# Badminton School Submission to the 2019 Blott Matthews Challenge:

## Pole to Pole

# ACKNOWLEDGEMENTS

There are many people and organisations that made this project possible for us, and we would like to take a moment to thank them for giving us this opportunity.

We are very grateful for the assistance and additional information provided by the British Antarctic Survey and NASA for granting us access to information as well as permission to use their images and concept within our report.

Furthermore, we are very grateful to our teacher Ms Wheeler, our Physics teacher who initiated and coordinated this project, accompanied us to the Awards ceremony, and enabled successful communication between Richard Blott, Charles Matthews and us. Thus allowing us invaluable information regarding the challenge.

Additionally, we would like to thank Badminton School for giving us a platform for completing this project and for challenging us to think for ourselves.

Finally, we are very grateful to Richard Blott and Charles Matthews for creating this program, and giving groups such as us an opportunity to tackle a stimulating and highly enriching beyond-the-classroom activity at such a high level.

# Contents

## 1.1 Team members

| | |
|---|---|
|  | **Aaliyah Adesida - Project Manager**<br>*I am currently studying Mathematics, Further Mathematics, Physics and Chemistry at A-Level. I completed GCSE Product Design and in the future I hope to study Robotics or Bioengineering. The Blott Matthews Challenge interests me because of the large scale of the challenge that would require different kinds of problem solving skills. The main component of the project that I found myself intrigued by was the multiple components of the journey working in tandem together. I hope to improve my skills regarding mechanics and design.* |
|  | **Athicha Techaposai (Artie) - Human and Financial Resource Manager**<br>*Right now I'm studying Further Mathematics, Mathematics, Physics and Chemistry as well as doing an EPQ. My hope is that my job as HFR Manager will help me develop new skills like multitasking and financial management. It is because of the opportunity to learn new skills such as these that I undertook the BMC challenge. Fortunately, with this role I feel I will have the opportunity to improve sought after skills, and much much more!* |
|  | **Cathy Ding - Software and Dynamics Manager**<br>I am currently studying Mathematics, Further Mathematics, Physics and Computer Science AS. I have a particular interest in mechanics and programming, which I hope to embrace during this project as Software manager. In the future I hope to study computer science and I feel that by completing this challenge I will experience something closer to my future career. |
|  | **Havra Adamali - Transport and Vehicle Manager**<br>*At A level I study Physics, Chemistry and Biology. I would like to do Medicine at University. As the Transport and Vehicle Coordinator my main goal is to craft a seamless voyage form the north to south pole. To me, the BMC challenge is an opportunity to develop my teamwork skills and hopefully learn more in an unconventional out-of-classroom environment. This project will enable me to take responsibility of a component of the brief and enhance my skills in research and vehicle design.* |

# 2 Method and Problem Evaluation

## 2.1 Key Requirements

We need to transport a 1 ton non-metallic load (with dimensions of 2m x 2m x 1.5 m) from the North Pole to the South Pole.

To meet all the requirements, we need to do the following tasks:

Ship:

- Types of fuel we use and how much power it can produce
- Navigation: use GPS to track the position of the ship

Vehicles and machinery:

- Choose a suitable ship (for detail, see vehicle requirement)
- Choose a vehicle to travel on land (ice): the vehicle needs to work well on rugged terrain and can travel safely on slippery ground.
- A way to transport the load on and off the ship

Plan:

- A schedule of the journey
- What route to take

Others:

- Staffing: we need to decide what kind of people to take and calculate their salary
- What types of food to take on the journey: it should provide enough nutrition and takes up as little storage space as possible
- Find out the cost for each element and hence calculate the total cost

While doing the project, we have considered some other problems that we might face or improvements that we can do, so we have added in some more tasks:

- Waste management: save space on the ship
- Clothing for staff

## 2.2 Requirements Analysis

### 2.2.1 Vehicle requirements

In terms of vehicle requirements we need to consider several factors.

Firstly will the vehicle/vehicles we decide to  travel from the North Pole to the South Pole in the 12 months which is our time limit?. Will the vehicle have enough space to transport a ton load with dimensions of 2m * 2m * 1.5m? It shouldn't be a vehicle which travels by air hence the requirements. The vehicle should be able to sustain itself to cut through ice and the material of the external should be suitable to sustain the extreme cold environments and change of temperatures. When we are looking for a vehicle we will need to look at how many staff members we are looking to hire and therefore find a suitable vehicle which will meet the needs of the staff which include comfortable accommodation on the vehicle and a safe, workable environment.

