM signal to control the power distributed to each motor, as well as their direction. The chosen motor drivers were required to withstand the high current and voltage conditions, whilst providing very accurate pulse-width modulation for necessary speed control. The chosen Motor Driver [21] is as shown in Figure 12.

Figure 12: SPCU10030 DC Speed Control 50A

This unit controller was chosen due to its durability, affordability, and its compatibility with the raspberry pi controller. This unit will moderate the input from the battery and provide sufficient power to control both motors at the desired speed, dictated by the Raspberry Pi and sensors.

The final system setup and circuit is as shown:

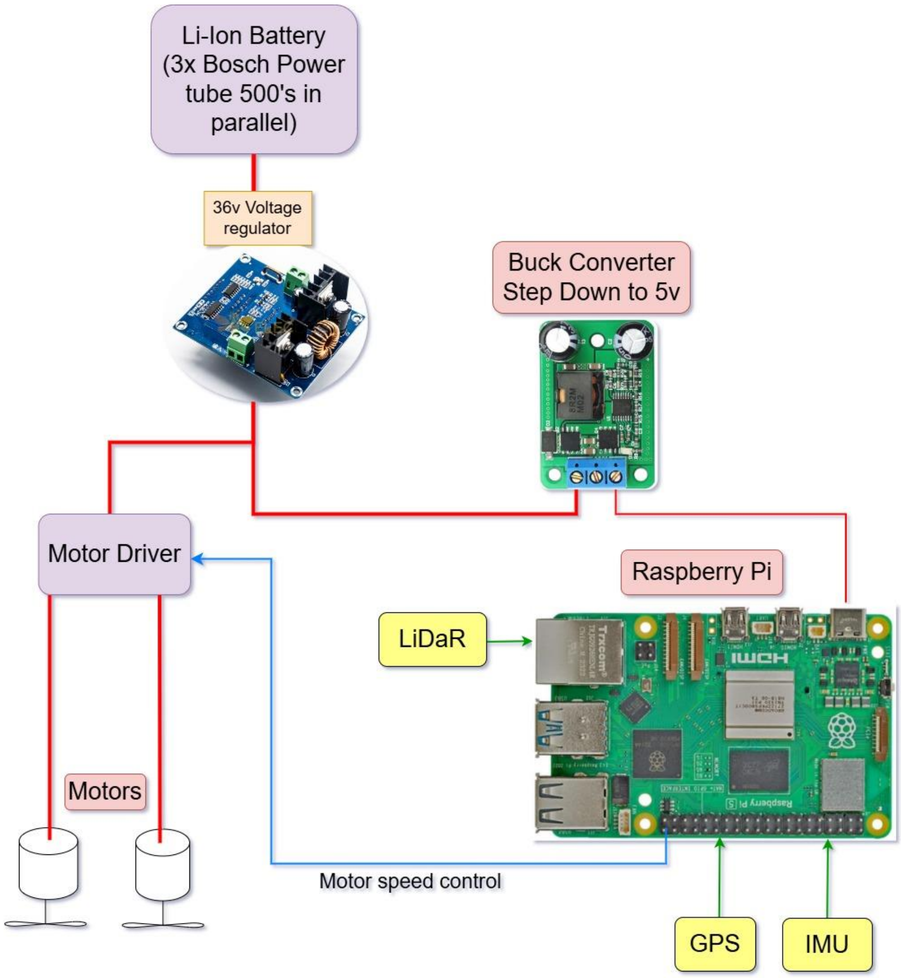


Figure 13: Circuit Diagram of the AUV

This final circuit in Figure 13 shows the configuration between all previously discussed components of the system. The voltage of the wires is displayed respective to the thickness shown in the diagram, since the maximum voltage of the Raspberry Pi is only 5V, so to not overheat and become non-operational.

The buck converter was chosen for its high efficiency in stepping down supplied voltage, minimizing power loss hence maximizing runtime of the AUV.

This system was designed with simplicity in mind, to reduce manufacturing difficulty as well as energy waste.

3.1.5 Buoyancy

An important aspect of the design is its ability to float, and what level the design floats at. The team decided that the design should aim to float halfway down the plastic catchment area, or 125mm from the top of the CFC bucket.

