POLE TO POLE

Blott-Matthews Challenge

POLAR REACH

Final Report

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ABOUT THE TEAM

Perry Tsai *Project Manager*

Throughout the project, my main role was to oversee the project to make sure everything was running smoothly. I was responsible for setting tasks and research areas for my fellow group members. I kept track of the progress of the project and made sure they met their deadlines. I also held regular meetings to allow us to discuss ideas, make decisions and check on progress. Apart from my leadership role, I also took part in research and designs, in particular the use of electronic systems and creating functional flow block diagrams. This also included researching the energy source for propulsion and electronic systems.

As a small kid, I was always fascinated by many of the modern technologies that were made possible due to the complex engineering behind it. Things like aeroplanes, space shuttles, cars have all excited me since a young age. I have always wanted to investigate the principles behind how they worked and all the preparation and planning process they go through. I thought the Blott Matthews Engineering Challenge could really help me feel what it is like to work in the engineering industry and so I decided to join. At this stage I can say for sure that the Blott Matthews Engineering Challenge has deepened my passion for engineering and has driven me to pursue a career in engineering.

Archie Bermingham *Chemical and Logistics Engineer*

I have mainly been working out what the most efficient fuel to use may be and their specifications. After researching about their upsides and downfalls I then compared them to other fuel types. After deciding on the fuel, I then used our estimates for the mass of the boat and maximum distance to be travelled to work out how much fuel we would need, the space it would take up as well as the extra mass it would add to the vehicle. I was also in charge of working out what motors we would need and their specifications.

I joined the Blott Matthews Engineering project as I wanted to learn more about the logistics and the planning involved in creating a vehicle and overcoming challenges along the way. Before the challenge, I was not very good at electrical physics but after this challenge, I would say I am confident as I had to calculate the power, energy needed, and many other electrical calculations. This helped me get used to a lot of electrical equations which will be useful for A-level physics and beyond.

Brian Ho *Graphic Designer and Civil Engineer*

I was mainly responsible for designing and modelling the boat and the mechanisms within it. I made rough sketches of our initial designs and slowly developed each component as more research was being completed. After the rough final design was decided upon, I converted the sketch into a 3D model using Fusion 360 as well as the mechanisms used for amphibious transitioning. I also took part in researching energy storage systems and solar cells. Later on, I was responsible for doing calculations regarding boat dimensions, boat manufacturing and hydraulics.

I decided to take part in the Blott Matthews Engineering project as I wanted to learn more and research about topics outside of the physics A-level syllabus. It would also allow me to improve my 3d modelling skills and look into how boats are constructed.

Charles Engwell *Cartographer and Surveyor*

I have spent my time during this project researching anything that may be seen as an advantage to us, looking into different types of fuel and vehicle. My main role was planning the route through Antarctica. This took a lot of extensive research due to the lack of information about the continent. Despite this, I made sure that I found the time to try and help all attributes of our vessel reach perfection by inputting various ideas and explaining all their advantages and disadvantages.

I decided to join the Blott Matthews Engineering Project as I have always been interested in engineering as a whole. I saw this engineering project as an opportunity to broaden my knowledge of chemical, mechanical, and electronic engineering. Over the time spent researching into different aspects of propulsion and vehicle type, I have learnt a lot. I have learnt how seemingly small changes may have a large impact on a vehicle and how such effects are imposed.

David Harding *Implications and Risk Assessor, Manufacturing Engineer*

I had a very diverse role in the group. I spent a lot of time in the first sessions of the project deciding if using humans to complete the challenge would be possible or would automation give our group an advantage. Later on, as more designs were brought forward, I spent much time researching the materials we could use in the project. Our materials had to fit a huge number of factors that all had to be taken into account. With my sailing experience I was a key part in the designing of the sea route including the restrictions and challenges that come with it.

I knew that I would be a valuable member to any team that I would join as I had a lot of ideas to offer. I am interested in engineering, especially mechanical engineering as my biggest dream is to one day work in a car garage as a mechanic. Seeing car mechanics as a child, I was always in awe of their work and its complexity. This lead to my dream of such a career that I have had since I could walk. I believe that one day I will achieve this career because of my hard work, and I am glad to say that this challenge will help me get there.

Ivan Chan *Mechanical Engineer and Resource Manager*

In this project, my main role was to research innovative propulsion methods that could be applied to our design and help calculate and estimate the total cost of the trimaran. For the different propulsion methods, I had to do lots of reading and list out the pros and cons of each method, which gave me a chance to learn about the different propulsion methods they use in space. For the cost of the trimaran, I found it challenging as I have had to find and estimate the price of different components which in some cases are not yet available commercially.

I decided to join the Blott Matthews Challenge as I always like to think about impossible things and the challenge gave me a chance to gather up all these thoughts and make it somewhat close to realistic.

INTRODUCTION

Description and Interpretation of Question

Our challenge is to transport a 1-ton load from the North pole to the South pole. Aviation is not allowed, and we cannot use any forms of aid from external sources in our journey. The load is non-metal and has a size of 2m × 2m × 1.5m. Plans after arrival are not needed.

After confirming with Blott Matthews, the payload cannot be split into smaller pieces, and must stay with the original dimensions of 2m × 2m × 1.5m.

Overall Description of Solution

Our choice of transport is an amphibious trimaran that is capable of sustaining the whole journey on three main types of propulsion systems.

- Sail Propulsion
- Caterpillar Tracks
- Electrical Propeller

Our vehicles will be fully automated with different electrical systems to support it. In addition, transitioning from Land to Water and Water to Land will be controlled by hydraulics. Below is a rough CAD design of our vehicle:

Figure 1

Overall Stats for Journey

	On Sea	On Land
Journey Time (Days)	112	50
Maximum Speed (km/h)	18.5	15
Average Speed (km/h)	11	10
Route Length (km)	1800	2500
Cost (£)	152190	
Energy Use per Km (kWh)	0.02	30
Pollution (Tones)	~0	~0

***The calculations and any further calculation can be found in the final design section of this proposal.**

Outline of proposal

The ***initial ideas*** section covers early decisions we made and brief research that were used to decrease the range of possible choices.

The ***developed ideas*** section covers the further research we delved into for each possible choice and our thought process when eliminating options.

Environment and challenges section will outline the route and factors that we took into consideration while planning it.

The ***final design*** section covers our different CAD models as well as calculations and factors in the construction of the vessel.

Initial Concepts

Land, Sea or Both?

The first question that sprung to our mind was the sort of vehicle that we would use. Would it be a boat? Or an amphibious vehicle that allowed us to use roads and tracks that already existed on land? Our group had an extensive discussion over what would be the best option, and we decided that we would use a vehicle that mainly travelled on sea, but also well equipped to travel on land at the South Pole. After all, 70% of the Earth is covered with water... It would be more convenient to travel on sea due to the fact that the route would be much more direct as it required less planning and would almost definitely cover a shorter distance.

Automation or Humans?

With the number of possible problems that we would encounter on our journey and the harsh conditions around the world, we initially wondered whether we would require a human on board. As a human on board would mean that maintenance decisions could be made by a trained professional with skills in the area of expertise.

Despite that, our group kept on running into a recurring problem of the space and energy required for the human because it would lead to a larger vehicle, which in turn, would increase the weight and therefore require more fuel, creating an endless cycle of increasing size. A lot of vital systems would have to be put in place in order to maintain a habitable environment. These systems include the temperature regulating systems, food storage systems, water storage/purification systems and many more factors related to health and safety. After identifying this problem, we decided that the vehicle system would have to be automated. There were many **advantages** to this:

- The vehicle could be smaller
- The vehicle would not require food, water or health care
- No energy would need to be stored for the human on board
- There wouldn't be any hatches required for human entering and leaving the vessel, allowing a more sturdy and streamlined build
- It would be safer as life is not put at risk in rough sea conditions
- Automated responses would be more logical and straightforward that human decision making, they are quicker as well and reduces human error

There would also be some **disadvantages** as to what we would need to think about in the any further research:

- The automated system would need to link to the cloud
- The system must be programmed with correct decision-making skills
- Parts could break and would need to be strengthened or have spares readily available.

Terrain on the Arctic and Antarctica

The Arctic never seemed to be much of a problem to us as we already knew that the landscape was fairly flat and didn't impose many risks at all. If we were to start on the ice, then the journey would be a simple straight trip from the centre of the ice to the edge. There are two potential dangers to this, one of them being whether we might accidentally drive our vehicle off the edge of the ice and that it may fall a distance up to 20m. However, even this wouldn't be a problem, as long as the vehicle was stable or self-righting. The other danger would be the possibility that it may hit something upon entry with the water.
The Antarctic was a different problem though, as there were not many inclines onto the land, the terrain seemed to be rough and there was always a possibility of large gusts of wind (these dangers will be discussed in greater detail further on in the report). We knew it would be a challenge landing the craft, as well as a challenge navigating it through such harsh conditions.

Possible Weather Encounters

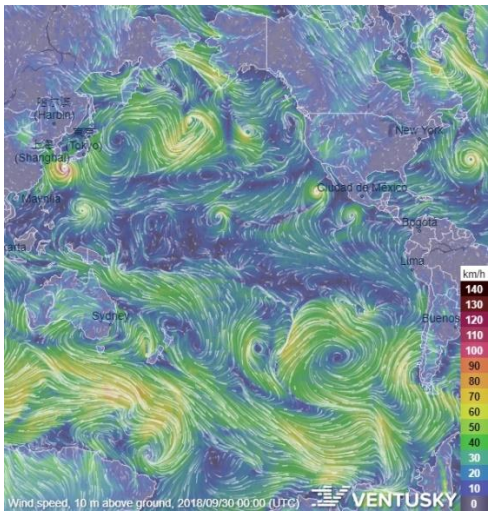


Figure 2.1

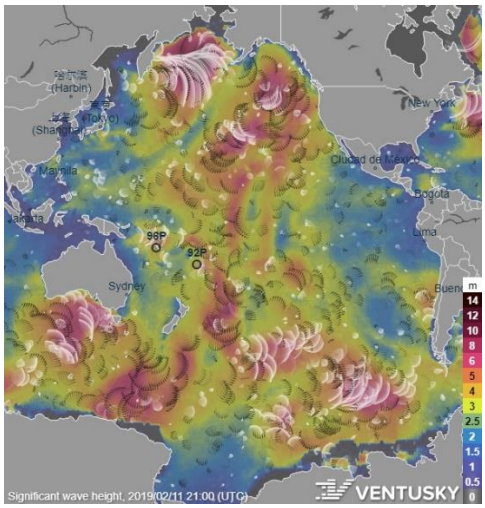


Figure 2.2

Figures 2.1 and 2.2 are typical photos of the weather pattern of the Pacific Ocean from Ventusky, an online platform that displays a range of data for the world. The photos are looking at the wind speed and wave height respectively. The weather on the route that we will be taking won't be typical and will be prone to change. Therefore, using the highest wind speed and highest gust speed we shall be able to prepare our vehicle for all eventualities. The data from the weather sensors on the boat will be used to modify the route to avoid the possibility of damage in the highest risk areas.

The weather was also going to be a problem on land as we knew the Antarctic could reach temperatures as low as -50°C. This alone could cause moving parts to seize up and stop our vehicle completely, or even drain batteries quicker, depending on the type. Not only this was a challenge though, as Antarctica could also have wind speeds as high as 100mph, which will be more than enough to blow a vehicle with a large sail over. This also presented the challenge of keeping everything cleared or sealed away as if a considerate amount of snow or ice were to blow into the moving parts of the vehicle. This would decrease the chance that weather would hinder its productivity.

Propulsion Method

Wind

Wind seemed like an obvious resource to choose from when moving around at sea, as it is accessible everywhere. However, we had to keep in mind that wind is not always reliable and can also cause massive problems.

Using wind for propulsion has been done for hundreds if not thousands of years, and because of this there is a huge amount of information about the benefits and sacrifices of using it. While being arguably more abundant than light, the wind would provide the possibility of travelling at night without using the critical battery energy stores. This would mean that the energy spent during the day could be recharged while the propulsion method of other sensors of communication is also using up energy.

On the other hand, there is a very dangerous side to using wind power to propel. Firstly, the wind could be unreliable even in the areas of known trade winds. This would mean that our group would have to factor this into our calculations of the average speed. To combat this disadvantage, we decided to put a backup method of propulsion into the boat as well. Another dangerous side was how violent the winds could become during storms. These strong winds mean that our materials would need to be stronger and more resistant than normal commercial grade boats. However, these problems could mainly be managed with better design, selection or materials, information updates and route adjustment.

After weighing the two sides together, our group decided to use wind power not only because of the positives outweighing the negatives, but the fact that all the significant negatives could be managed, and the risk could be reduced.

Motor

The easiest method of propelling boats forward would be to install one or more motors at the rear end of the boat. These motors usually drive a propeller that acts as a fan in the water, collecting the water that is in front of it and pushing it away behind it. This method does not rely on a natural resource and so it could be used at any time of day and in most weather events. This 'anytime use' is a major benefit in comparison to other methods. This would also contribute to making a fast vehicle although we would need fuel to power these propellers. This would lead to more fuel, which infers that there is more mass added, and more space taken up in the boat.

Wave

As we had decided to travel over the sea for most of our journey, we knew that we would constantly be surrounded by potentially rough water. Because of this, we tried to play this to our advantage. As this was no new idea, we researched into multiple forms of wave propulsion as some relied on a spring-loaded hydrofoil, while some relied on a small robot deployed 5 or so meters beneath the boat, and others require neither. Since we had to travel on land, and that our vessel would have to be large, we ruled out the option of using wave propulsion using a submersible robot. This was simply because it would cause extra systems that seemed unnecessary.

NASA Space Propulsion Methods

The research was done to investigate the possibility of using space propulsion technologies. However, almost all these systems were low acceleration propulsion systems that worked wonderfully in space but would fail to perform as well on the sea, as the water and air resistance wouldn't allow ideal performance. Also, most of these propulsion systems required fairly

complicated control systems and occupied large amounts of space. Furthermore, all these methods are relatively unstable; having a high chance of being disturbed by the natural environment and damaged by sea water. Hence, we decided that it was not suitable to implement into our vehicle.

Radioisotope power systems (RPS)

We also researched into a common energy storage system used in space travel called the radioisotope power system. It incorporates the heat from the decay of plutonium-238 into electrical energy. It contains thermocouples that are used to regulate temperatures, such as air conditioners, refrigerators and medical thermometers. Thermocouples involve two plates, each made from a different metal that conducts electricity. From joining these two plates and forming a closed electrical circuit it produces an electrical current when the two junctions are kept at different temperatures. Each of these pairs of junctions forms an individual thermocouple. In an RTG, the radioisotope fuel heats one of these junctions while the other junction remains unheated and is cooled by the space environment or a planetary atmosphere. In terms of statistics, this sort of energy system is used in deep-space missions beyond 4 AU (4 distances between the earth and the sun) It has a specific power of around 3 W/kg. The life capability of an RTG spans less than 20 years but has a conversion efficiency of approximately 10% However, the heat regulation was extremely demanding and so we gave up on this idea.