### 2.2.2 Route Requirements

The route portion of this project heavily depends on proper planning and scheduling, as the climate and conditions at the North Pole vary *widely depending on the time of year. Ideally the chosen route would account for this and be configured to allow us a path to the south pole with the least complications. Hence many different things were taken into account. Firstly the time limit given by the challenge specifies that the voyage must be complete within 12 months, this lends itself to a minimum speed of 2.5km/h or more specifically, 1.35 knots.*

*The voyage begins at the south pole, which for the majority of the year is water, we would also have to navigate major seas to reach the south pole. The challenge specifies that air travel is forbidden, thus we can assume that the route must be carried out the majority of which be sea, thus removing the issue of transferring for land to water and vice versa several times without the use of harbours.*

## 2.3 Fuel/Power source

*One of the first things we considered was a power source for our ship. We understood that it may be inefficient to use a normal diesel engine due to the amount of fuel we would have to use. Such a large amount of fuel would weigh a lot and take up a large portion of space in the ship. Most ships come with inverters but for such a long journey the inverter would need to be recharged. The following information describes the methods we could possibly use to recharge the inverter or to forgo the inverter all together to power the ship. The specification we found describing the ship we chose lacked detail regarding whether or not the engine powers electronics on the ship. Hence we took it upon ourselves to account for that.*

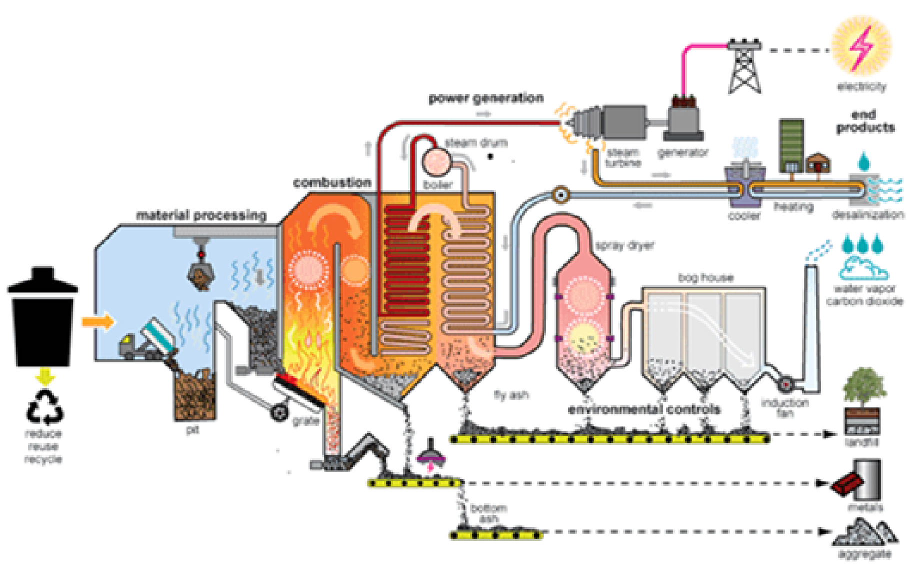
### <u>Biofuels and Waste as Fuel</u>

Waste to energy plants already exist and are fairly efficient, they use MSW (Municipal solid waste) this basically covers everything that staff may generate on the voyage:

- Biomass (plant or animal products), materials such as paper, cardboard, food waste, grass clippings, leaves, wood, and leather products
- Combustible materials such as plastics and other synthetic materials made from petroleum
- Glass and metals

This process is usually conducted on a large scale at Waste-to-energy plants. We may have to consider the logistics of scaling down the process and whether or not it will suit our needs. Waste to energy plants use the basic concept of a steam engine (pictured below).
Although a route which it utilised in smaller power plants is to compress MSW into fuel pellets that can be used.

**A mass burn waste-to-energy plant**



The process in which power is generated in a mass burn (pellets are not used) can be summarised as so:

1. Waste is dumped into a large pit
2. A claw on a crane takes waste from the pit and dumps it into the combustion chamber
3. The waste is burned and releases heat
4. The heat turns water into steam in a boiler
5. The steam increases in pressure until it can continuously turn the blades of a turbine generator (see explanation below) to produce electricity.
6. The combustion gas is filtered and then removed through a smoke stack.
7. Ash is collected for the filter and the boiler (Ash is one of the major waste products from this process)

The major waste product (ash) takes up little space in comparison to the waste we would have had to dispose of otherwise. In a waste-to-energy plant, 1000kg of MSW is reduced to around 204 kg of ash. We could probably hope for numbers more efficient than this if we mediate the food, and amenities on the vehicle.( E.g taking less non-combustibles with us.)