For the design to float the buoyant force must surpass the weight force. The CFC bucket material density is 1080 [11], and calculating the volume for the design in section 1.3.2 gave a weight of 5.067kg for the main body, and 26.90kg [appendix B] for the entire bucket including sensors, batteries and propellers. Multiplying this value by gravity gives 263.8467 Newtons of weight force.

To calculate the buoyant force, the following equation was used:

$$F_b = -\rho g V$$

- $\rho = density\ of\ water$
- $g = acceleration\ due\ to\ gravity$
- $V = volume\ of\ water\ displaced$

The volume of water displaced is equal to the volume of the design that is under water. As mentioned previously, the volume that is underwater is any part of the CFC bucket below 125mm from the top. The volume for the design in section 1.3.2 was calculated as 0.0107 m^3, and as saltwater density is 1025 kg/m^3, currently the boat has a buoyant force of 101.3997[appendix C] Newtons, which is much less than the required 263 Newtons needed.

To fix this problem, the team decided to create floaties for the device. The team decided that the floaties would be made from the same material as the main unit for simplicity purposes and would be hollow to maximize volume and minimize weight. The required volume for the floaties was calculated by dividing the difference of the forces by gravity times the density of saltwater. This gave 0.0156 m^3, however this value is completely correct as adding the floaties increased the total weight of the system. After some trial and error, it was deduced that the dimensions 12 x 135 x 600mm would work for the floaties, as they are small enough to not interfere with the propellers but large enough to keep the drone afloat.

With two of the floaties, the total weight is increased to 30.5504 kg, and the total buoyant force in supportable kg is 30.8740[appendix c]. Once the drone picks up rubbish, the buoyancy will most likely increase as the robot is targeting floating plastic mostly.

3.2 Sensor Selection

The robot will require sensors to be able to operate efficiently. Positional sensors will be used for the robot's aid in navigation, and for correctly following a prescribed route.
Other object detection sensors will be required to detect nearby floating trash, and to detect obstacles obstructing the robot's path.

The sensor system also needs to be suitable for the marine environment, being able to either immune to saltwater damage for extended periods of time, and have its function not be impeded by waves rocking the robot. Other considerations include power requirements; the sensor system should not draw too much power as it allows for enough energy to be used on the propulsion system.
All chosen sensors will need to be compatible for use with the Raspberry Pi.

3.2.1 Sensor selection and analysis

3.2.1.1 Positional Sensors

There are a variety of positional sensors which can be used, each with their own strengths and weaknesses. The position sensors play a critical role in the design. Positional sensors will be used for capturing and relaying data about the position and orientation of drones, enabling navigation in the water.

Table 2: Positional Sensor Analysis

Sensor Type and Product	Advantages	Disadvantages
GPS receiver- Ublox NEO-M8N GPS 	High positional accuracy (2 – 3 meters) Ideal in outdoor environment Lightweight and energy efficient Uses I2C interface which will allow it to easily be used in conjunction with other off the shelf processing units. Can provide the required precision and works well in open waters as its signal is not obstructed by buildings.	Requires satellite connectivity, limiting use in areas with signal obstruction Does not provide orientation data
IMU sensor - MPU-9250 	Very accurate, uses accelerometer and computations to predict the position.	Needs to be recalibrated occasionally Sensitive to noise in dynamic environments

	Does not rely on external systems Uses I2C interfacing. Can be shielded from water exposure easily Lower power consumption than GPS	

After evaluating the advantages and disadvantages of the two sensors, it becomes clear that both sensors should be used. While the GPS provides accurate positions, it is important for this project to keep track of real-time orientation and velocity of drone to maintain stability and precise manoeuvring for dynamic marine environments.
The IMU contains functionality which allows the sensor to work indecently from external signals, this allows the drone to function in environments where GPS signals are weak.
The Ublox NEO-M8N GPS is excellent at tracking the location, ensuring that the drone stays within the predefined boundaries, however it lacks the ability to track the orientation of the drone, due to this it is best to utilize the advantages of both sensors for best performance.

3.2.1.2 Obstacle Avoidance Sensors

Obstacle avoidance is another key feature of Cleanup for coastlines. It ensures that the drone can navigate and detect surrounding obstacles and stay clear of them. The success of the entire project depends on how well the drone performs obstacle avoidance; therefore, one needs to have a detailed and comprehensive look at available sensors which would show best results.