Energy Source

Wind

If we had decided to use the motor, wind generators on the boat could provide us with a sustainable, eco-friendly source of energy. As it will almost always be windy out on the open sea, harnessing such energy would allow us to power the motor for the propeller. However, this could potentially be unrealistic as the small amounts of energy obtained would not be sufficient to power the motor. The potential to harness this renewable energy made us continue to research into possibilities of using such means of obtaining energy.

Solar

The use of solar panels would allow us to harness energy from the sun. Coating the boat with solar panels would seem like an ideal way of obtaining green energy for the motor. However, it wouldn't always be sunny out on the sea and the low efficiency of solar panels would result in only small amounts of energy collected. Further research and calculations to decide on whether to use solar panels were carried out as we feel there is potential in using this energy source as it did not hinder any other component.

<u>Solar Panel Facts</u>

- Currently used in Earth-orbital missions and deep-space missions
- Efficiency of <35%
- Specific Power <200W/Kg
- Can't work in extreme environments such as hail and storms. It also will decrease in efficiency by 1.4% per degree above 30.6°C

Solar cells are used in Earth-orbital missions and deep-space missions with an efficiency of less than 35% and a specific power of less than 200W/Kg. However, they can't be used in extreme environments as they are extremely fragile. The photovoltaic cell is a single solar energy cell that acts for the conversion of light energy to an electrical current. Solar cell arrays are

the combination of several solar panels. In brief, the way solar panels work is when photons in sunlight are absorbed by semiconducting materials such as silicon, the electrons end up being knocked loose. These negatively charged electrons flow through the material to produce electricity and the special composition of solar cells restrict the electrons from moving in one direction. This direct current is then converted into alternating current with an inverter. They tend to operate for 25 years or more.

Models of Solar cells include:

Model	Efficiency	Area per kW(m^2)
Polycrystalline	11-15%	7-9
Monocrystalline	13-17%	6-8
Hybrid	>17%	5-6

Table 2.1

Solar cells make up a large part of how our boat might be able to sustain the energy needed, so this has been researched in further detail and explained further in the research section.

Tri-fuel Diesel Electrical

Tri-fuel diesel electrical propulsion consists of three fuels: Marine Diesel Oil (MDO), Heavy Fuel Oil (HFO), and Liquefied Natural Gas (LNG). This method is used by large cargo ships that frequently travel the globe. During a normal sea voyage, MDO or HFO fuel is used to generate power even though it is extremely polluting. Some benefits to using this, are that the required equipment weighs less and takes up less space than a conventional diesel engine and also that they require very little maintenance. In addition, they are a lot cheaper than conventional diesel engines, since they do not require air compressors or fuel purifiers. There are many benefits to using these fuels rather than a large diesel engine as they also give out less noise pollution and that there are no limits to the number of times that the engine can restart. This appeared as though it may be a good option, but this method appeared to be very excessive for simply moving only 1 ton of a substance. Therefore, if this were to be used, it would need to have the ability to be scaled down.

Figure 2.3

LNG

Liquefied Natural Gas is a fuel source that appeared very green in comparison to the tri fuel diesel electric propulsion. Initially, we thought that this was a good option and so we did some research. Questions that we thought to ourselves before researching the answers included those that asked why it wasn't as commonly used as diesel or why it was only used in ports for large container ships. It seemed obvious to us that it was less energy dense than diesel, simply due to the fact that it is a gas at room temperature and pressure, and diesel is a liquid. Other than this, we discovered that as it is naturally a gas and, in this instance, it is a liquid, it must be kept at very low temperatures and high pressures.

Liquefied natural gas is methane with a mixture of ethane that has been cooled down to liquid state, both of which can be made easily from the dehydration of methanol and ethanol or from the by-products of cracking of large chain alkenes and alkanes this would make it easy to make and seem very useful as the methane and ethane created in some cracking reactions we could use as they are usually the by-products they could be used for our propulsion also we could make ethane easily from the dehydration of ethanol and hydrogenation of ethene which would mean we would not need to use non-renewable resources as you can make it from just concentrated alcohol which can be made from the fermentation of glucose as this could be made before the trip and so this would mean we would not need to use non-renewable resources.

Methane Hydrate

It is a crystalline solid, ice-like structure. In this case, methane molecules are trapped in the lattice structure formed by water molecules; They occur in subsurface deposits (permafrost, continental shelf, etc). The energy generated by 1 m^3 of methane hydrate is equal to 164 m^3 of methane, which is nearly 160 times more than methane and has about 80% of the heat content of crude oil. Furthermore, it is a cleaner combustion reaction.

Hydrogen

Hydrogen's presence in seawater made us feel like it was the best solution at first glance. It also has a very high energy density compared to other fuels such as coal and diesel. The reaction to produce energy would only produce water which makes the fuel extremely environmentally friendly. However, after further thought, it appears that it would be very difficult to separate the oxygen from the hydrogen in water. The high energy requirement could mean the energy required to extract the hydrogen would exceed the energy produced. The whole process was a complicated, energy demanding industrial process that wouldn't work well on a compact boat. The cost is high, and the hydrogen gas produced is highly flammable. Therefore, our group deemed this energy source an undesirable method of obtaining energy.

Specific Energy, Energy Density & CO2

Fuel	Specific Energy kj/g	Density KWH/gal	Chemical Formula	lbs CO2/gal
Propane	50.4	26.8	C3H8	13
Ethanol	29.7	24.7	C2H5OH	13
Gasoline	46.5	36.6	C7H16	20
Diesel	45.8	40.6	C12H26	22
Biodiesel	39.6	35.0	C18H32O2	19
Methane	55.8	27.0	CH4	3
Oil	47.9	40.5	C14H30	20
Wood	14.9	11.3	approx weight	9
Coal	30.2	22.9	approx weight	19
Hydrogen	141.9	10.1	H2	0

Source: DOE, Stanford University, College of the Desert, & Green Econometrics research

Table 2.2

Energy Storage

Chemical Fuel Storage

In terms of energy storage, what we are looking for most importantly is *rechargeability, high specific energy* and a *long-life capability*. This would enable *reduced costs, survivability in extreme conditions* and *enable this difficult mission to be successful*. Primary batteries used in NASA are used in planetary probes, landers, rovers, etc. They have a specific energy of around 250 W/kg and have a storage-life capability of fewer than 15 years. They can't operate in extreme environments and so this can't be used in our scenario. Lithium-cobalt sulphide primary batteries can be used in conditions up to more than 400° C and have high specific energy, but they cannot handle low temperatures so would also be unsuitable for our scenario. Lithium-carbon monofluoride primary batteries can be used below -80° C but cannot be used at high temperatures and so have been eliminated as well.

In terms of rechargeable batteries, they are used in robotic and human space missions as an electrical energy storage device and have a specific energy of around 100 W/kg. More advanced rechargeable batteries that NASA uses are needed for missions that require operational capability in extreme conditions have a specific energy of more than 200W/kg and a life capability of more than 15 years. For high energy density lithium batteries, they can operate in low temperatures of around -60° C and have a specific energy of more than 200W/kg as well. But for both cases, these are not applicable for our needs.

NASA space shuttles also use fuel cells that have specific energy in the range of 70-100 W/kg and a life capability of 2500 hours which means it is perfect for short journeys in space. This cannot be used in our case as our journey has an estimated journey time of 190 days. Although after further development, short term fuel cells may reach an efficiency of more than 75% and a life capability of more than 15000 hours while maintaining 200 W/kg.

Lastly, there is a new Battery fuel cell which is still being researched by the Argonne National Lab in the US. but there are a couple of working batteries which are Lithium-Air batteries which have a specific energy of up to 11400 W/kg which is a massive amount seeing as the NASA cells have a specific energy of 200 W/kg. As we will be travelling for 190 days,

we will need a lot of power and this means that we would have less mass by the end. When discharging, the batteries have a cell of lithium which reacts with the oxygen in the air to produce Li_2O_2 which is useful as the oxygen can be used straight from the air and then when it is charging the Li_2O_2 breaks down to $2Li$ and O_2 so it does not use up the oxygen.

Modification of Design

The environmental analysis shows that we will be encountering extreme weather patterns including high wind speed and high wave heights. It would not be sensible to use an ordinary small boat design as it would easily capsize. After initial research, we came up with the idea to use a catamaran, on further research, we realised that a trimaran would work best. The large base area would mean that the boat doesn't easily topple to one side, the separate hulls would be beneficial for stabilisation. One of the advantages of the trimaran is that it has large amounts of living space since we have decided that our vehicle will be autonomous, we don't require such space hence a trimaran could provide higher speed at the expense of reduced living area, which we don't require. The main propulsion method would be having sails and using the wind to propel us forward as this is almost always present in the open sea and would be an eco-friendly propulsion method. A propeller would be in place to provide propulsion in cases where the wind isn't present. This will prevent the vehicle from being carried away by the current or lagging behind schedule.

Developing Concepts

Propulsion Method

Motor

We would need twin 260 hp engines to power the propeller which would have a fuel economy of 20 gallons per hour. As most catamarans have a 10-18 gallons per hour fuel economy at 15 knots.

As one gallon of diesel is at 40.6 KWh we would use 812 KWh.

The max distance from the edge of the ice at the arctic to the edge of Antarctica is 9720 nautical miles at 15 knots would take 648 hours.

This means we would need 526200 KWh of energy to power the trimaran on the water.

As that is the energy needed to move the trimaran that would be the same if we used any fuel source including batteries.

Sail

Wind is an abundant resource while at sea. Sailors for hundreds of years have used wind to sail all around the globe. Therefore, it seemed logical to use wind to as a possible method to propel the trimaran.

The major developments made in modern technology are the materials of sail as well as its size. This is expanded on below.

A major advantage to this method is that there will be no emissions.

Wave

The form of wave propulsion that we decided would be best was a simple concept that relies on the movement of the trimaran over the waves. Inside the trimaran would sit a weight that holds a gear in the same position in relation to the ground, but as the trimaran rolls slightly it causes the cog to rotate in relation to the trimaran. This means that as the trimaran goes over a wave and rotates, this cog will turn, turning an axle that then turns a compressed spring. This compressed spring would be attached to a dolphin-like fin device that is fixed on one axis. This should make the 'dolphin tail' beat up and down as the trimaran rotates over a wave. This seems to be a very good option as we are using a problem to create an alternate solution. This, however, may cause more drag in the trimaran when going over relatively calm waters. This method is small enough to fit in any crevice in our trimaran, but the larger it is, the more propulsion it will produce.

Wind

Wind energy can be harnessed using wind turbines installed on the trimaran. Using traditional vertical fan blade turbines wouldn't be ideal as they would disrupt the aerodynamic design of the trimaran and increase air resistance. After further research, we originally decided to use bladeless wind turbines as they are relatively small sized. The idea was that we could mount them on the hulls of the trimaran and use the wind energy from that. Each wind turbine would be able to generate 2.5 kWh per day. Each hull would be mounted with 3 of these turbines and a total of 6 turbines would be able to provide 15 kWh per day. However, after further consideration, we decided that this would disrupt the laminar flow of the trimaran. A hole in the hull for the wind turbine blades would cause the airflow to curl into the hole and disrupt the smooth flow of air, forming turbulence to increase drag. Also, due to the law of conservation of energy, the force applied by the wind onto the wind turbine blades will be transferred to the hull itself, causing a force against the trimaran opposite the direction of travel. The negative impact caused to the speed of the trimaran and directional control of it far outweighs the advantages of the wind turbines, hence we ultimately decided against it.

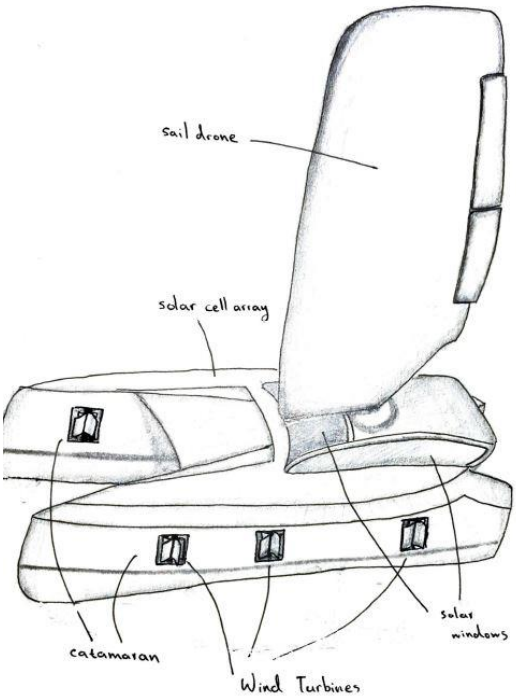


Figure 3.1

Solar

Solar panels will be used to coat the upper deck of the trimaran as that is the main part that would be exposed to sunlight. After further research, we discovered that graphene solar panels would be the ideal type of solar panel to use due to its ability to withstand extreme temperatures and conditions. Graphene is 100 times harder than steel and diamond, and has the ability to self-repair, it is also elastic and flexible, allowing us to model it to an aerodynamic shape.

LNG

Liquified Natural Gas takes up about 1/600th the volume of natural gas which makes it incredibly energy dense at which it is 60% of the specific energy of diesel which means that LNG has a specific energy of 45MJ/kg this makes LNG cost efficient in marine transport for long distances. It is odourless, colourless, non-toxic and non-corrosive this means that there are not many dangers working around it but the fact that it's almost undetectable is also its downfall as you are easily able to asphyxiate if you were working in the hull and there could be a leak which you could not easily be found. The natural gas is then condensed into a liquid by cooling it to approximately –162 °C. The density of LNG is roughly 0.41 kg/litre compared to water at 1.0 kg/litre is very light. The usual energy density is 20.5-22 MJ/litre

Methane Hydrate

As mentioned in the initial research, methane hydrate seemed like the most viable solution for our energy problems; it is a relatively clean energy source and is innovative. However, after further research we found out that there was a huge flaw in using methane hydrates - they needed to be stored at negative 4°C. This can't be sustainable as it requires a lot of energy to cool it down. And the cooling system and the storage of methane hydrates would take up a lot of space. Furthermore, in order to maximise the output, a complicated combustion chamber is needed. All these disadvantages add up and have caused us to give up on it as a viable source of energy.

Energy Storage Needed

We would use Lithium-Air batteries as they were mostly green, energy efficient and lightweight. To work out the amount of power we would need, we performed these calculations.

Firstly, the height of the tracks was approximated 0.5m diameter.