## How does a turbine generator work?

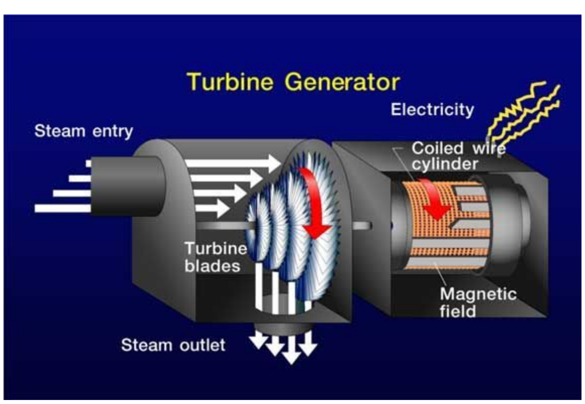
A turbine generator works by converting kinetic energy to electrical energy, a concept all the team should be familiar with form IGCSE Physics and Science Outreach.

As according to Faraday's Law,when a magnet is moved inside a coil of wire, an electric current flows in the wire.

## What do astronauts use?

To achieve space travel, different types of power sources are used for different things. The main power sources used in space voyages include:

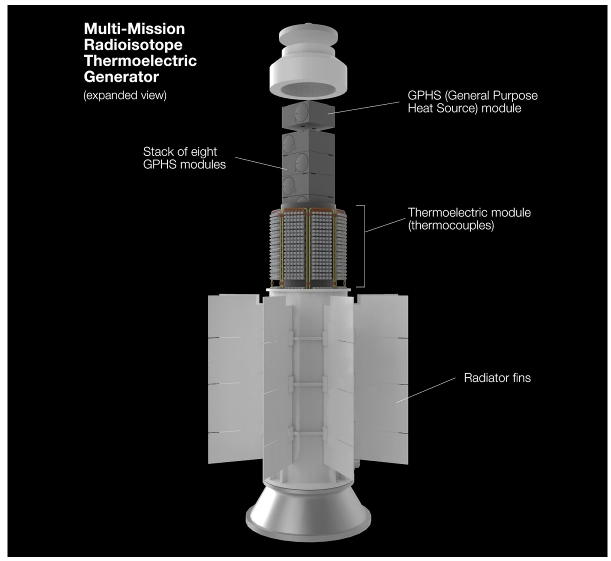
- Hydrogen-oxygen fuel cells
- Radioisotope Thermoelectric Generators (RTGs)
- Solar Power



## Radioisotope Thermoelectric Generators

RTGs provide electrical power by converting thermal energy to electricity using decaying plutonium-238 fuel and devices called thermocouples. The workings of the generator can be simplified and summarised as such:

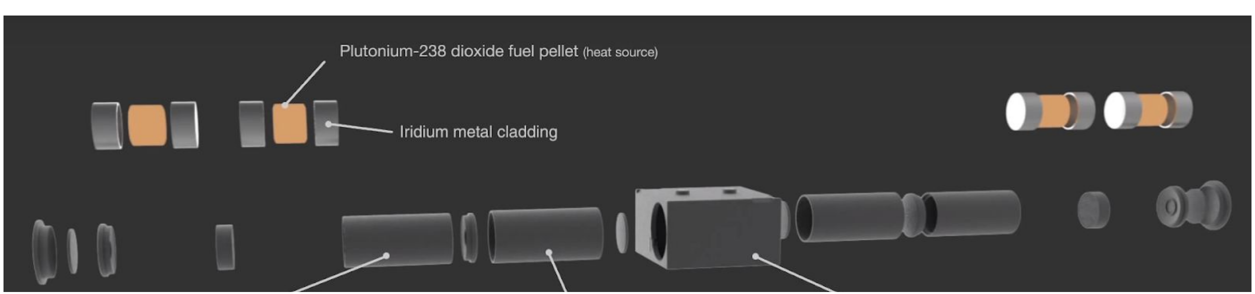
- Pu-238 decays and produces heat
- This heat is converted to electricity by the thermocouples
    - A thermocouple is essentially two plates, each made of a different electrically conductive metal. These two plates are joined to form a closed electrical circuit. As it is a closed circuit with the two junctions at different temperatures, a current is generated. The Plutonium only heats one of the junctions, causing the disparity in temperature which leads to the current.
- The other junction is usually cooled by the space environment of the planets atmosphere.
    - We may need to design a way to allow the second junction to cool and maximise the difference in temperature ( $\Delta T$ ), as we will not be in space. Although we will have the planets atmosphere, it may not be consistent enough that we can depend on it, especially as we will be passing through the equator where it will be quite warm all year round.