Table 3: Object Detection Sensor Analysis

Sensor Type and Product	Advantages	Disadvantages
LiDAR Sensor Benewake TF02-Pro 	LiDAR sensors measure distance by shining a laser and measuring how long it takes for the light to return. This allows it to function in the night, with no reliance on external light sources. The LiDAR sensor measures a series of distances in front of it in fan shape which is used to create a point cloud.	Large computational power can be required to interpret measurements into meaningful results. The LiDAR sensor simply provides the point cloud of data, however on-board processing is required to adjust measurements to account for the robot rocking in the waves, and machine learning and object

	This makes it suitable for detecting obstacles, and trash, and allowing for on-board computation to distinguish the two. This model has an IP65 waterproof rating, it is completely sealed and can handle splashes from salt water. This model has a range of up to 40 meters. Which is sufficient to detect nearby floating trash, and to detect obstacles ahead with plenty of notice. Low power requirement of 1 Watt	recognition is required to distinguish trash from obstacles. The Sensor can't detect colour, which means more onboard computing and more complicated algorithms are required to distinguish objects from each other.
Depth Camera - Intel® RealSense™ D435 	The sensor collects information on both depth and colour. This allows for more conventional computer vision algorithms to be used for distinguishing trash from obstacles, to reduce the risk of misidentification. It already comes with its own software and computational abilities.	Its ideal range is 3 meters, which is on the short side, this will make it difficult for the robot to reroute around obstacles, and plan to intercept trash ahead of time. The sensor uses stereo vision to calculate depth. This does not perform well in low-light settings as it relies on external light sources. It is not immune to splashes of water, and more specialized mounting options would need to be considered to place it on a safe spot on the robot.

Ultrasonic sensor – Underwater Obstacle Avoidance Senor 	These ultra sonic sensors have a low power requirement of 0.12 Watts. They have an IP68 water rating which means they can be submerged in a marine environment. It is designed to operate solely underwater, which allows for detecting obstacles which are submerged.	A range of 6 Meters may make it difficult to detect obstacles well ahead of time. Provides no means of distinguishing object types from each other unless paired with other sensors.

Weighing up the benefits and drawbacks of each sensor assessed, the LiDAR sensor is the most suitable choice for our design. Its ability to function at up to 40 meters is essential for our robot to plan how to avoid obstacles such as boats and for tracking the movement of trash floating on the surface. Furthermore, the low power requirement allows the robot to be deployed out on the water for longer periods of time.

3.2.3 Pseudocode Algorithms

The robot will have a predetermined path that it will follow, this will be achieved by using an array of waypoints. If the robot drifts of course, it will use PI control logic to adjust its steering and motor speed and correct its orientation so that it is heading towards the next way point. When the robot detects an obstacle which is obstructing the robot's path, such as an anchored boat, it will calculate new waypoints which go around the obstacle, and a run of Dijkstra's algorithm will be performed to calculate the new optimal path.
In a similar matter, if the robot detects trash floating towards it, or near to its planned path, it will dynamically alter the path chosen so that it intercepts the rubbish and collects it.

```
Function AutonomousNavigation()
    While drone is operating
        Get current position from GPS
        Get current orientation from IMU
        Get obstacle distance and direction from LiDAR

        If obstacle is within threshold
            Call AvoidObstacle with obstacle data
        Else
            Move forward by setting motor speeds to full

        Check battery level
        If battery is low
            Call ReturnToBase
        End If

        Check trash capacity
        If trash capacity is full
            Call ReturnToBase
        End If
    End While
End Function
```

Figure 14: Pseudocode for autonomous navigation

Figure 14 above presents a piece of pseudocode for autonomous navigation, while the drone is operating it constantly is getting information from the sensors, like the position from the GPS sensor, orientation from IMU sensor and obstacle whereabouts from the LiDAR sensor. Using the information the drone can navigate the surroundings and continue its mission to collect rubbish. The complete pseudocode is available to see in appendix A.

4. CAD Model and Mechanical Part Drawing

The following CAD models and part drawings are of the CFC bucket main unit, electronics cover, propellers, floaties and the front cover. All drawings follow the AS1100 guidelines and standards and provide a holistic overview of our design.