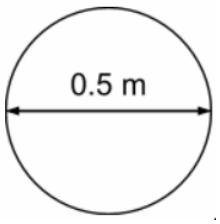


Figure 3.2

Thus, working out the distance one rotation would be equivaltent to the circumference of one of the wheels.

$$A = 2\pi r$$

$$A = 2\pi \times 0.5$$

$$A = 1.571m$$

Knowing that we wanted to travel at 10 kmh^{-1}, we worked out the rotations per second of the wheels by converting kmh^{-1} to ms^{-1}, which is

$$2.778ms^{-1} = \frac{10000}{3600}$$

$$\frac{2.778}{1.571} = 1.768rps$$

Then we converted rps to rpm

$$1.768 \times 60 = 106.1rpm$$

This will be the rpm of the motor

The estimated mass was 11 tonnes so we researched online at electric heavy goods vehicles and estimated that we would need a 149.1 kW motor for each track each at 1000 Nm as we will need lots of torque to keep the vehicle moving over icy, powdery and sometimes steep conditions.

At the start, before crossing the ice at the Arctic before we set off, we would make sure the batteries are charged and as the distance is shorter on the Arctic than Antarctica we can ignore it for our calculations.

With this in mind, using the route that we are taking across Antarctica the distance is 1900 km and as we are travelling at an average of 10 kmh^{-1} that's 190 hours travel time.

We then worked out the energy needed in kWh

$$kW \times h = kWh$$

$$149.1 \times 190 = 28325kWh\ each$$

Or it can be said that it will be 56650 kWh in total

As the voltage we use is 240V, that means we can work out the ampere hours:

$$\frac{Watt\ Hours}{Voltage} = Ampere\ Hours$$

$$\frac{66880000}{240} = 278667\ Ah$$

$$= 139334\ Ah\ each$$

We would need 5 small motors which would control all the sails on the sea, and these would not be in constant use so I estimated that they would be used for 200 hours total each. They are all 350 watts per motor at 36v, 1.11Nm of torque and 3200 rpm. These are used in most catamarans/trimarans

Once again, we work out the kWh

$$kW \times h = kWh$$
$$0.35 \times 200 = 70kWh\ per\ motor$$

This means it will give a total of 350 kWh

Ampere Hours are worked out:

$$\frac{Watt\ Hours}{Voltage} = Ampere\ Hours$$

$$\frac{350000}{36} = 9722A$$

We then work out the total Ampere hours needed

$$9722 + 278667 = 288389\ Ah_{Total}$$

We then estimated we would need 20% more as reserve fuel.

$$288389 \times 1.2 = 346067\ Ah$$

To work out the mass of Lithium Air batteries, we summed up all the Wh and divided it by the specific power of Lithium

$$\frac{(56650000 + 350000)}{11400} = 5000\ kg$$

$$5000 \times 1.2 = 6000kg$$

Material

Solar Panels

The trimaran would have a layer of solar panels on the surface that is 10-meter square. The photovoltaic cells are mounted on the deck on the trimaran and on the stern of the trimaran. One of the biggest challenges has been to store enough solar energy so that the vessel can maintain its progress even when the wind is absent. To achieve this, the trimaran is fitted with 216 kg of batteries which have a capacity of 32757 Ah which can last 190-200 hours without charging. The batteries will be housed in the main section of the trimaran that runs the full length of the trimaran. To minimise the environmental damage from this transportation method, this clean energy transfer method was chosen. Solar panels harnessing renewable light energy is an ideal method to use.

To minimise drag and therefore reduce the energy loss as the trimaran sails, it is necessary to reduce weight but also make the trimaran as streamlined as possible. This weight reduction can be achieved with lightweight modern construction methods. The use of carbon fibre composites in the hull structure meets the requirements of excellent properties while also having a very low weight. 5 electric motors are driven by the Lithium Air batteries. The electric motor at the back of the trimaran provides a total power of 387.7 kW and the motors powering the tracks provide a total power of 11.1 kW. The electric motors used to control the exterior parts of the trimaran are fixed with metal supports. The metal brackets/supports are lightweight, and robust. The cables that connect the motor to the power supply should have thick plastic covers to be able to withstand rocking on the trimaran and potential damage.

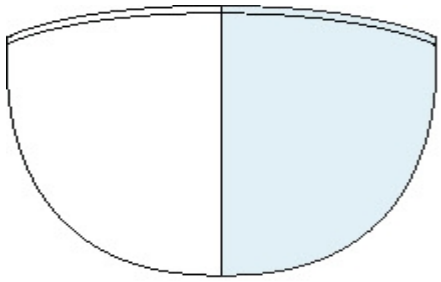
Shape of Boat

For an automated vehicle, the key to safe travel stems from stability. Normal monohulled boats have to minimise water resistance as well as provide stability. To increase stability and balance, we add hulls. By separating three hulls widely, this allows very limited displacement in the water while keeping the trimaran very stable. This is because of the fact that the centre of gravity will be lower, and the base will be larger. An object will topple when the centre of gravity is no longer over the base. With a trimaran, this will be a lot harder to topple than a catamaran. This allows their amas to barely touch the water. At the same time, their hulls are able to be narrow and provide buoyancy at the same time. Trimarans are capable of high-speed travel and high weight carrying capacity, which is ideal for our scenario. They also provide moderate space below the main deck, which means we can store electrical systems. Compared to catamarans, the cross-deck bridge is a lot more flexible in terms of length. On catamarans, the cross-deck bridges cross a moderately large empty gap; this makes engineering the boat and structuring the boat a lot harder and would require more weight and material costs. On the other hand, the trimaran cross decks are relatively small and so it would mean that our design could be simplified, and structural weight could be reduced for the cross deck.

We investigated the shape of the hull as well through our research and came across two distinct shapes and how they may benefit the journey. One hull type would be the displacement hull. This is where the hull has a semi-circular type hull as shown below in figure 3.3. The benefits of this hull would include greater fuel economy, a smoother journey along the sea, and can carry more load, yet is not beneficial for particularly fast vessels.

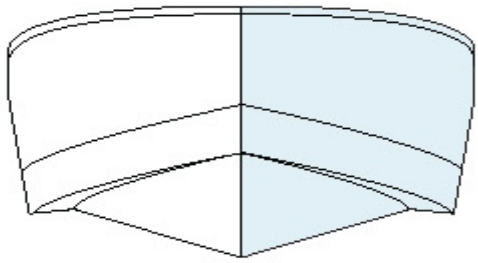
Another hull type is the planing hull that has more of a v shape. This is helpful for boats that are designed to go fast. It allows them to have a greater speed as well as greater manoeuvrability. Figure 3.4 demonstrates the shape. The V shape on the underside of the hull pushes the water outwards rather than ploughing through it, this means that there is a lot less drag on the front of the hull. It also allows for greater speed due to the fact that it almost allows you to surf. On all boats, a small wave often known as wake is formed due to the front of the hull displacing the water ahead of it. When this wave is greater in length than half the length of the boat, the boat will angle upwards and will not go any faster. At this point, there will only be more stress on the engine. This type of hull, however, lifts the whole of the boat off the water slightly reducing the drag and allowing it to be faster than other types of hull.

After finding out about the problem that we may come across the wake causing the boat to lose potential speed, we looked into ways of combating this. There seemed to be only one effective method to counter this, and it is most commonly used on cargo ships to make the journeys more fuel efficient. The bulbous bow, seen on said ships causes a separate wave of wake that is out of phase with the wake given off by the upper part of the bow. These waves then undergo destructive interference, making them smaller and less significant of a threat to the stress on the engine. Owing to the fact that our vessel was going to be fully automated, the journey does not have to be very comfortable, it was unlikely that the trimaran would travel at any considerable speed and so we did not feel the need for a bulbous bow. We did, however, settle on a design that was a mix of the displacement and planing hull as we relied mainly on the wind for propulsion, it didn't need to be particularly fuel efficient, yet it should be easily manoeuvrable.



DISPLACEMENT

Figure 3.3



PLANING

Figure 3.4

Fibreglass

There are three main types of fibreglass construction methods:

Hand Layup

Hand Lay-up is the most common method for high-cost vessels, but it requires the most time and large amounts of manual labour. A well laid out fibreglass coat by hand ensures an even surface in an out and a constant thickness throughout each region of the boat. The mechanical properties are average but are sufficient for industry standard

Vacuum-Bagging

Vacuum bagging can be called a hand lay-up enhancement as it also requires manual labour and adds on to the initial hand layup. After the lay-up, before the resin fully cures, the sheet of plastic is taped in place to the hollow female mould and the plastic is put into a vacuum in a way that the outside air pushes onto the plastic sheet and the laminate onto the mould. As this is done with a pressure of 3.7psi or 25.5kPa, which is equivalent to a 115-ton hydraulic press, the end product is an extremely dense, strong and evenly coated. It also allows for more glass in proportion to the resin. Less resin in proportion to glass-fibre reinforcement means higher fracture toughness and hardness with the same thickness. As it also reduces weight, performance is naturally increased.

Chopper Gun Technique

Chopper gun technique is the most common method for mass produced ships as it is low cost and can be done in short amounts of time. It gives the highest resin content per weight and the most resin in proportion to the glass. This means that the end result is the weakest out of the three methods and is used to fabricate internal and secondary hand-laid-up hulls.

Standard Vanilla Hull

In normal glass fibre hulls, the protective layer is normally made from alternating layers of woven roving and chopped strand mats. This is usually called bi-ply or combi-mat. In addition to this, vanilla hulls usually have a fibre-to-binder ratio that is otherwise called 'glass to resin ratio' and the normal percentage of glass is 35%.

Types of Fibreglass

The type of fibreglass we will be using is called the unidirectional fibre bundles, which can be called uni-di for short. It consists of all fibres laid in the same direction, which will ensure maximum strength in one axis. It also allows for low resin or binder content as they are packed extremely closely and wet-out very easily. Thus, having a very high glass to resin ratio (70%). However, as it only provides maximum strength in one direction, we will need to use a bi-axial, tri-axial or quadra-axial style to account for it. It is pre-stitched by a single roll of cloth and generates even strength in all direction. In addition, due to our choice of the application being vacuum-bagging, we will not require a mat as it is of high quality.

Standard Resin and Catalyst

In standard fibreglass construction, the resin used is usually an ortho-polyester resin, hence the name of fibre reinforced plastic or glass reinforced plastic. The polyester is mixed with a catalyst and accelerator which is technically called polymerization or curing. For the catalyst, methyl ethyl ketone reacted with hydrogen peroxide is normally used. However, it should be noted that this catalyst is quite volatile. A common high-grade resin used is the vinyl ester resin. This resin is very strong and has a high modulus(flexibility), which are both highly sought-after properties for this application. It also stretches far before cracking and breaking and provides strong interlaminar bonds. The type of resin we will use is epoxy resin as it fills large gaps easily and has stronger and higher elongation than vinyl ester. It is resistant to chemical attack and blistering and can be considered to have the highest peel strength.

A comparison of vinyl ester and epoxy resin can be seen in the table below:

Resin	Tensile Strength/psi	Tensile Strength/MPa	Elongation
Vinyl Ester	11800	82	5%
Epoxy	**12500**	**56**	**>5%**

Table 3.1

Standard Fibreglass Laminate

There are four main types of standard fibreglass laminate, the Chopped-strand mat, woven roving, and the fibreglass cloth.

For the chopped-strand mat laminate, the strands of fibreglass are chopped into pieces of 12-50 mm and are mashed together with a binder. This method is called seizing and is very easy to wet out. This type of laminate is good for bonding to layers of other types of glass and so its most common application is using it as alternate layers of mat and woven roving.

Woven roving is made through coarse fabric woven from bundles of glass fibre. It provides strong reinforcements and is twice as strong for the same weight as the combined roving mat. It is high quality but all roving layups cost quite a lot. It also requires a soft, spongy mat between layers.

The last type of standard fibreglass laminate is the cloth. This consists of a very fine weave, similar to fibreglass. The glass cloth is normally used at a layer to smooth out the surface which is why it is usually referred to as 'finishing cloth'

Through a harsh selection process of materials used in hull construction and evaluation of standard laminates, we have decided to use

Vacuum-Bagged Bi-Axial S-Glass Epoxy Laminate

which allows for these desirable properties:

- Flexural strength of 85,000 (586 MPa)
- Strength equivalent to Stainless Steel
- 15th of the weight of Stainless Steel
- Properties that allows it to not corrode

Autonomous Method Development

LiDAR

LiDAR technology has been widely researched and experimented in recent years due to the development of self-driving cars. LiDAR is used in self-driving technology to scan the road and map obstacles, elevation and other objects along the road. This technology could be useful to our trimaran as it could be applied to anti-collision programs and autonomous driving on the Antarctic. The scanning technology could be in place as a safety precaution.

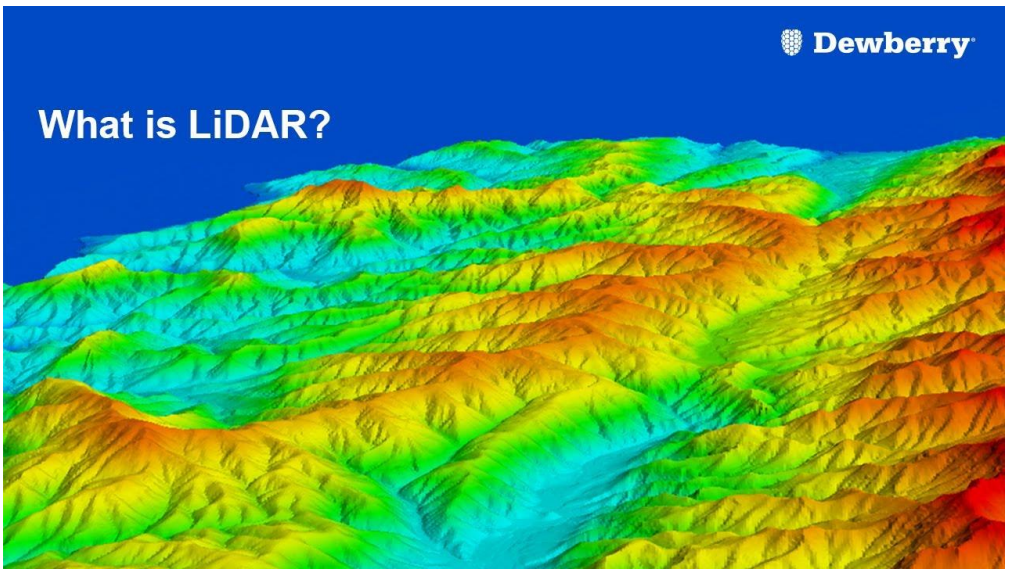


Figure 3.5

Potential Method 1

After research our group was keen on using an autonomous navigation method. Our idea was to use programs combined with the data collected from sensors, GPS and satellite to self-navigate through the waters. Wind speed sensors and wind direction sensors collect information and store them in a storage chip where a pre-planned route has been stored. The trimaran will follow this pre-planned route to start with. The GPS chip sends location data to a satellite, where another program is run to scan the weather pattern along the pre-planned route. If there are any low-pressure areas indicating the formation of a tropical cyclone, the program will recalculate the route and send the updated route plan to the storage chip. The chip will then send commands to the motor of the sail to alter the sail position according to the wind speed and direction data and follow new route data.

Potential Method 2

After doing research into the changing of the route according to the weather, we wondered if we could use machine learning to control the weather route changes.