Pictured on the left is a 3D model of the RTG currently used for missions by NASA. It is called the (MMRTG) Multi-Mission Radioisotope Thermoelectric Generator. It is designed so that it can be used in either the vacuum of space or within the atmosphere of a planet. The excess thermal energy from it is used as a steady source of warmth to maintain ideal operating temperatures for a spacecraft in cold environments. Using this same principle we could repurpose this to provide heating on our vehicle.

The components of the MMRTG are as follows:

- Thermoelectric module
- Radiator fins - are attached to the outside of the generator and allow the excess heat produced to heat the craft.
- GPHS (General Purpose Heat Source) modules - that contain the plutonium-238 fuel pellets that act as a resource. In each MMRTG there are eight modules, each of which contain four plutonium fuel pellets (see diagram below):



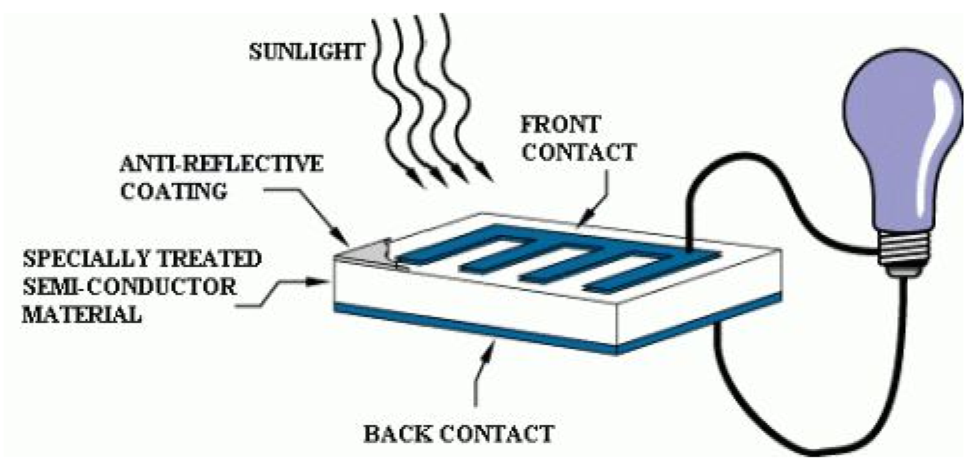
This is the Enhanced Multi-Mission Radioisotope Thermoelectric Generator (eMMRTG). The eMMRTG is currently a concept but according to NASA will be developed within the next 5 years. Therefore, will be well within our time frame. (see image above).

## Solar Power

International Space Station Solar Arrays

On the international space station solar arrays are used to provide electricity, solar arrays are made of thousands of solar cells. The solar cells are made from purified silicon, and using photovoltaics directly convert light to electricity. One solar array is by 34 by 12 metres (we could customise the dimensions for our voyage). Four sets of arrays can generate 84 to 120 kilowatts of electricity.

- Photovoltaics - the direct conversion of light into electricity. Thus occurs because some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured,it results in an electric current. The amount of current produced by a photovoltaic module is dependent on how much light strikes the module.




## Hydrogen-oxygen fuel cells

Modern shuttles no longer use hydrogen-oxygen fuel cells, but when considering different fuel sources we found that the information still may be useful to us. Fuel cells were used in the space shuttle as one component of the electrical power system. Three fuel cell power plants, through a chemical reaction, generate all of the electrical power for the vehicle from launch through landing rollout.

**Hydrogen + Oxygen = Electricity + Water Vapor**

**Cathode: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$**

**Anode: $2H_2 \rightarrow 4H^+ + 4e^-$**

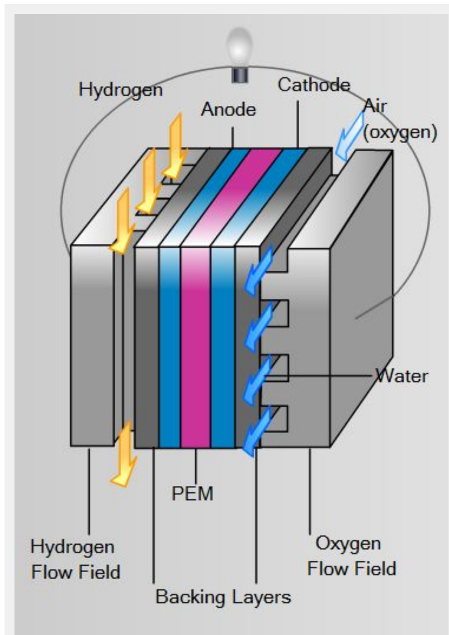
**Overall: $2H_2 + O_2 \rightarrow 2H_2O$**

A PEM (Proton Exchange Membrane) cell uses hydrogen gas and oxygen gas as fuel. The products of the reaction in the cell are water, electricity, and heat.