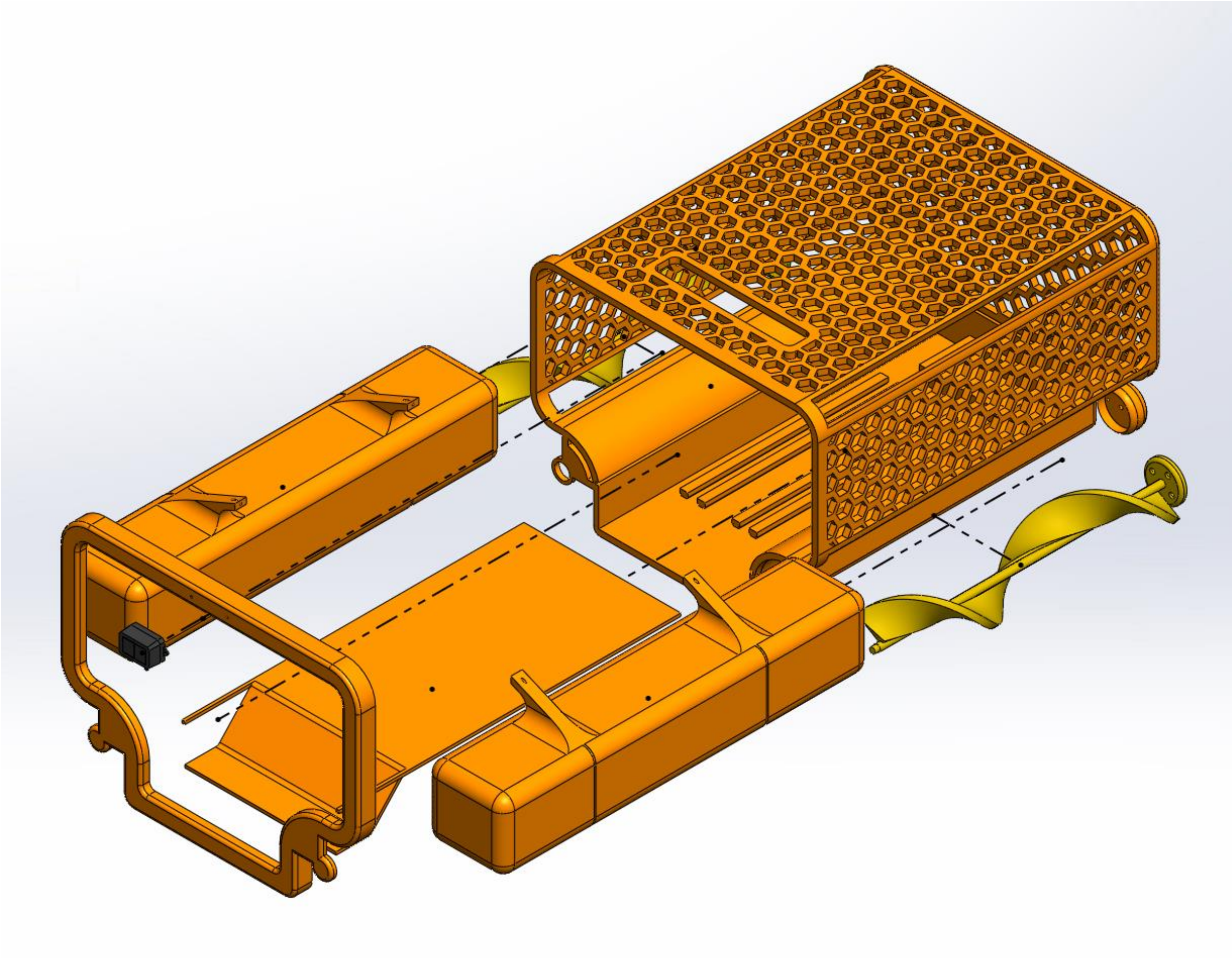
Drawing 1

Drawing 2

Drawing 3

Drawing 4

Drawing 5



5. Conclusion

The final design concept for project CFC demonstrates feasibility in design from supporting calculations on power, buoyancy which prove the robot can function. For example, from the calculations done in 3.1.1 and 3.1.5 which prove enough power is generated to propel the robot, and whether the robot would float. Additionally, the supplied pseudocode in 3.2.3 provide a thoughtful basis on how the robot would behave when manufactured. The integration of sensors such as LiDaR for obstacle detection and GPS + IMU for navigation ensures the robot can detect plastic waste from the ocean in complex environments where it mauver in and around obstacles. Based on these design validations, the device is a feasible solution for waste removal in water ways.