The machine learning would also have existing parameters that changes must be made within. Microsoft Azure offered an easy way for us to gather data and allow the computer to read it quickly and then make adjustments accordingly. This method would give us an advantage over any human on board or trying to control the trimaran over some kind of internet or satellite connection. Azure's programming was difficult and after speaking to some experienced sailors, they said there are many more systems that need to be integrated. With the interaction of alternative software that is already programmed and tested, it is easier to integrate this with existing software and then place it on our chosen hardware rather than making an inferior copy ourselves. Although our final plan is not using Azure we still learnt a huge amount about data selection which we are now using in our new plan.

Potential Method 3

This 3rd method would be easier as there is already a huge amount of software that has been created for sailors to travel across the world already. The existing programs already have years of experience of fixing problems and bugs This method would be the most simple as less time is spent processing and analysing different data and information as most of the important data would be already integrated. The benefit of using existing software is that it can be downloaded today and looked at to see if it would be suitable for the mission. The systems and programs that we looked at are:

AIS- Automatic Identification System is a must have for all sailing boats that are making long voyages. The risk with an automated sailboat is the possibility of collision between other craft in busy areas. Most boats use this system to avoid other craft and were an obvious choice for us as

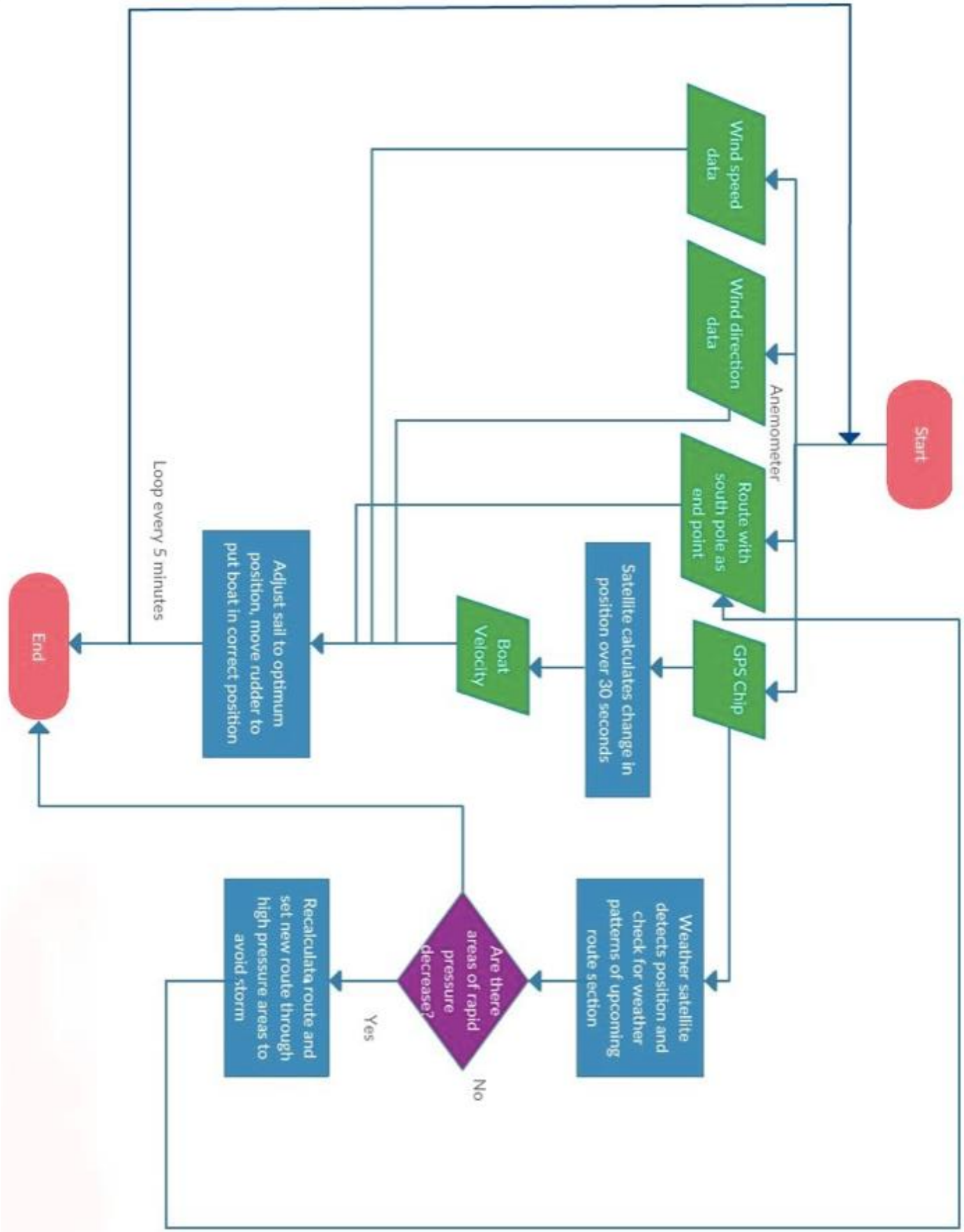

Start
Anemometer
Wind speed data
Wind direction data
Route with south pole as end point
GPS Chip
Satellite calculates change in position over 30 seconds
Boat Velocity
Adjust sail to optimum position, move rudder to put boat in correct position
Loop every 5 minutes
End
Weather satellite detects position and check for weather patterns of upcoming route section
Are there areas of rapid pressure decrease?
Yes
No
Recalculate route and set new route through high pressure areas to avoid storm

Figure 3.6

How AIS can be used

AIS is primarily used to allow ships to view marine traffic in their area. This requires a dedicated receiver AIS transceiver that allows local traffic to be viewed on an AIS enabled chart plotter. All AIS transceivers equipped on water traffic can be viewed very reliable but are limited to a VHF range of 10-20 nautical miles. However, its 10-20 nautical mile range should be plenty for other traffic to avoid us avoid.

Time Zero

This existing software seemed to fill all the requirements that we needed. It was also great as it could be integrated with our trimaran to move from Pole to Pole. Time Zero has a number of packages available although for our method we would need the most advanced package "TZ Professional". These main features can then be integrated into our final routing software for when we are traveling at sea. The integrated software would control out mainsheet motors and rudder motors accordingly to the route. This integrated system of existing programs is less likely to have bugs or issues in use because of years of testing that have already been done.

Weather Routing

Wind speed cap and wave height cap are new features that now allow sailors to sail in security by limiting these two variables. Therefore, we can limit the paths according to the strength of the material. These main areas include the sail for the wind speed and hull for the wave height.

Wind speed and Direction

Wind speed cap and wave height cap are new features that now allow sailors to sail in security by limiting these two variables. This two information can be generated from the sail and hull material and dimensions. This helps us plan our route with a smaller range of safe options.

Alternate Route Suggestions

You now have the ability to check for an alternative route. Great addition if you want to avoid a certain zone such as when sailing near the coastline.

Variability

The new version of the Weather Routing module goes even further by allowing you to fine tune the calculations with even more precision. This module now includes a risk variable which can assess the danger of the routes.

This feature displays zones with high risks, such as a dramatic change in wind speed and direction. It does this using an easy to identify shading spectrum, from which a decision can be made to launch an alternative route.

S63 Charts with built in S57 charts

The charts are updated weekly and therefore any changes to the restrictions on the water that we are passing through can be accounted for.

International Standards

The charts meet the International Maritime Organization's standards which are in place to maintain the same high level of safety no matter where you are so that shipping can be as secure as possible.

Keeping up to date charts is an essential element to ensuring the safety of all those at sea. TZ Professional v3 now comes with the ability to display S57 charts as well as a module for S63 charts.

Route Management

The new technology assures the security of a route upon creation: Through colour codes (green/red) it is instantaneously possible to know if the depth is sufficient for the safe passing of your boat. An automatic route wizard will provide you with information regarding the optimal departure and arrival time, taking into account tides and currents.

Integrated AIS

The integration of AIS can sometimes be difficult although with this software it is already integrated and therefore the information can be passed on easily.

Security Cone

Any potentially shallow areas inside the path of the boat then the software will alert the user.

Profile

Instantaneously displays a point to point depth profile window. This 2D view will allow you to identify the depth variations with unequalled precision (rocks, shipwrecks, etc.)

In conclusion, all the features of this software will make it easier to integrate into the motors that control the sailboat. While making route adjustments according to weather, profile, international standards or other ship easy and reliable.

Mainsheet Adjustment

The mainsheet will control the mainsail on the trimaran. The mainsheet will be attached to a large wheel that can turn to shorten the length of the main sheet. To lock the main sheet into place the mainsheet will be cleated into place buy another motor.

Rudder Adjustment (Direction)

The rudder will be controlled by a single motor with arms either side. The motor will turn anticlockwise or clockwise to turn the rudder to the left or the right. After the turn as been finished the rudder will return back the middle with an opposite movement to the first rudder move.

Decisions

At this stage, we held quite a few group meetings and decided on a few modifications and improvements to the vehicle. In the navigation section, instead of using wind sensors, we decided that using an AIS (Automatic Identification System) and LiDAR system would be much easier as they are more compact, advanced and widely used. As well as integrating all of the software extras from TimeZero while traveling at sea. Further explanation as to how they work will be included in the final design section. Also, we had to discuss and make decisions on how we were to propel ourselves on land. Taking into consideration the large area, and possible weight of our vehicle, we decided to use a caterpillar track mounted in the middle hull to propel the trimaran. Skis deployed on the side hulls would assist the trimaran in balancing itself as well. We have decided that the hull will be made of vacuum bagged, uni-directional, bi-axial, S-glass epoxy resin laminate. The sources of energy would be solar power from solar panels being stored as electrical energy in Li-Air battery packs. Wind power, electrical energy and waves would be used to propel the trimaran forward using the sail and motor with propeller.

Environment & Challenges

Initial Route

Once we had settled on the idea of having a completely autonomous vehicle, our first idea was to have it travel through the sea, along the edge of the western coast of North and South America. We were going to stay far enough away from the coastline so that it still counted as international waters but close enough so that if anything happened then we would be able to have a team there to quickly fix it. We noticed though that if we were to have a team follow the trimaran (whether it be on sea or on land) that they would be counted as part of the crew/vehicle and so they would also have to start at the north pole and finish at the south pole. Because of this, we thought that it would be too much hassle and that if this were the case then the vehicle won't be autonomous, and we may as well accommodate for multiple people to live onboard.

Geophysical Features and Dangers

Assessing both the Arctic and Antarctic for their geophysical features and dangers proved to be fairly hard as there is so little data on them.

The Arctic proved to be a challenge as there was no real data on the physical features. This is because it is made up entirely of ice and so the features of the landscape are almost constantly changing. Due to the fact that it consists solely of ice, we assumed that there would be very little or no rocks or debris in the way. The surface of the ice is also relatively flat, posing no risk to the structural integrity of our trimaran. The only other foreseeable danger was on the edge of the ice. We could not tell how high the edge of the ice may be because it is constantly changing. This posed a threat as we didn't know whether our trimaran would have to go over an edge and fall into the water or whether it could drive into the water.

The Antarctic proved to be a very different environment, namely the fact that it is quite mountainous with rocks and crevasses at every point along the continent. We already knew that there would be rough terrain and potentially harsh weather, but it seemed a challenge navigating around them. The use of LiDAR technology will allow us to navigate around any stray rocks or boulders that may lie in our path. The crevasses will only be a maximum of 20m across as well meaning that the length of the vehicle will allow it to hopefully glide over the ice without being affected. We contacted the British Antarctic Survey asking about whether there were any particular areas that may be prone to crevasses, rough terrain, stray rocks, or even high winds. Taking into account their suggestions and a very helpful software, we were able to efficiently plan our route around any potential hazards.

Final Route

Sea

When on the sea, the navigation method will be similar to that mentioned in the further research: Autonomous Method section, except that instead of using lots of chips and sensors, we will use the AIS (Automatic Identification System) instead. The AIS system on the vehicle will have an

inbuilt GPS system connected to a satellite system that has access to weather patterns. It also has data of every other ship that is nearby including their speed, direction and size (type). A similar program will allow us to constantly update the route according to other boats in the way and unfavourable weather conditions. The route we have chosen goes from the North Pole, between Russia and Alaska towards the Pacific Ocean. Straight down towards the Antarctic ocean and arriving at Ross Sea where there will be smooth inclined beaches to get onto Antarctica. The route is about 18000km in total and would take about 112 days.

Shown in figure 4.1

Land

Antarctica

Once we get to Antarctica, we plan to have our trimaran land on a small island connected to the mainland via thick, permanent ice sheets. The island will give us a beach-like incline on which we are able to land, allowing us to easily drive up the slope. After this point, we will travel across the ice and up to a small hill surrounded by rocks. From there, the journey is a steady slope with the steepest gradient being a gain of 200 metres every 2 km. As shown in the mapped route, it is roughly 1,900 km long and the total distance travelled upwards is 2.7km, using the equation $\tan^{-1}(2.7/1900)$ the average angle is roughly 0.08 degrees upward. This is very small and so there will not be any problem with how the vehicle will be able to propel itself up the slopes. There won't be many stray rocks along the route as they will not be in the centre of the continent but around the edge. This is where the LiDAR technology will be useful if any rocks block our path. The technology will be used to identify where rocks may lie on the path and allow us to go around them without damaging the vehicle.