Since oxygen is readily available in the atmosphere, we only need to supply the fuel cell with hydrogen gas, which can come from an electrolysis process.

**There are four basic elements of a PEM Fuel Cell:**

- The anode conducts the electrons that are freed from the hydrogen molecules so that they can be used in an external circuit. It has channels inside of it that spread the hydrogen gas equally over the surface of the catalyst.




- The cathode has channels etched into it that distribute the oxygen to the surface of the catalyst. It also conducts the electrons back from the external circuit to the catalyst, where they can recombine with the hydrogen ions and oxygen to form water.(which we can then reuse)
- The electrolyte is the proton exchange membrane. This material only conducts positively charged ions. The membrane blocks electrons.
- The catalyst is usually made of platinum nanoparticles very thinly coated onto carbon paper or cloth. The catalyst is rough and porous so that the maximum surface area of the platinum can be exposed to the hydrogen or oxygen. The platinum-coated side of the catalyst faces the proton exchange membrane (see diagram below).

## <u>How does it work?</u>

1. Pressurized hydrogen gas enters the fuel cell on the anode side. This gas is forced through the catalyst by the pressure.

2. When an hydrogen molecule comes in contact with the platinum on the catalyst, it splits into two H+ ions and two electrons. The electrons are conducted through the anode, where they make their way through the external circuit (this is where we use the current generated) and return to the cathode side of the fuel cell.
3. On the cathode side of the fuel cell, oxygen gas is being forced through the catalyst, where it forms two oxygen atoms. Each of these atoms has a strong negative charge.
4. This negative charge attracts the two H+ ions through the membrane, where they combine with an oxygen atom and two of the electrons from the external circuit to form a water molecule.

All these reaction occurs in the cell stack. We would have to consider how we would connect components to the cell stack.

We should consider placing the stack in an area that has air management and coolant control.

A hydrogen-oxygen fuel cell has a 55% energy efficiency.

**Advantages of the technology:**

- Direct emissions from a fuel cell vehicle are just water and a little heat. This is a huge improvement over the internal combustion engine's litany of greenhouse gases.
- Fuel cells have no moving parts. They are thus much more reliable than traditional engines.
- Hydrogen can be produced in an environmentally friendly manner, while oil extraction and refining is very damaging.

## Stirling Converter Technology

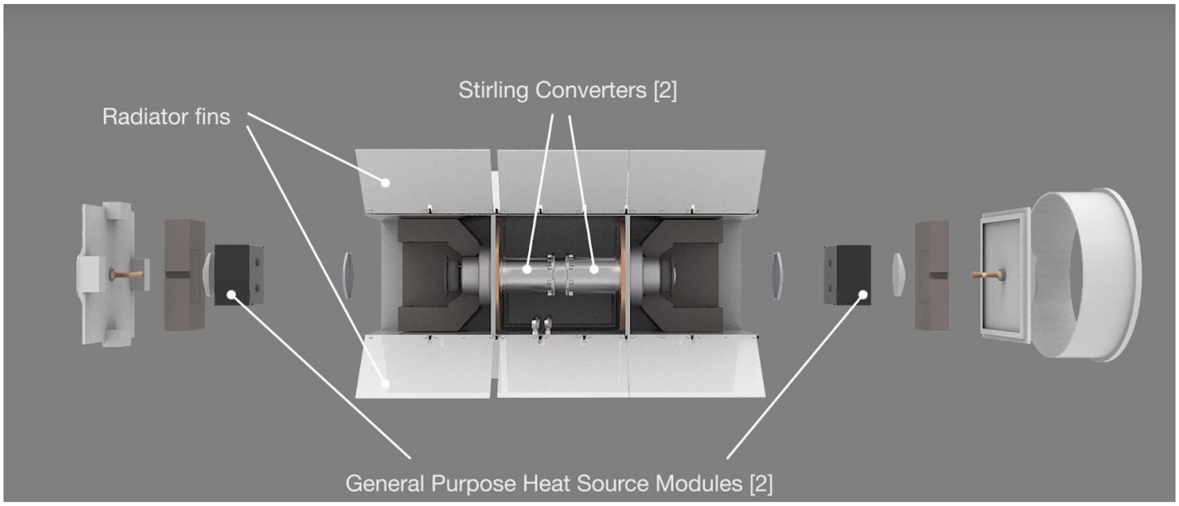
Stirling Converters are efficient engines that convert heat to electricity.