The design addresses SDG #14: Life Below Water directly by targeting on removing ocean pollution which otherwise poses as a threat to marine life and hence addresses the needs of the relevant stakeholders.

Going forwards into the future, a prototype will be created. This will allow for assessing of the robot's floatation and its manoeuvrability. Additionally, stakeholders will be further consulted to ensure that the design meets their needs. Adjustments to design will be made if they are determined to be necessary.

Other future work could involve refining certain control systems and investigating the lifespan of the device as well as it's durability, and innovations in manufacturing methods and equipment choices to lower the cost of the unit.

Ultimately, this holds high potential for achieving its goals and meeting the needs of stakeholders.

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Appendices

Appendix A: Pseudocode

```
// to start the drone all components need to be initialized, which is what this function does
// basically turns on all the components which are required for the drone
Initialize battery system, voltage regulator, buck converter
Initialize motor driver
Initialize GPS, IMU, LiDAR, and Raspberry Pi

// function to set the speeds  of the motors, this is used in the other functions depending on the situation
// i.e the motors speeds can be set to negative to make the drone go backwards
Function ControlMotors(leftSpeed, rightSpeed)
    Set left motor speed to leftSpeed
    Set right motor speed to rightSpeed
End Function

// function to Avoid obstacles, by turning in one direction to avoid it, if using thhe sensors the drone picks up
// that there is an obstacle infront it will go around it by turning left
Function AvoidObstacle(obstacleDistance, obstacleDirection)
    If obstacleDirection is RIGHT
        Turn LEFT by adjusting motor speeds
    Else If obstacleDirection is LEFT
        Turn RIGHT by adjusting motor speeds
    Else If obstacleDirection is FRONT
        Turn RIGHT by adjusting motor speeds
        Go forwards  for 2 meters
        Return to original path
    Else
        Turn DEFAULT_DIRECTION (e.g., LEFT)
    Pause briefly to complete the turn
End Function
```

```
// Main autonomous control loop, this function uses all the other functions to make the drone autonomous,
// it uses the sensors to detect obsticles if so AvoidObstacle function is called, which makes the drone go around
// this function also checks if the battery has enough charge, if not then the returnToBase function is called
// making the drone go back home
Function AutonomousNavigation()
    While drone is operating
        Get current position from GPS
        Get current orientation from IMU
        Get obstacle distance and direction from LiDAR

        If obstacle is within threshold
            Call AvoidObstacle with obstacle data
        Else
            Move forward by setting motor speeds to full

        Check battery level
        If battery is low
            Call ReturnToBase
        End If

        Check trash capacity
        If trash capacity is full
            Call ReturnToBase
        End If
    End While
End Function
```

```
// Return to base, in case of emergency or low battery, the robots starts to head back home to avoid
// any more complications
Function ReturnToBase()
    Define base coordinates

    While not at base
        Get current position from GPS
        Get current orientation from IMU
        Get obstacle data from LiDAR

        If obstacle is within threshold
            Call AvoidObstacle with obstacle data
        Else
            Adjust heading toward base using GPS and IMU
            Move forward
        End If
    End While

    Stop motors
End Function

// Main function, this function is the main function where the functions get called, first me initialize all the
//components required and then set the drone on autonomous cleaning
Function Main()
    Call Initialize components
    Call AutonomousNavigation
End Function
```

Figure 15: Pseudo Code

Figure 15 above displays the complete pseudocode, within the code there are functions that control the motors, which sets the speed of the drone, the speed can be anything within the range of the motors. Other functions included contain the logic for obstacle avoidance, which depending on the side the obstacle is relative to the drone, would cause the drone to steer away or continue straight. Return to base function is responsible for determining whether there is enough battery capacity left for the drone to continue its task, if the battery is below a set threshold, the return to base function will be enabled causing the drone to return. Autonomous navigation is a combination of all the functions, this function allows the drone to navigate the marine environment, detect rubbish or obstacles and respond in the correct manner.