Shown in figure 4.2

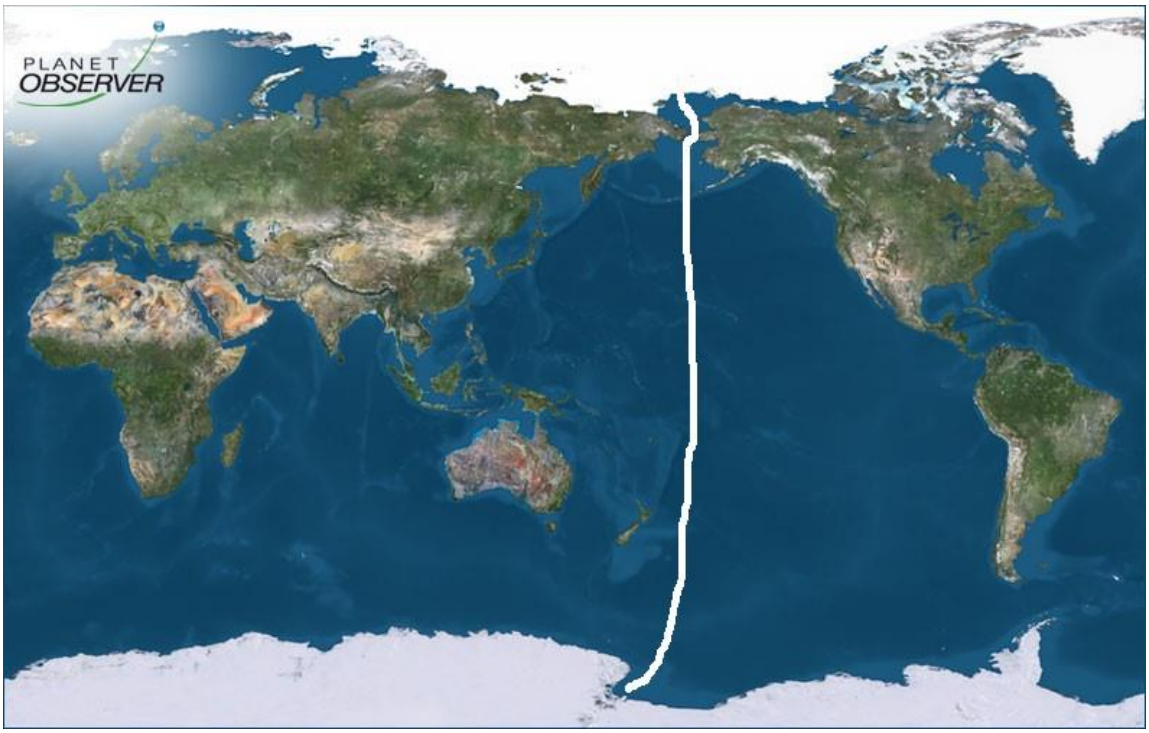


Figure 4.1

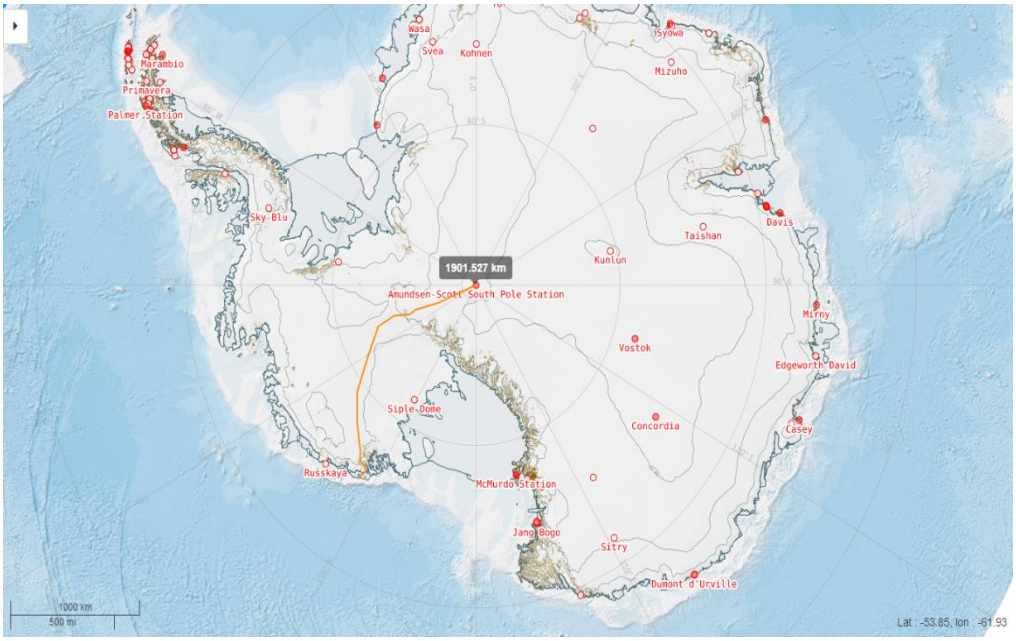


Figure 4.2

Final Design

Introduction

Our final design is an automated amphibious vehicle that can go from the Arctic onto the sea and then transition back onto the Antarctic. It uses a variety of electrical systems to keep it on track and avoid dangerous weather conditions, which will be gone into in further detail later on in this section. Throughout this section, our choices of components will be explained in detail with precise calculations to back up the validity of each decision. Having taken into consideration all the extremes of the Antarctic and the sea leading up to it, we have decided to use a trimaran with a mounted sail as our main propulsion system. In addition to wind propulsion, the trimaran would be coated with graphene solar cells to maximise energy gained from the sun. As a backup, an electric motor, connected to a propeller will be installed in the centre hull in case of situations where the wind is minimal. Apart from a large amount of electrical energy used in keeping the trimaran on track and maintaining all electrical systems, all excess energy will be stored in the batteries to be used in emergency situations.

Upon reaching land, the skis on either side of the centre hull, or the amas, will open up and lock in position using hydraulics and hinges. In addition, the centre hull will open up and lock into place to let the caterpillar track lower down. These mechanisms will initiate as the trimaran finds a solid patch of ice through the aid of LiDAR.

Engineering

Development of Designs

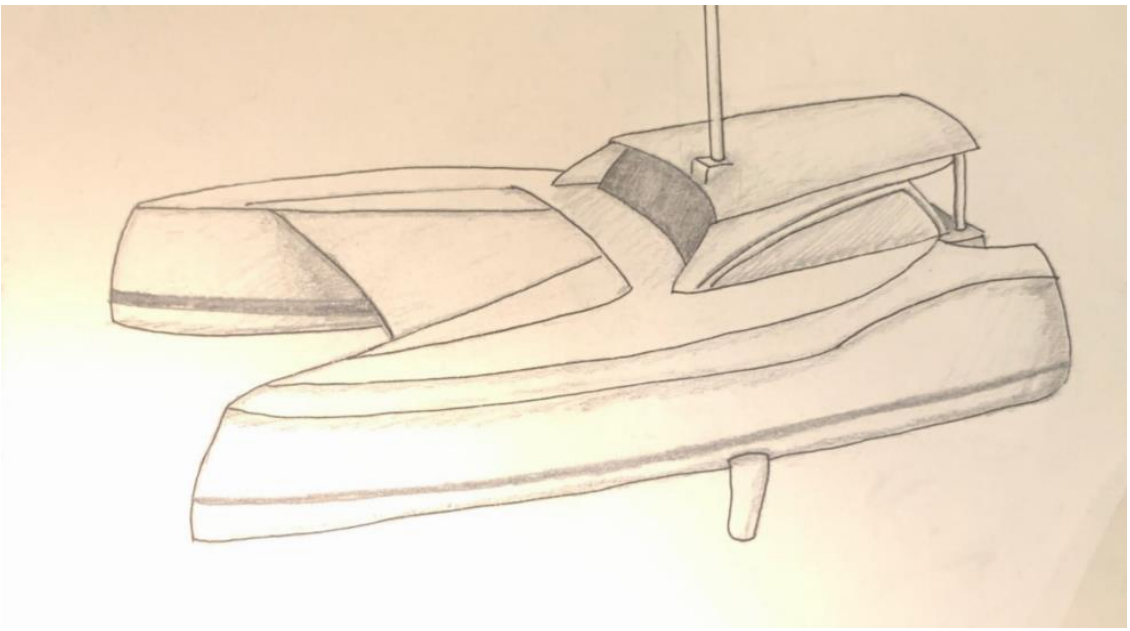


Figure 5.1

We developed our concepts from a commercial catamaran that was found online, roughly sketched out in figure 5.1 We then implemented all of the components we wanted to use and added it to the original catamaran, seen in figure 5.2. Also, at that point in time, we had not eliminated using wind turbines as energy harvesting system and so they were still in our sketches

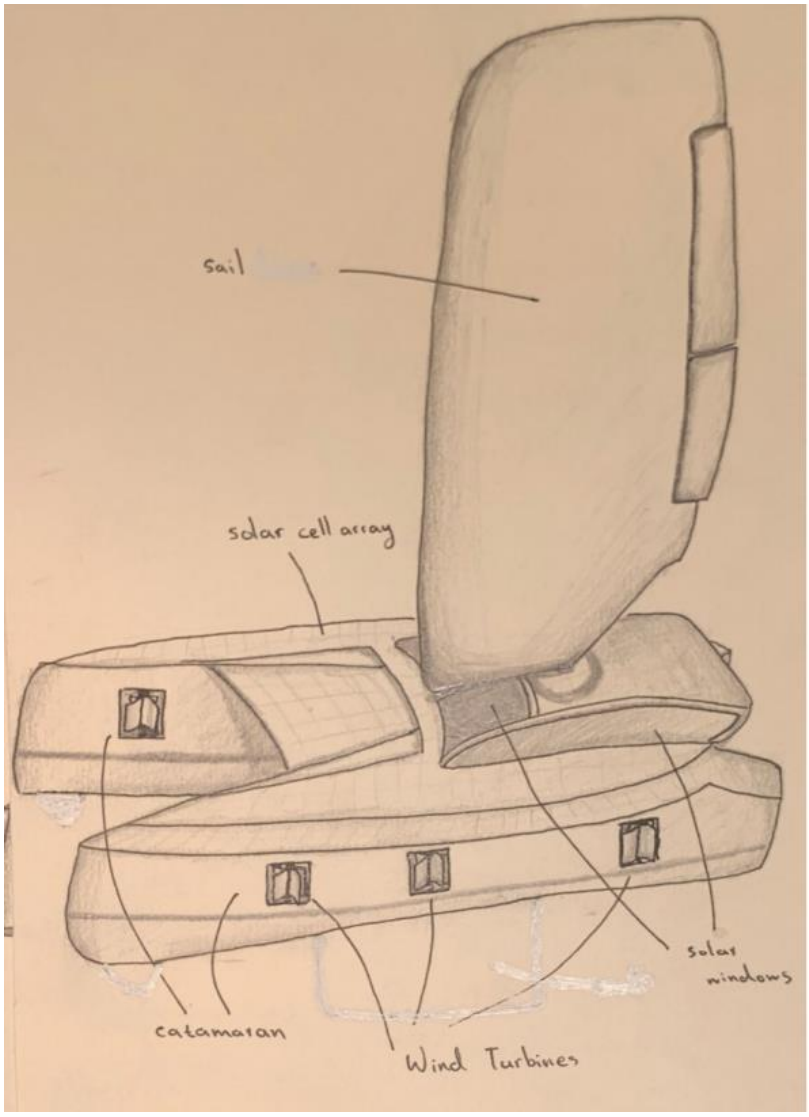
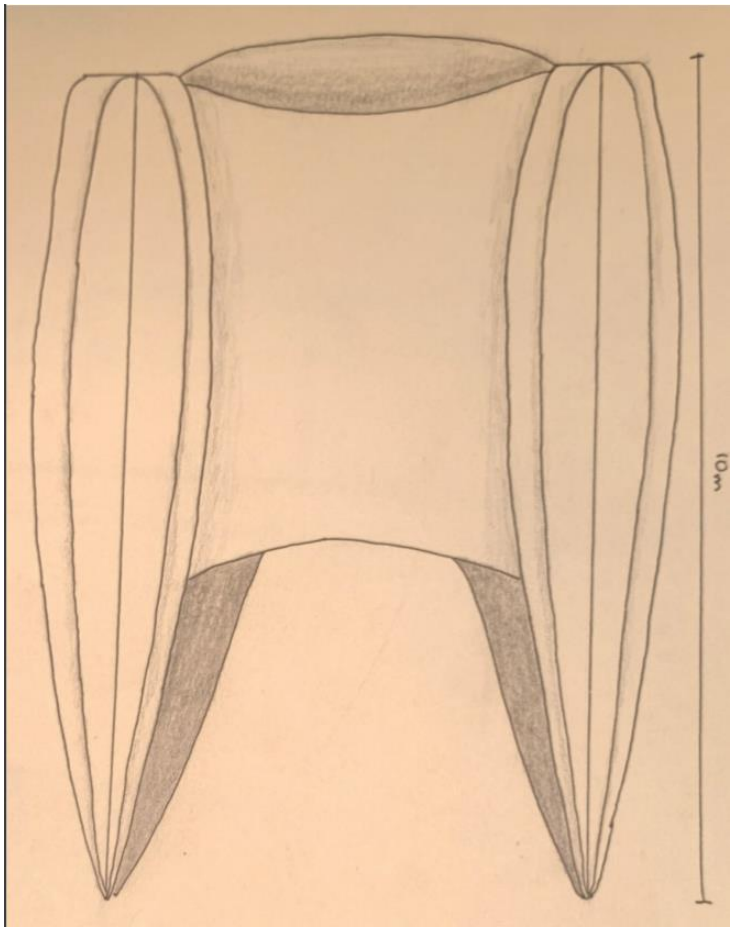


Figure 5.2



We also illustrated a bottom view of the side hulls to demonstrate how the hulls are planing, seen in figure 5.3. In addition, the bottom view also shows how the hulls have two different parts that curve in. It curves in more rapidly at the top and then caves in slowly towards the waterline nearer the bottom.

Figure 5.3

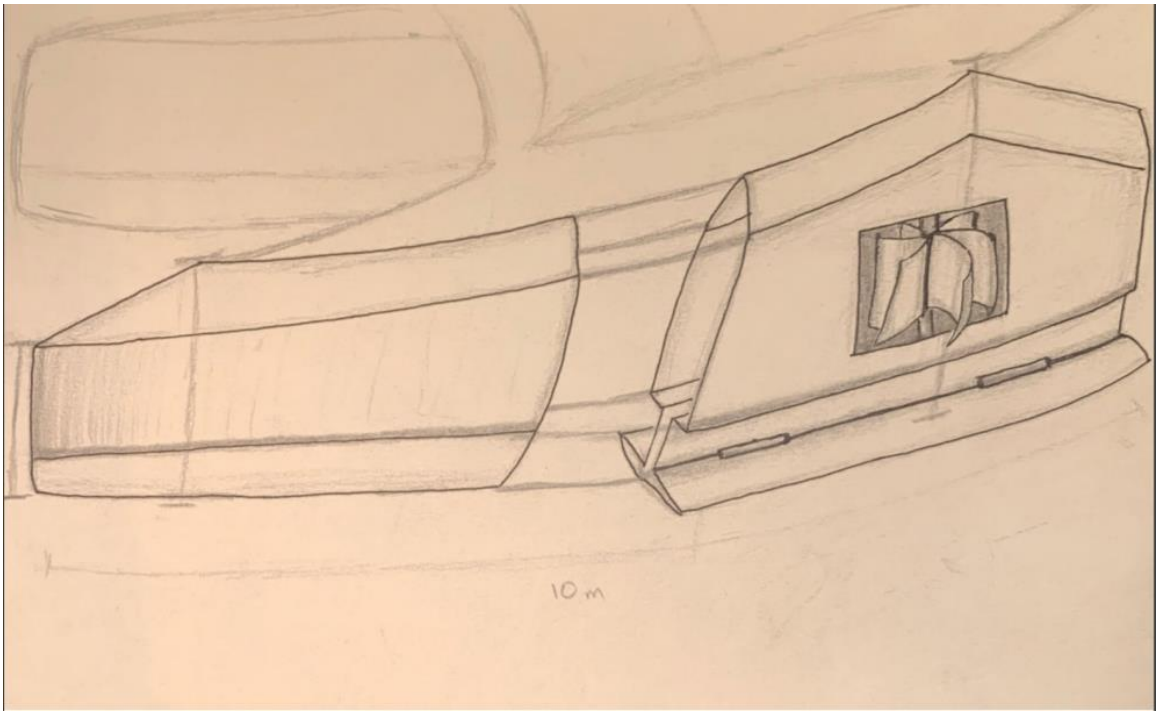


Figure 5.4

Figure 5.4 is a side view of one of the hulls on the side of the catamaran. This illustration was used to show a potential idea of how the skis would flip out and also help stabilize the boat. After further research, we decided to use a trimaran instead of a catamaran and so we translated all components over to a trimaran to get a general idea as to what it would look like before we added more details. This drawing can be seen on figure 5.5.