Inside a Stirling converter, a moving piston is driven by the heat of a fuel source. The piston would move a magnet back and forth through a coil of wire to generate electrical current in the wire.

The piston is suspended in a helium gas bearing, meaning it does not actually touch the inside of the mechanism. (this is to prevent the mechanism wearing out)

The process used to convert heat energy into electricity is more efficient than the thermoelectric and solar powered systems and NASA has had previous projects which plan on developing two ASRG (Advanced Stirling Radioisotope Generator) units.

The internal components of an ASRG are as shown below:




| | Advantages | Disadvantages |
|---|---|---|
| Biofuels | • Good for the environment<br>• Gets rid of our biological waste for us<br>• Doesn't use up that much space. | • Expensive<br>• The little waste that it does produce is toxic |
| RTG | • Already designed to support a self-contained setting<br>• Eco-friendly<br>• Low operating costs<br>• Reliable and long-lasting | • Would need human maintenance engineers<br>• Radioactive waste<br>• Leaks or explosions can be extremely dangerous<br>• High upfront costs |
| Solar Power | • Low maintenance<br>• Clean energy | • Takes up alot of space<br>• We would not be able to use it for the whole journey, therefore would work best in conjunction to another fuel source.<br>• Not very efficient<br>• Weather dependant<br>• Solar panels are fragile |
| Hydrogen Oxygen cells | • Direct emissions from a fuel cell vehicle are just water and a little heat<br>• Fuel cells have no moving parts, therefore they are more reliable<br>• Hydrogen is fairly | • Storage Issues<br>• High Cost<br>• Highly Flammable |

| | | |
|---|---|---|
| | accessible | |
| Stirling converter | • Efficient<br>• Already built to integrate with RTG<br>• Takes up little space | • Expensive and experimental<br>• Little information available |

After evaluating the possible fuel sources we decided that we would use a combination of ASRG technology with a steam turbine to charge the inverter on the ship.

**Powering the Ship's motor using a diesel engine**

A motor for a ship this size would require a lot of energy for the ships motor, but we also understand that central heating and other electrical fixings will also mean that a lot of other energy is required to power the ship. Hence we have decided to power the motor and the other electronic components on the ship separately. This acts as a fail safe for both systems, in the event that one of the power sources fails, the crew would be able to either use the VHF radio to contact assistance, or relocate the ship to a safer area. For propulsion only the ship would require 6000 kW at its top speed.

The components which contribute to the overall movement of the ship are as follows:

- 4 x fixed pitch propellers
- 1 x 120 kW electrically driven bow thruster
- 4 x Gearbox - used to allocate power

These components are powered by the eight engines in total, four caterpillar engines and four MTU (Motor Turbine Union) engines. These engines produce variable amounts of power;

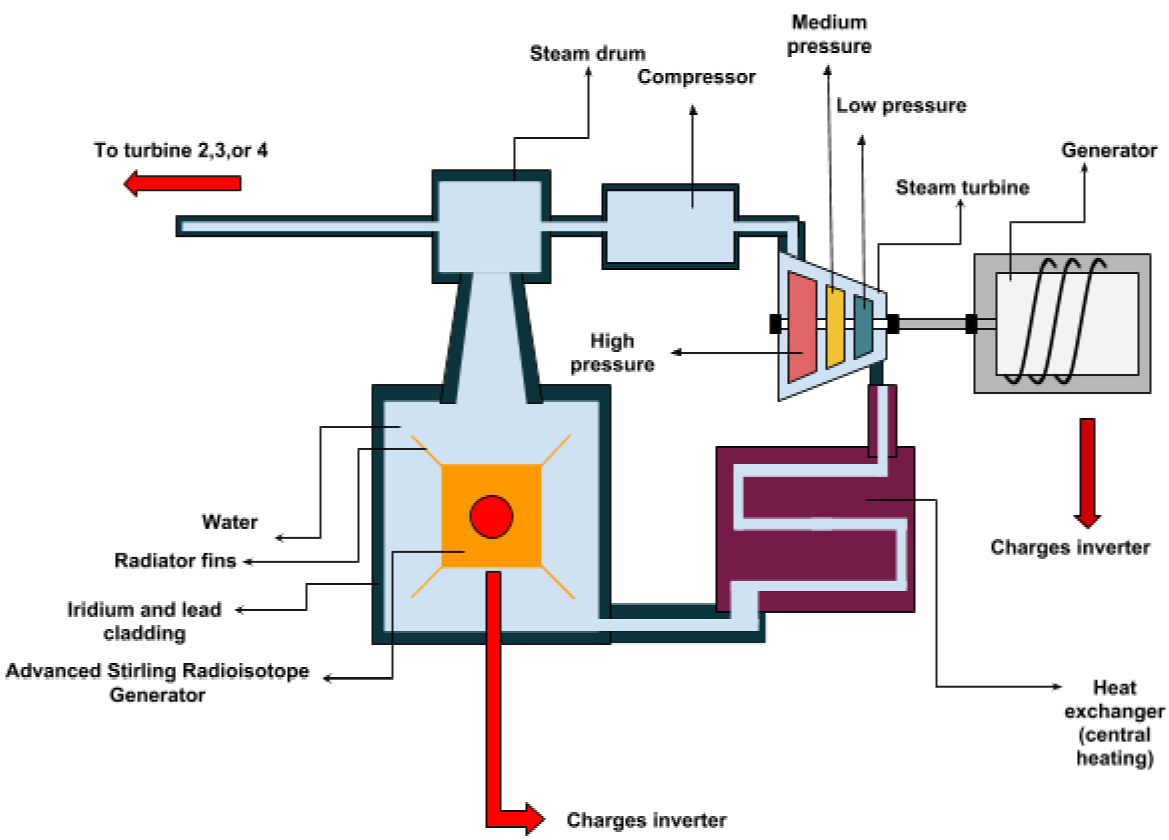
| Engine no. | Type of engine | Power produce (kW) |
|---|---|---|
| 1 | Caterpillar | 1193 |
| 2 | Caterpillar | 1081 |
| 3 | Caterpillar | 895 |
| 4 | Caterpillar | 746 |
| 5 | MTU | 1630 |
| 6 | MTU | 1080 |
| 7 | MTU | 1630 |
| 8 | MTU | 1080 |