Appendix B: Weight calculations

$$wall\ thickness = 0.01$$

$$elec\ bottom = 0.28 \times 0.6$$
$$elec\ side\ walls = 2 \times 0.064 \times 0.600$$
$$elec\ back\ wall = 0.26 \times 0.064$$
$$elec\ total = wall\ thickness \times (elec\ back\ wall + elec\ side\ walls + elec\ bottom)$$

$$Side\ walls\ v = 2 \times 0.6 \times 0.210$$
$$Back\ wall\ v = 0.290 \times 0.490 - 1/2 \times 2 \times pi \times 0.065^2$$
$$roof\ v = 0.6 \times 0.420 - 0.04 \times 0.240;$$
$$upper\ half\ total = wall\ thickness \times 1/3 \times (Side\ walls\ v + Back\ wall\ v + roof\ v)$$

$$propeller\ weight = 1080 \times 0.05 \times 0.01 \times 0.475 = 0.2565$$
$$cover\ weight = 1080 \times 0.595 \times 0.27 \times wall\ thickness = 1.7350$$
$$Main\ body\ weight = 1080 * (electotal + upper\ half\ total) = 5.0672$$
$$motor\ weight = 2 \times 5.5;$$
$$Batteryweight = 3 \times 2.9$$
$$Lidarweight = 0.05$$
$$Gpsweight = 0.035$$
$$Imuweight = 0.005$$
$$RaspberryPiweight = 0.047$$

$$Totalweight = propellerweight + coverweight + mainbodyweight + motorweight + batteryweight + lidarweight + gpsweight + imuweight + raspberryPiweight = 26.8957$$

$$floatyw\ eight = 1080 \times wall\ thickness \times (0.6 \times 0.135 + 0.6 \times 0.12 + 0.12 \times 0.135) = 1.8274$$
$$weight\ with\ floaty = total\ weight + 2 \times floaty\ weight = 30.5504$$

Appendix C: Buoyancy Calculations

$$wall\,Thickness = 0.01;$$

$$elec\ volume = 0.280 \times 0.070 \times 0.600 - \left(.27 \times .07\ \times \left((0.052 + 0.122)/2\right)\right)$$
$$Side\ walls\ v = 2 \times 0.6 \times (0.210 - 0.125)$$

$$Back\ wall\ v\ = (0.290 - 0.125) \times 0.490 - 1/2 \times 2 \times pi \times 0.065^2$$
$$upper\ half\ volume = wall\ thickness \times 1/3 \times (Side\ walls\ v + Back\ wall\ v)$$

$$Mainbodyvolume = elecvolume + upperhalfvolume$$

$$Buoyant\ weight = main\ body\ volume \times 1025 = 10.9480$$
$$buoyantforce = buoyantweight \times 9.81 = 107.3997$$

$$floaty\ buoyant\ weight = 2 \times 0.12 \times 0.135 \times 0.6 \times 1025 = 19.8288$$
$$\max w\ eight = buoyant\ weight + floaty\ buoyant\ weight = 30.8740$$

Appendix D: Spiral Propeller Considerations

Typically, spiral designs are not effective due to the increased mass they would apply to a marine vehicle. It the very reason why you'll never see them industrial applications. However, due to the low-density qualities of HDPE and the much smaller scale relative to large scale watercraft, it would prove to be a viable solution for propulsion.

Due to this, an efficiency value is harder to pinpoint. Our value is based on a range of varying sources and model types, alongside principals of the design, including the greater length and lower revolutions per length allowing for greater efficiency.

As this design reduces noise and turbulence due to its design alongside the above factors, it’s found that a 75% to 85% efficiency range could be reached upon testing of the propeller system. Due to limitations placed on the authors by the nature of the course, these could not be done, but with time it was firmly believed this would be a viable solution to the task, only supported by the fact that it would minimise blockages and would be overall safer for marine life due to the lower speeds required.

Appendix E: Bill of Materials

For HDPT, [10] was used to calculate cost.