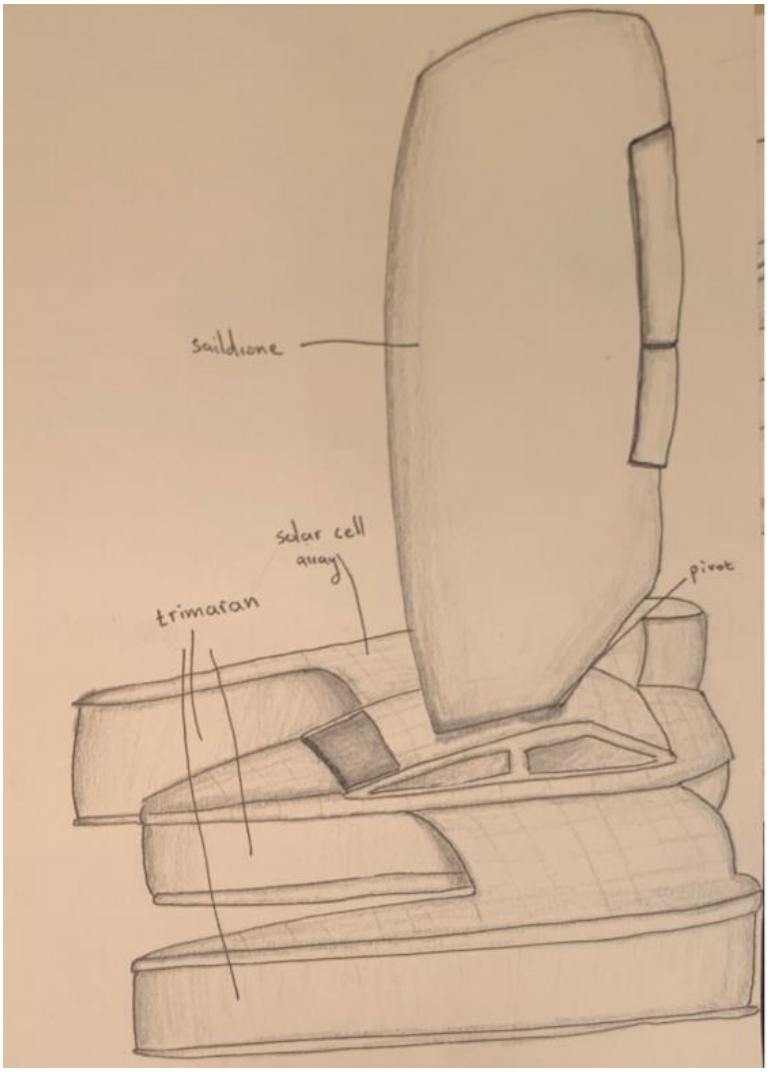


Figure 5.5

After deciding most of our systems and eliminating options, we came up with a rough sketch of how the real design will be like. Figure 5.6 is a rough model of our final design, with rough dimensions added as well. The sail in the photo was an initial idea which was changed quickly after this design was made. Instead of using a sail like the ones used in Saildrone, we were going to use more conventional means and include a mast and jib. Figure 5.7 shows the land transitioning. After this sketch was made, we realised that the side triangular tracks would be useless and removed them.

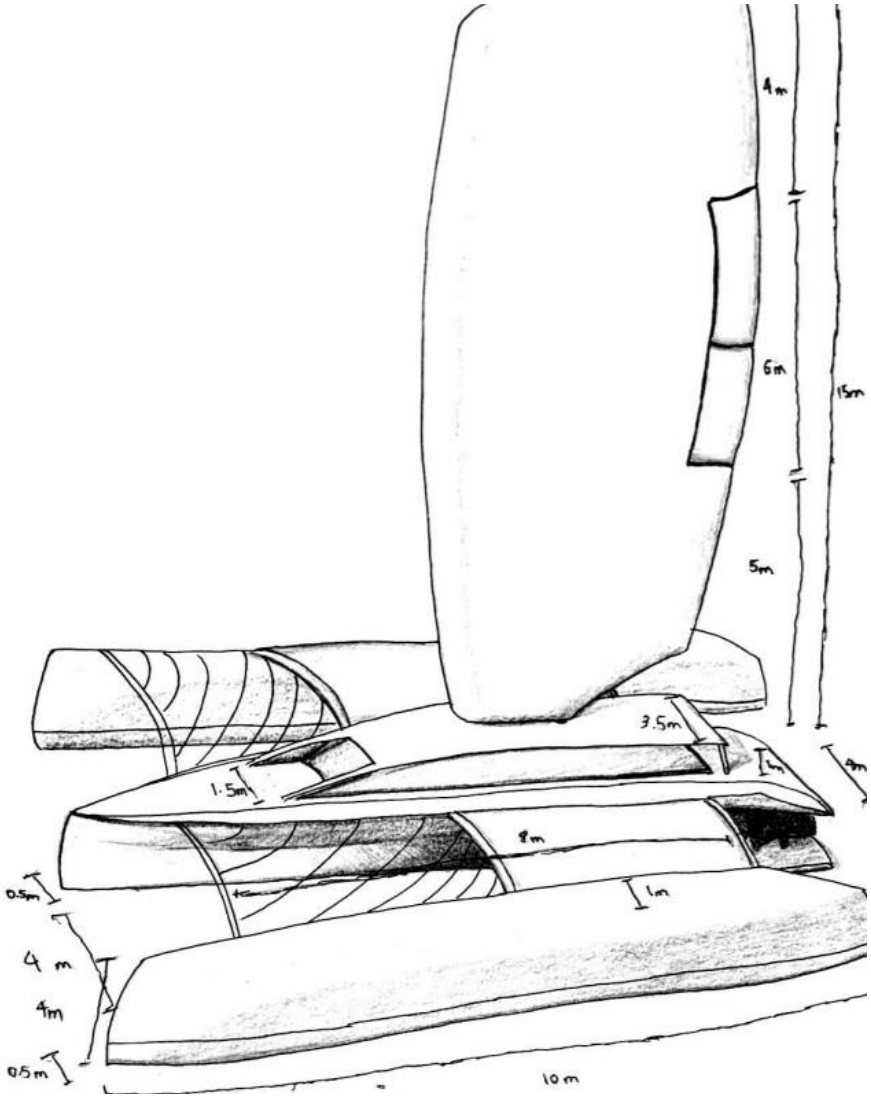


Figure 5.6

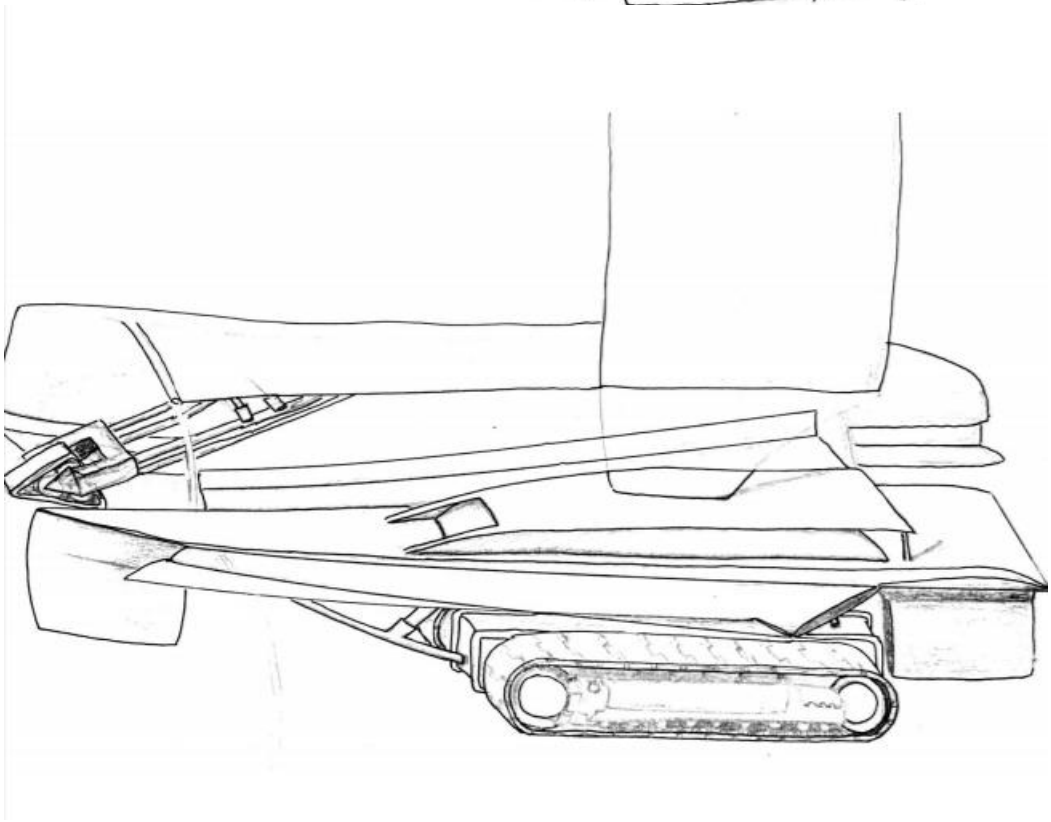


Figure 5.7

Component Distribution

We took a sectional analysis of the boat right down the middle to illustrate where each component would lie inside our vessel. The pink area with stripes shows all the wiring while the orange section with stripes is an area with no wiring as that section will flip out when the boat reaches land to make way for the caterpillar tracks. Each component is coloured and is shown below. On the next page, a rendered CAD design can be found of our vessel on sea. (figure 5.9)

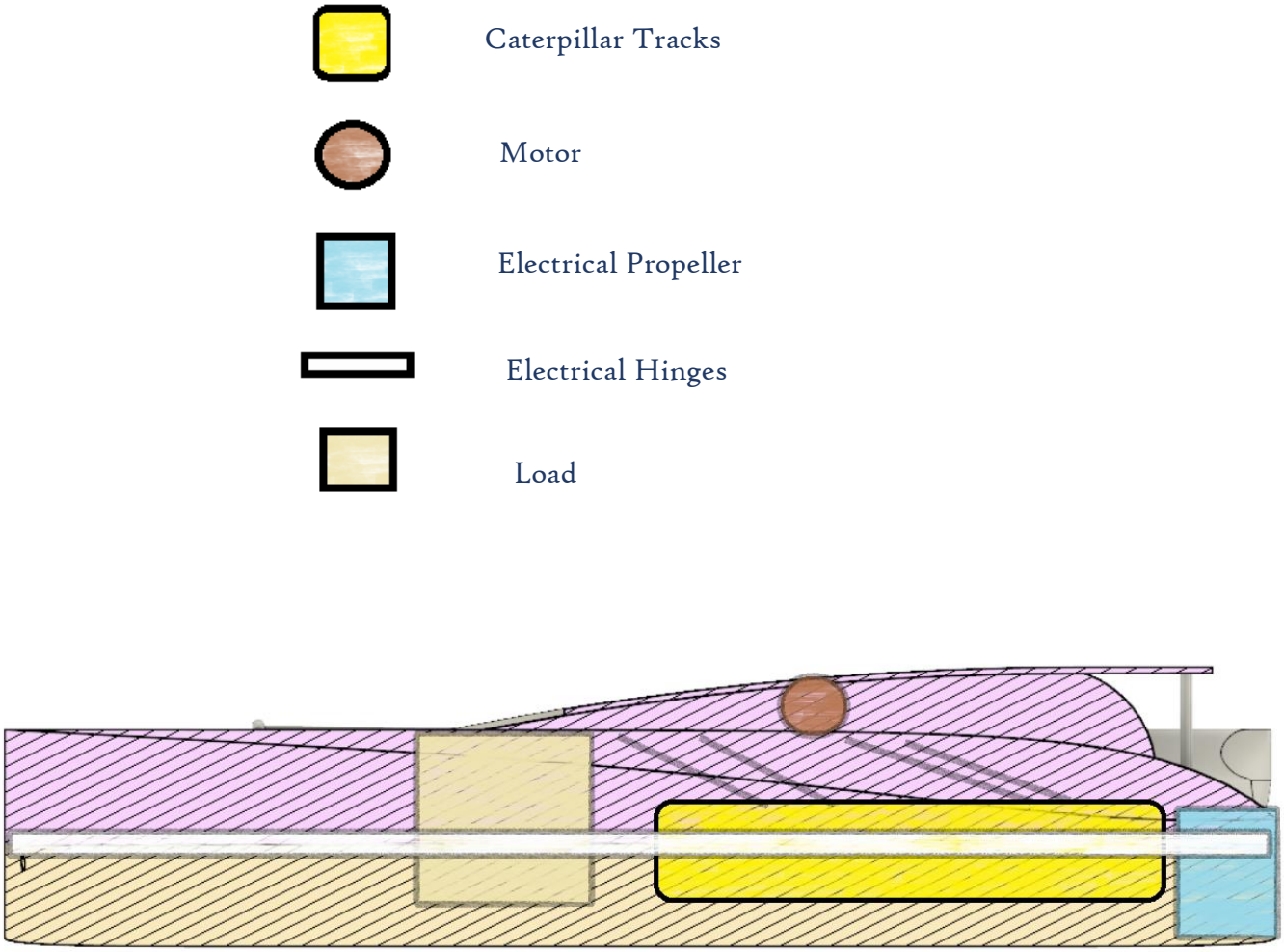


Figure 5.8

Final CAD Design

Figure 5.9

Dimensions

Without any trimaran design guidelines, we found ratios that existed for catamarans and tried altering them where necessary.