The ship uses fixed pitch propellers in opposed to controllable pitch propellers. This means that is it cheaper, but offers a lower efficiency than the controllable pitch propellers.

**Powering electronics on the Ship using radioisotopes.**

Using the ASRG in development by NASA, we can produce around 130 W in terms of electrical power. Taking inspiration from the ASRG our generator also uses radioisotope to generate heat. But where the eMMRTG uses the principle of thermoelectrics and the ASRG uses stirling converter technology we found that it would be better to directly utilise the heat produced to create something similar to the configuration of a nuclear power plant. The generator can be split into three modules; radioisotope chamber, electricity generator and heat exchanger.

The arrangement of the three modules can be summarised as follows:




The generator function can be described as follows.

1. The mass of plutonium generates steady heat, this is utilised by the ASRG which utilises the thermoelectric effect to generate electricity
2. This electricity is then used to charge the inverter.
3. But as the plutonium has temperatures of up to 1323K the lowest temperature will be around 473K
4. The radiator fins are at at least 473K and heat up the water surrounding the chamber and cause the water to evaporate into steam.
5. The steam then rises to the steam drum where there are four identical configurations of steam turbine and generator. The steam spreads between these four turbines, they function identically. (From above the steam drum looks similar to an equal armed cross.)

6. Due to the increasing pressure as more steam is produced the steam is forced through to the steam turbine connected to a generator. It is here that the current that powers the ships motor will be induced.
7. The heated steam is condensed using a heat exchanger which provides internal heating for the ship.
8. The water is then returned to the iridium clad tank of water that surround the plutonium chamber.

| | eMMRTG | ASRG | Our modified radioisotope fuelled steam generator |
|---|---|---|---|
| Number of GPHS modules | 8 | 2 | 1 |
| Mass of Plutonium | 4.8 kg of plutonium dioxide, of which 3.41kg is Pu238 | 1.2 kg of plutonium dioxide of which 0.85kg is Pu238 | 0.2 kg of plutonium dioxide of which 0.14kg is Pu238 |
| Price of fuel | £384,00,000 | ~£600,000 | ~£98,823 |
| Price of material and cladding | £110,000 | ~£68,760 | ~£3,629 |
| Total price | | ~£668,760 | ~£102,452 |
| Useful Electrical Power from radioisotope generator (W) | 145 | 130 | n/a |
| Electrical Efficiency ASRG | 8% | 26% | 26% |
| Useful electrical power (turbine generator) | n/a | n/a | 1280kW |
| Electrical efficiency (turbine generator) | n/a | n/a | 20-30% |
| Mass (kg) | unknown | 32 | 50 |
| Maximum and minimum temp (K) | 873 to 473 | 1123 to 393 | 1323 to 473 |
| Dimensions (m) | unknown | 0.76 x 0.46 x 0.39 | (0.8 x 0.8 x 0.8) the majority of this space is to give the water enough space to cool |

| | | | |
|---|---|---|---|
| | | | and to allow enough room for the water surrounding the ASRG radiator fins. |

A major thing to take into consideration when calculating the values for our modified generator is the GPHS modules. The eMMRTG uses 8 GPHS modules whilst the current design for the ASRG only uses two. Using one GPHS module in this case seems to be unnecessarily costly as we would only be using the generator for a fraction of the 17 year life that it has. Hence we have scaled down the size of a GPHS module and reduced the amount of plutonium to get our values.