Item	qty	Description	Material	Mass (each, kg)	Cost ($, for all qty)
1	1	Main body	HDPT (high density polyurethane)	5.0672	301.37
2	1	Electronic cover		1.7350	103.04
3	2	Propeller		0.2565	30.55
4	1	Front Panel		1.4636	87.17
5	2	Floaties		1.8274	217.68
6	1	Raspberry Pi	N/A	0.047	134.50
7	1	TF02-Pro LiDAR	N/A	0.05	151.80
8	1	Ublox NEO-M8N GPS	N/A	0.035	48.47
9	1	MPU-9250 IMU	N/A	0.005	18.75
10	2	2 hp (1.5 kW) Brushless DC Motor	N/A	5.5	864.72
11	3	Bosch Powertube 500 Vertical Battery	N/A	2.9	3594
12	1	12V-48V DC Speed Controller 50A (PCB Model)	N/A	0.210	117.95
13	1	Fishing net		0.02	13.20
TOTAL				30.5504	5683.20

Appendix F: Design Process

F.1 Original design

The first concept for CFC, depicted in Figure 16**Error! Reference source not found.** was generated after a group brainstorm of the required components for a device to collect rubbish and pollution in our waterways. The main desired components were agreed to be:

- a way of moving around,
- containment module for rubbish,
- sensors to move around,
- sensors to detect if containment is full, and

- ways to remove the rubbish from the water.

From this, Project CFC's team then went away and individually came up with rough concepts including all the concepts. Separate concept generation allowed a wide range of variety in the designs, which was a great advantage for the original design.

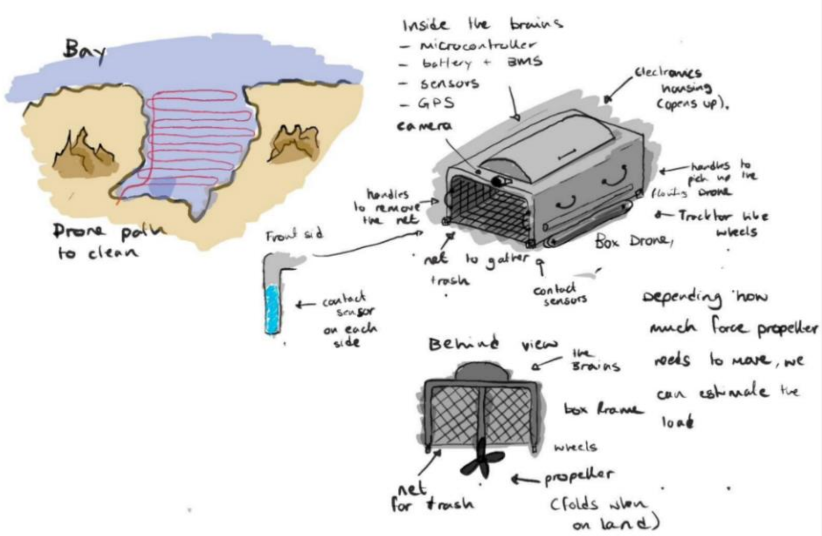

Figure 16: CFC Bucket Original Sketch

F.2 Presentation design

By the time of the presentation, the electronics section location, propeller design and design of the frame all had significant changes which can be visually seen in Figure 17 when compared to Figure 16.

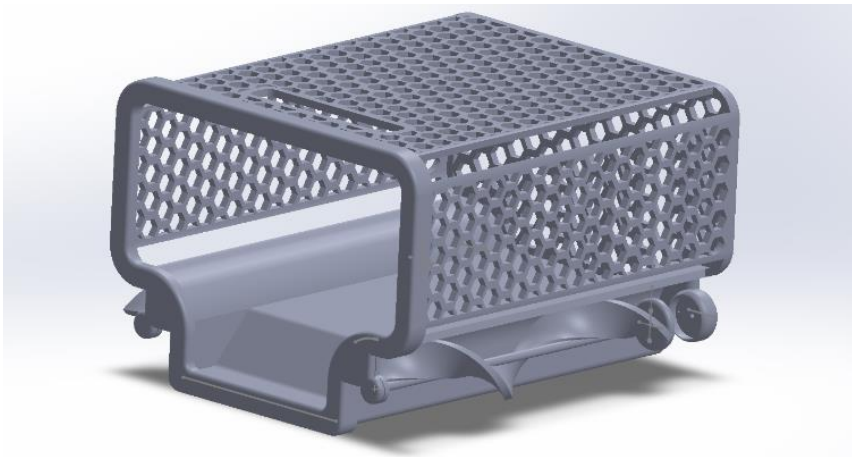

Figure 17: CFC Bucket Presentation 3D Model

The electronics section was moved to below the unit as it would help the unit to sink a bit, aiming to have an optimal height for rubbish collection on the water surface, as well as providing more stability against ocean waves that could force it upside-down.