In relation to the length waterline L_{WL}

Mainsail luff ratio: k_P := 125%

Mainsail base ratio: k_E := 52%

Foretriangle base ratio: k_J := 33%

Jib area ratio: k_F := 140% (while a 100% is the foretriangle area)

Foresails: self-tacking jib 90%, jib 110-120%, genoa 130-150%

Freeboard at mast F_{BI} := 1.63

Mainsail above mast foot B_{AS} := 1.1

Calculations of Dimensions:

Foundation Measurements: L_{WL} - 10m

B_{AS} - 1.1m

F_{BI} - 2.13m

Figure 5.10 – Trimaran Design

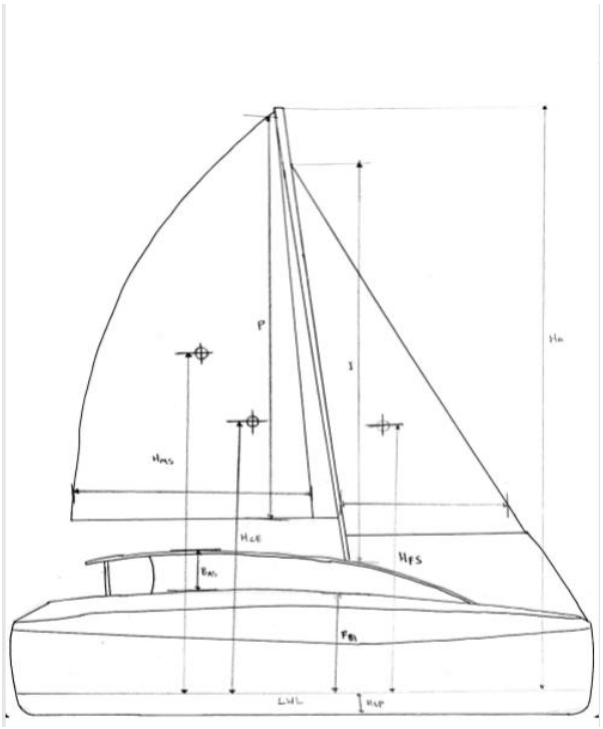
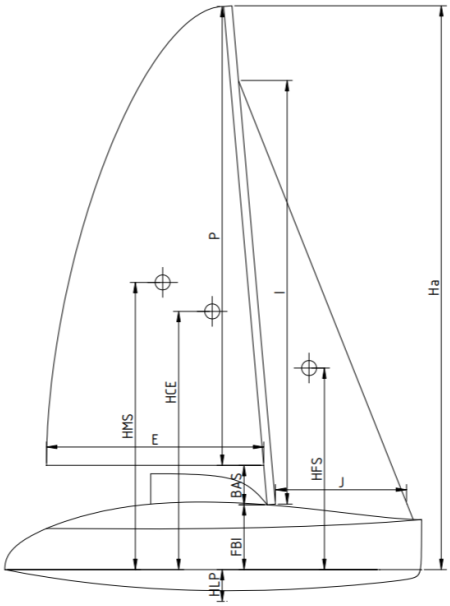


Figure 5.11 – Catamaran Design



Mainsail Luff

$P = k_p \times L_{WL}$

$k_P = 1.25 \times L_{WL}$ $\quad$ $P = 12.5m$

Mainsail Base

$E = k_E \times L_{WL}$

$k_E = 0.52 \times L_{WL}$ $\quad$ $E = 5.2m$

Foretriangle Height

$I = 0.85 \times (P + B_{AS})$ $\quad$ $I = 11.69m$

Foretriangle Base

$J = k_J \times L_{WL}$

$k_J = 0.33 \times L_{WL}$ $\quad$ $J = 3.3m$

Mainsail Aspect Ratio

$\Lambda_M = \frac{P}{E}$ $\quad$ $\Lambda_M = 2.40$

Foretriangle Aspect Ratio

$\Lambda_F = \frac{I}{J}$ $\quad$ $\Lambda_F = 3.54$

Mainsail Area

$A_{MS} = 0.7 \times P \times E$ $\quad$ $A_{MS} = 45.5\ m^2$

Foresail Area

$A_{FS} = 0.5 \times I \times J \times k_F$

$k_F = 1.40 \times L_{WL}$ $\quad$ $A_{FS} = 27\ m^2$

Sail Area Upwind

$A_S = A_{MS} + A_{FS}$ $\quad$ $A_S = 72.5$

Gennaker Area

$A_G = 1.65 \times I \times J$ $\quad$ $A_G = 63.65\ m^2$

Air Draft

$H_a = P + B_{AS} + F_{BI}$ $\quad$ $H_a = 15.73m$

Height of mainsail centre

$H_{MS} = F_{BI} + B_{AS} + 0.4 \times P$ $\quad$ $H_{MS} = 8.23m$

Height of foresail centre

$H_{FS} = F_{BI} + 0.4 \times I$ $\quad$ $H_{FS} = 6.806m$

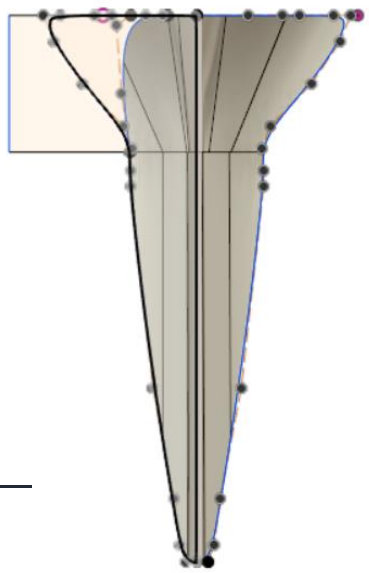


Figure 5.12

Specific Hull Calculations

Scantling Number

$S_n = L_{OA} \times$ Beam Length $\times$ Depth of Hull $\div$ 28.32

L_{OA} = 10m

Beam = 5m therefore, $10 \times 5 \times 2.13 \times 28.32 = 3.76$

Depth of Hull= 2.13m

WL = 1.32

Lower Topside Fibreglass Thickness

$6.35 \times \sqrt[3]{Sn}$

$6.35 \times \sqrt[3]{3.76} = 9.87$mm

Bottom Laminate Height (BLH)

$13.71 \times S_n^{0.38}$

$13.71 \times .76^{0.38} = 22.7$cm

Speed Adjusted BLH

Upper topside thickness is a 15% increase of Lower 9.87mm $\times$ 1.15 = 11.35mm

Speed Adjustment for every knot above 10:

$11.35 \times 1.15 = 13.05$ mm

Chopped Strand Mat Weight

of Dry mat = Laminate Thickness $\times$ 375.3

Bi-Axial Uni-Di weight

Weight of bi-axial uni-di = Laminate Thickness $\times$ 774

Density of finished layup = 1585 kg/m^3

Glass Content of Finished Layup = 40%

$\therefore$ weight: 9.87mm $\times$ 774 = 7639 oz/sq.yd

= 259006 g/m^2

Finding the weight of fibreglass layup

By modelling the trimaran as two rectangular side amas and one centre hull that has the shape of a pyramid, we were able to calculate a rough estimate of volume that was going to be covered with the fibreglass layup and thus find the weight.

For the side amas, we modelled it like this:

From this model the length would be 10 metres, the width would be 1 metre and the height would be 2.13 metres. We calculated the volume of the whole amas block and then took away the volume of the block inside without the thickness of the amas.

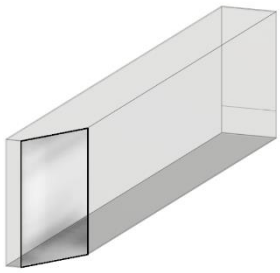


Figure 5.13

∴ Volume of Whole block:

$2.13 \times 1 \times 10 = 21.3m^3$

Volume of empty space:

$(2.13 - 9.87 \times 10^{-3} \times 2) \times (1 - 9.87 \times 10^{-3} \times 2) \times (10 - 9.87 \times 10^{-3} \times 2) = 20.645m^3$

Vol. of whole block - Vol. of empty space = Vol. of Fibreglass layup in a single amas

$21.3m^3 - 20.645m^3 = 0.6548m^3$

Because there are two amas in the trimaran,

Ans $\times$ 2 = $1.3096m^3$

For the central hull, we modelled it like this:

In this model, the height of the horizontal triangle at the top was 10 metres with a base of 3 metres and the height of the whole object was 2.13 metres.

Likewise, we calculated the volume of the object and removed the volume of the space taken up by air in the middle.

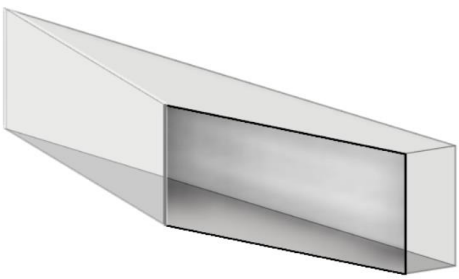


Figure 5.14

∴ Volume of Whole block:

$\frac{1}{2}(1.5 \times 10) \times 2 \times 2.13 = 31.95\ m^3$

Volume of empty space:

$\frac{1}{2}((3 - 0.01974) \div 2 \times (10 - 0.01974)) \times 2 \times (2.13 - 0.01974) = 31.3835\ m^3$

Vol. of whole object - Vol. of empty space = Vol. of Fibreglass layup in central hull

$31.95\ m^3 - 31.3835\ m^3 = 0.566456 m^3$

Vol. of Fibreglass Layup in Trimaran:

$0.566456 m^3 + 1.3096 m^3 = 1.87606 m^3$

Density of finished layup = 1585 kg/m^3

∴ Weight of Fibreglass layup in Trimaran = 2973.6kg

Hull Manufacture

Use of wood in the hull

1. Balsa Core

We are using end-grain balsa core as it is the stiffest with the highest shear strength, holding a density of 104 kg/m^3. However, in the construction of the hull, we will have to make sure all existing balsa core is bonded, saturated or coated. In addition, any wood that needs to be applied with fiberglass laminate must be with resin.

2. Plywood

We will be using marine grade plywood that is fabricated from a glue rated waterproof by boil tests. This is essential as it will be used as a core for the engine bed, transom and high load transom attachments. Any fasteners used also must have edges sealed off.

Solid/ Single-skin construction

As our vessel is designed to go through rough terrain and extreme conditions, many precautions and perfecting methods must be used to ensure a good foundation for the hull. It is important that all corners that need to be coated must be filleted as laminate does not work well with sharp corners. This applies in secondary bonds as well. In our design, we are planning balsa fillets and putty-grout to round off any sharp inside turns. The secondary bond for the fibreglass must be applied with 16-hour gaps in one continuous process so that it can be ensured that all layers cure together. In addition, it is essential that the area being bonded are wiped down and rendered oil-free. For our manufacturing, we are planning on using styrene as it softens old resin and allows for better secondary adhesion. Any wood that is present in our design must also be coated or sealed with cuprinol to prevent it from soaking and inducing long term damage. For our surface finish, we will be using a high-quality resin pigmented with colour, otherwise known as gelcoat. It will be applied for 3-4 hours and then a layer of mat laid in the partially cured gelcoat. Gelcoat has

a surface density of 1 and a half oz/sq.yd or 457 g/m². After this is applied, the mat is allowed to cure overnight and then the remainder of the laminate is applied. This mat is used to eliminate the rough weave as the mat has high resin content. The general rule is that the finer the weave, the less it will print-through.

Sandwich Construction

As fibreglass by itself does not provide enough stiffness or strength in comparison to the weight, we are planning on having our trimaran laid up using *sandwich construction*. This construction method consists of using a core of end-grain balsa with thin fibreglass skins inside and out. Getting a good core-to-laminate bond is essential as many low-quality boats have core-bond failures that are frequently un-correctable. It is commonly caused by the balsa core not being properly pre-saturated with resin before the layup. This results in the first layer of the fibreglass being applied against the core and the balsa quickly wicking away the resin due to its dry nature. As seen in figure 5.15, sandwich construction allows for a much stronger foundation without having to double the thickness of the fibreglass as that would double the weight as well. Fitting low-density material inside like foam or end grain balsa would ensure that the weight is low but also have the same amount of strength.

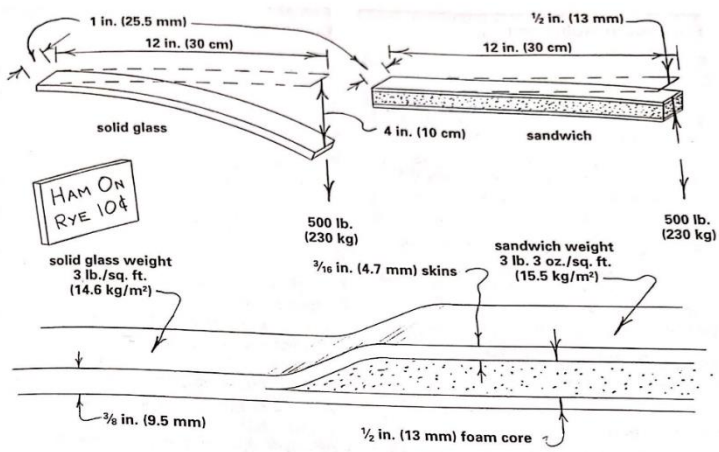


Figure 5.15

Measuring 489.8 square feet, these enormous sails catch huge amounts of wind. They are also shaped just like an aircraft wing, with a wide, rigid front edge and a thin trailing edge. In the same way as an aircraft wing, the sails take advantage of the Bernoulli principle, which states that a higher pressure on the one side of the sail will create lift, or in this case forward motion through the water.

On these boats the wing sail is built in two separate elements, producing an asymmetric wing where the air flows can be altered by changing the angle between these elements. The wing sail works because the air on the rear, or leeward, side of the sail travel faster than the air on the front, or windward, side. This difference in air speed creates low pressure on the leeward side of the sail and high pressure on the windward side, essentially lifting the sail forward just like an aircraft wing generates upward lift. By adjusting the angle between the two elements of the wing, the sailors on board can control the amount of "forward lift" they get from the sail. The more the flaps bend, the more power is generated.

Materials to Choose From

Nylon: A lightweight material with high tensile strength, superior abrasion resistance, and flexibility. However, it has a low modulus, allowing too much stretch for upwind sails. Nylon is susceptible to UV and chemical degradation, and its properties can change due to moisture absorption.

Polyester (Dacron): The most common type of sailcloth, typically known as Dacron, with excellent resiliency, high abrasion and UV resistance, high flex strength, and low cost. Low absorbency allows the fibre to dry quickly.

Kevlar: The predominant fibre for racing sails, Kevlar is stronger, has a higher strength-to-weight ratio than steel, and a higher modulus than Dacron. It loses its strength with flexing, folding, and flogging, and does not resist UV light well.

Spectra: An ultra-high, molecular-weight polyethylene with high UV resistance, high initial modulus, high flex strength, and superior breaking strength. Over time, Spectra is susceptible to elongation under sustained loads, which changes its shape. Due to the potential for shape change, the material is typically used for spinnakers on high-performance boats.

Dyneema: Similar to Spectra, Dyneema is extremely strong and growing in popularity. Dyneema combines a high strength-to-weight ratio with excellent low stretch and abrasion and UV resistance qualities.

Mylar: A polyester film made from polyethylene terephthalate. Typically, Mylar is laminated into sailcloth and provides high tensile strength, dimensional stability, and transparency. Mylar is used extensively in racing sails.

Carbon Fibre: A high modulus fibre made from carbon, virtually unaffected by UV exposure with exceptional low stretch. Carbon fibre sails are extremely durable and flexible, but costly.

Electronic Infrastructure:

Other than the batteries that have been described on page 18 we will have two GPS units and the AIS systems with the LiDAR these will all draw a very small amount of power which would easily fit under the 20% reserve energy stored.

Land

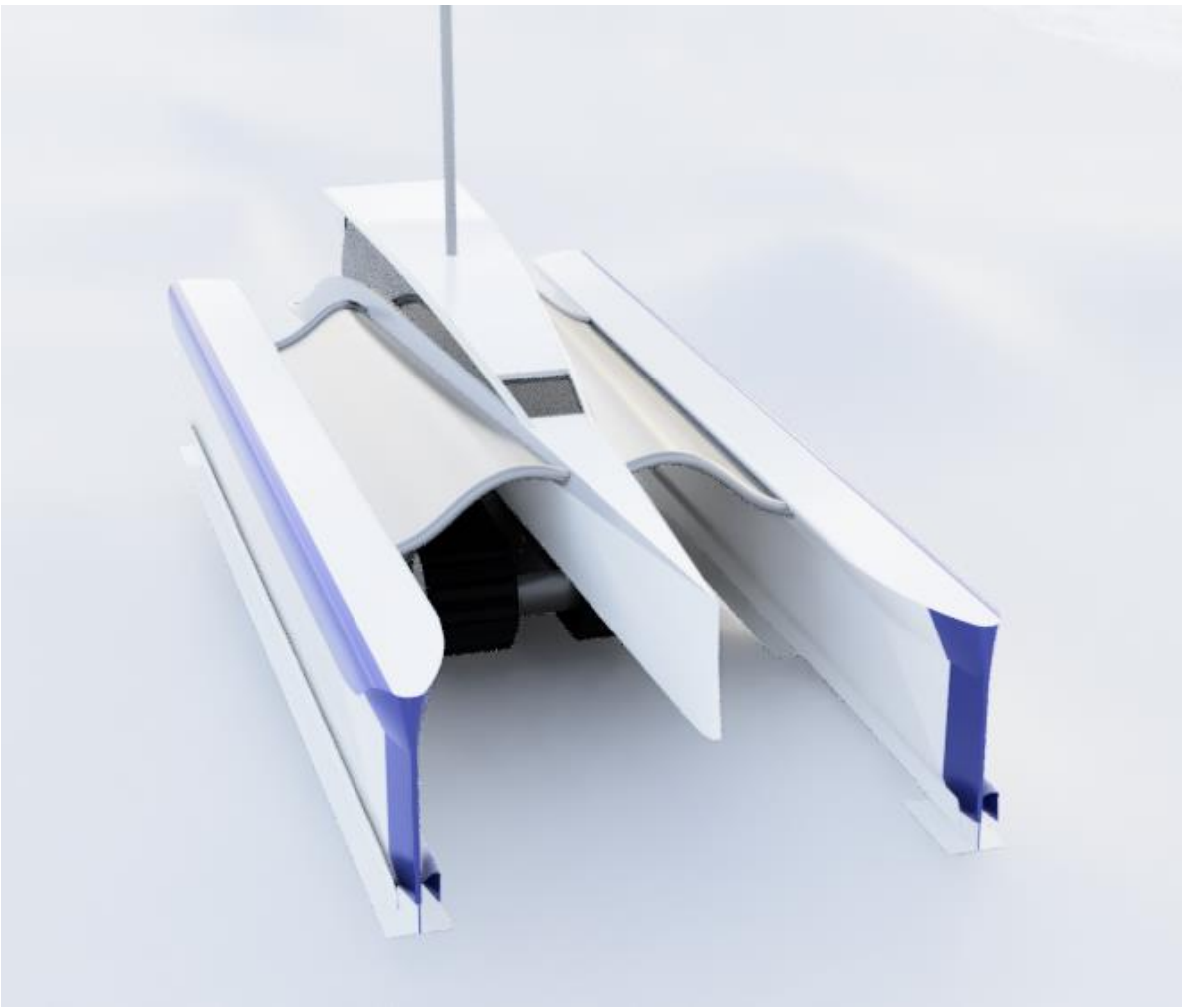


Figure 5.16

Caterpillar Tracks

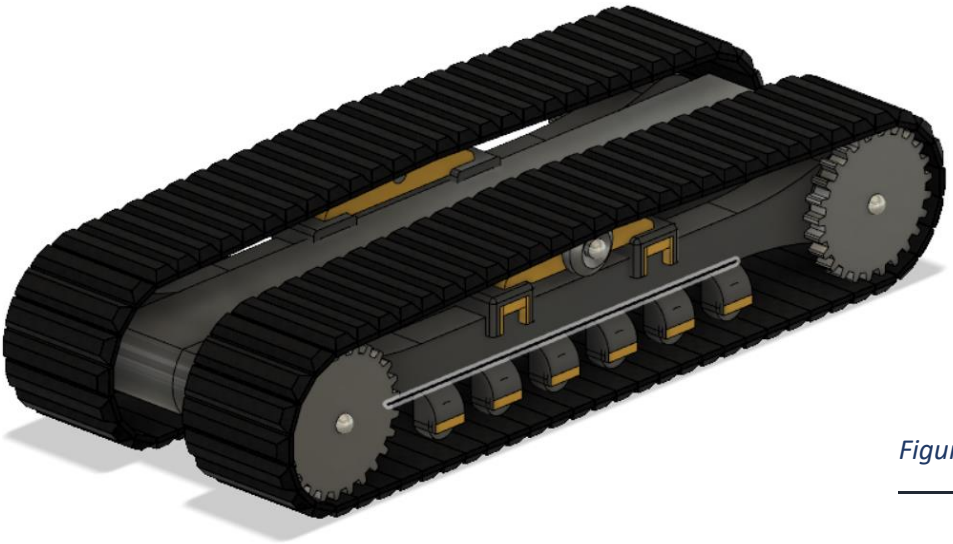


Figure 5.17

Skis

To maintain stability and protection to our amas(side hulls), we have implemented a flip-down ski onto the side hulls. A rough model of how it will flip down can be seen below. As our caterpillar tracks are narrow compared to the whole vessel, we would need something on the sides to maintain balance as we cross difficult terrain. Therefore, we will be using skis to guide the trimaran through the snow as well as protect the side amas from colliding as it would slide over obstacles instead.

Figure 5.18

Hydraulics

To accommodate our caterpillar tracks, we will be using piston pumps as they are extremely efficient and have a maximum of 6000 psi operating pressure, which is a lot larger than our required pressure. We will also be using full synthetic fluids with a viscosity of 100 cSt. Full synthetic fluids have the benefit of being able to handle drastic temperature and pressure swings. They also can reduce the oxidation rate and have excellent fluid stability. In addition, they have performance-enhancing characteristics, allowing them to be the ideal heat transfer, power transfer and lubrication medium. The layout of the hydraulics used in our scenario is outlined on images on the right. Figure 5.19 shows what it will look like when fully extended which is when the vehicle is on land. Figure 5.20 shows the fully retracted version where the vehicle will be on the sea. The two figures do not show the other end of the coil maintaining the flow of the fluid.

Figure 5.19

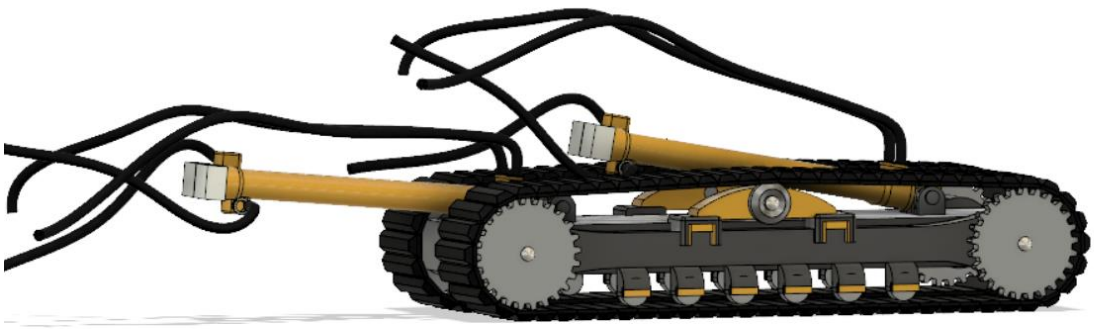


Figure 5.20

Calculation

Below shows a cross sectional analysis of one of the four hydraulic cylinders we will be using. To limit the flow of fluid in either rubber pipe, the middle rod will retract or extend.

As the fluid obeys Pascal's Law

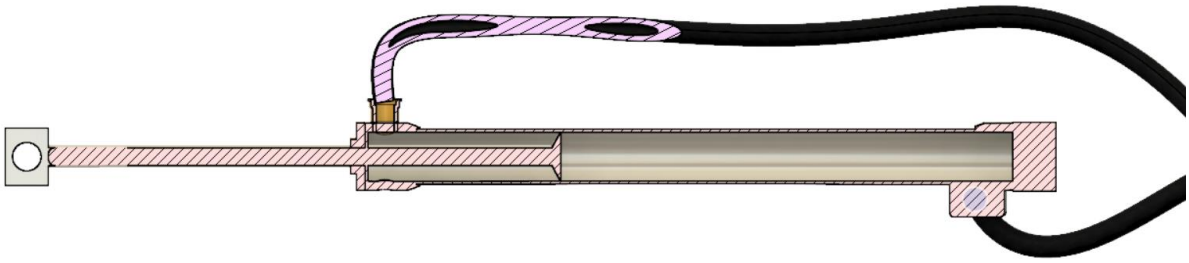


Figure 5.21

The volume of the hydraulic cylinder without rod (Extended):

$0.18^2 \times \pi \div 4 \times 1.5 = 0.038m^3$

Volume of hydraulic cylinder with rod (Retracted):

$0.038 - 0.1^2 \times \pi \div 4 \;\; 1.2 = 0.029m^3$

S.A. of plate on rod :

$0.18^2 \times \pi \div 4 = 0.025m^3$

As the hydraulics will be required to support the weight of the whole caterpillar tracks, we need to find the force required by each hydraulic and thus find the hydraulic power to see how much electrical power will be needed

The weight of vessel without caterpillar tracks ~ 5706.25 kg

= 55978 N

Total force that 4 hydraulics will have to lift is 55978N

So each hydraulic will have to lift 13994 N

Ans ÷ 0.025

Pressure = 560000 N/m²

= 81.2 psi

= 5.6 bar

In our theoretical model, the caterpillar tracks should lower in 10 seconds, so to calculate the flow rate, we divide the volume filled by the time taken.

Flow rate : 0.038 ÷ (10/60) = 0.228 litre/min

To find Hydraulic power, we multiply pressure in pascals by the flow rate measured in m³/s

0.0038 × 559854.3 = 2127.43W

Cost & Scheduling

Cost

One of the most important aspects of our research and to keep this challenge as realistic as possible is to keep the price affordable.

Item	Cost(USD)	Quantity	Total Cost(USD)	Total Cost(GBP)
Lithium Air Battery (per kg)	200	6000	1200000	918342
Motor	80	6	480	367.34
Fiberglass (per kg)	1.814	2973.6	5394.1104	4128.02
Solar Panel (m^2)	300	10	3000	2295.86
Sail	21.5	105	2257.5	1727.63
GPS	20	1	20	15.31
Caterpillar Track	55000	1	55000	42090.68
Sensor	2000	8	16000	12244.56
Digital Yacht AIT2000 Class B Transponder with GPS Antenna	383	1	383	293.10
Labor Cost	10000	1	10000	7652.85
Small Navigation Lights	8	2	16	12.24
Suspension System	100	1	100	76.53
Lidar System	5000	1	5000	3826.43
Total Cost			1297650.60	993073

Table 6.1

From the table above, it shows that our trimaran will have an estimated cost of £1,000,000 which is relatively low compared to a trimaran currently on sale on boats.com of similar size (£485000). In the following paragraph, I will break it down showing how the prices are calculated and estimated.

Cost of motor, solar panel, sensor, GPS, antenna, navigation lights, LiDAR system and suspension system. These items can be bought online easily, we can just look up the price of each item and multiply the value by the quantity that we need.

Cost of fibreglass. We need to work out the amount of fibreglass that we need in order to build the trimaran. We break the trimaran into different parts and model them as different shapes to calculate.

Cost of lithium air battery. The battery is still in the development stage which means that it isn't commercially available, which means that we don't know the price of it. In order to find out the cost of it, we find the closest battery cell that is commercially available which is the Lithium-ion battery which costs 200 USD per kg, which will have an estimated cost of £1200000.

Scheduling

As one of the primary sources of energy is solar energy, to prevent our trimaran from losing power, we have to avoid days on both poles where the sunlight is not accessible. The polar night for the South Pole is from the 24 March to 22 September, and for the North Pole, it is from 21 September to 21 March. Also, natural disasters such as hurricanes will cause great damage to the trimaran, so we should try our best to avoid them. The Pacific hurricane season will start from June to early November, so by the time the trimaran arrives at the Pacific, the hurricane season will be avoided.

The distance from the North Pole to the South Pole is about 9720 miles, at our average cruising speed 7.5 knots and our land speed at 15 km/h, the whole journey will take about 9 months to complete. The trimaran will leave the North Pole in mid-June and will arrive at the South pole in mid-March. This will allow the trimaran to make full use of long daylights to generate enough energy to power itself and avoid the polar nights as well as the peak of the Pacific hurricane season which may cause harm to the trimaran.

Date of Departure	15th of June
Date of Arrival	17th of March

Table 6.2

Event	Time (days)
Cutting out the Parts	7
Assembling	3
Reinforcing the Hull Joints	4
Fiberglass the Hull	7
Installing the Sail	8
Installing the Caterpillar	14
Installing Battery and Motor	3
Installing Cables	7
Installing Autopilot and Communication Systems	15
Total	**70**

Table 6.3

CITATIONS

1)	**Article title:** **Website title:** **URL:**	What is a solar array? - RGS Energy RGS Energy https://rgsenergy.com/how-solar-panels-work/what-is-a-solar-array/
2)	**Article title:** **Website title:** **URL:**	Advanced Propulsion and Power | Science and Technology Scienceandtechnology.jpl.nasa.gov https://scienceandtechnology.jpl.nasa.gov/research/research-topics-list/spacecraft-technologies/advanced-propulsion-and-power
3)	**Article title:** **Website title:** **URL:**	How solar power works - Energeasy Solar Solar-energeasy.com http://www.solar-energeasy.com/uk/en/37/how-does-solar-power-work
4)	**Article title:** **Website title:** **URL:**	Power Systems – NASA Radioisotope Power Systems NASA Radioisotope Power Systems https://rps.nasa.gov/power-and-thermal-systems/power-systems/current/
5)	**Author** **Article title:** **Website title:** **URL:**	Sascha Koslowsky Graphene: the future of solar cells IDEOJ http://www.ideoj.org/graphene-the-future-of-solar-cells/?lang=en
6)	**Article title:** **Website title:** **URL:**	ZNShine Solar to supply graphene-enhanced PV modules to India's BHEL Graphene-Info Graphene-info.com https://www.graphene-info.com/znshine-solar-supply-graphene-enhanced-pv-modules-indias-bhel
7)	**Article title:** **Website title:** **URL:**	Liquefied Natural Gas (LNG) Energy.gov https://www.energy.gov/fe/science-innovation/oil-gas/liquefied-natural-gas
8)	**Article title:** **Website title:** **URL:**	Liquefied natural gas En.wikipedia.org https://en.wikipedia.org/wiki/Liquefied_natural_gas
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