The propeller design was adjusted to allow a simple method of turning the vehicle, as earlier designs would have also required a rudder or for the propeller to turn on a hinge. Multiple propeller designs were researched before this chosen model was decided upon. See Section 2.1 on further details for the propeller design and benefits. A motor wasn't specified in the original design, and the motor what would be most compatible with the propeller is a 36V brushless DC motor, so this was chosen. Its benefits are long-life, low noise and vibration levels which make it environmentally friendly, and lightweight and not reducing the buoyancy.

The frame was also adjusted to be made of a hexagonal pattern instead of a completely solid wall, as it minimized the impact of ocean forces from its minimal surface area for drag. See Section 2.1 on further details for the frame.

The shape of the frame and body additionally needed to change according to these adjustments.

It was decided a PowerPlus ECO 48V 4KWh lithium battery would be the best option to power the unit.

F.3 Final design

As calculations were finalized and the team performed more serious scrutiny of the design, some further adjustments were made. The final Design can be seen in Figure 18.

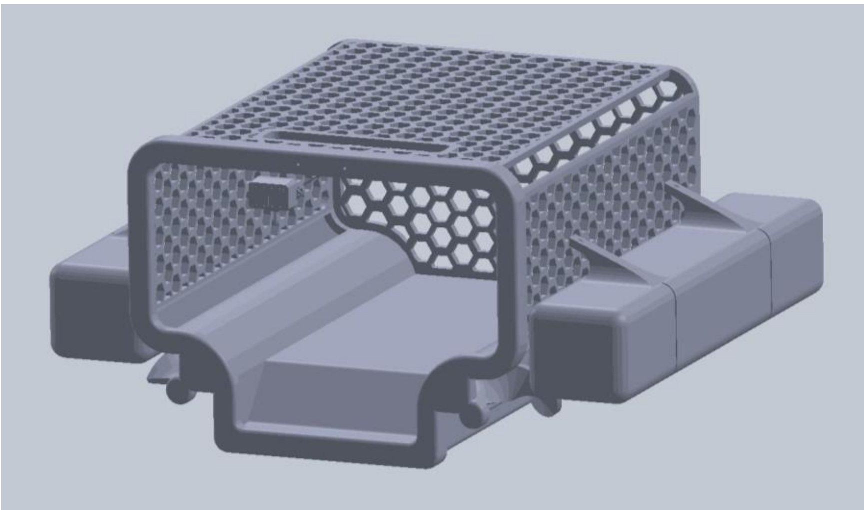

Figure 18: 3D Model of Final Design

Upon further calculations of the required torque for the motor, it was clear that the 36V brushless DC Motor would not meet the torque needed for the propellors.

The previous motor could only produce a maximum of 0.61474Nm of peak torque. It had a torque constant of 0.063Nm and a max current of 9.8A, which is 9.8x0.063=0.6174N and from the equation on 3.1.4, it is calculated that 2.022Nm of torque is needed for the new propeller design that was changed just before the presentation. So, with these new pieces of information, these motors could never have opposed the current underwater and additionally they could only take 9.8 amps, and because the original batteries were in parallel the amperage produced was 40.2 amps. This clarified that a super heavy-duty high torque motor that would be more compatible with the new propellers and the battery configuration.

After more consideration about the battery, it was clear that buying a single battery was not only more expensive and difficult to integrate into the desired dimensions, but also those batteries were not resistant to vibration, and potential impact etc, and they couldn't be changed out easily for charging, whereas the bike batteries fulfilled all necessary functional requirements. See 3.1 for more detail on the decision for batteries.

Additionally, due to the change in motor and some minor adjustments in the size of the unit, the buoyancy calculations were redone and showed that despite the buoyancy from the unit's choice of material, it is too heavy and would sink.

The design had a buoyant force of 101.3997 Newtons, which is much less than the required 263 Newtons needed.

To combat the weight, the design was adjusted to have two floatation modules, one on either side of the frame, which allowed the unit to float at the height for maximal collection and ensure buoyancy during its trip.

Finally, a small adjustment to the front panel was made to attach the lidar modules in.