Originally we had hoped that as Pu 238 produces 5.593 MeV or $8.96\times10^{-13}$ J and has a surface temperature of 1323 K, it would produce steam at a high pressures and therefore produce high amounts of electrical energy. But after reevaluating our generator we realized that 1323 K is only a surface temperature.

__Microturbines__

A microturbine are relatively new generation technology which have found uses in stationary energy generation. They produce heat and electricity of a relatively small scale and have a small number of moving parts. Microturbines also offer greater efficiency and lower emissions, as well as being lightweight.

In principle, microturbines are combustion turbines on a smaller scale, from outputs ranging from 25kW to 500kW.
The components of microturbines are as follows;

- Compressor
- Combustor
- Turbine
- Alternator
- Recuperator
- Generator.

**Table 5-2. Microturbine Cost and Performance Characteristics**

| Microturbine Characteristics [1] | System | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Nominal Electricity Capacity (kW) | 30 | 65 | 200 | 250 | 333 | 1000 |
| Compressor Parasitic Power (kW) | 2 | 4 | 10 | 10 | 13 | 50 |
| Net Electricity Capacity (kW) | 28 | 61 | 190 | 240 | 320 | 950 |
| Fuel Input (MMBtu/hr), HHV | 0.434 | 0.876 | 2.431 | 3.139 | 3.894 | 12.155 |
| Required Fuel Gas Pressure (psig) | 55-60 | 75-80 | 75-80 | 80-140 | 90-140 | 75-80 |
| Electric Heat Rate (Btu/kWh), LHV [2] | 13,995 | 12,966 | 11,553 | 11,809 | 10,987 | 11,553 |
| Electric Efficiency (%), LHV [3] | 24.4% | 26.3% | 29.5% | 28.9% | 31.1% | 29.5% |
| Electric Heat Rate (Btu/kWh), HHV | 15,535 | 14,393 | 12,824 | 13,110 | 12,198 | 12,824 |
| Electric Efficiency (%), HHV | 21.9% | 23.7% | 26.6% | 26.0% | 28.0% | 26.6% |
| **CHP Characteristics** | | | | | | |
| Exhaust Flow (lbs/sec) | 0.68 | 1.13 | 2.93 | 4.7 | 5.3 | 14.7 |
| Exhaust Temp (°F) | 530 | 592 | 535 | 493 | 512 | 535 |
| Heat Exchanger Exhaust Temp (°F) | 190 | 190 | 200 | 190 | 190 | 200 |
| Heat Output (MMBtu/hr) | 0.21 | 0.41 | 0.88 | 1.28 | 1.54 | 4.43 |

Generally microturbines rotate around 40,000 revolutions per minute.

_Calculations_

The following information was taken from a catalog of the U.S Combined Heat and Power technologies, where microturbines were mentioned. Using this we can estimate the amount of power that will be produced based on the pressure of the steam our generator produces.

If we model our steam using the ideal gas equation we can make an estimate for the pressure. Hence;

$P = \frac{nRT}{Vs}$ , Where Vs is the volume of the steam drum

$n = \frac{mass}{relative\ formula\ mass}$ ,

$mass = \rho V$ , Where V is the volume of the water.

$V = volume\ of\ chamber - volume\ of\ ASRG$

$V = (0.8 \times 0.8 \times 0.8) - (0.76 \times 0.46 \times 0.39)$

Therefore $V = 0.66m^3\ (2.s.f)$ of water if we assume that all the water will be steam at the same time which we cannot assume, hence we assume that only 10% of the water is steam at one moment

Hence the mass of the water is $(997 \times 0.33 \times 0.1) = 32.9\ kg = 33kg(2.s.f)$

Moles of water, $n = \frac{(33 \times 1000)}{18} = 1800\ moles\ (2.s.f)$

The volume of the steam drum = $2.0 \times 2.0 \times 2.0 = 8.0m^3$

Therefore $P = \frac{1800 \times 8.31 \times 473}{8} = 880000\ Pa = 128\ psig$

This would mean the microturbine is compatible with the 5th type of microturbine system which has a net electrical capacity of 320kW per turbine, as we plan on having four turbines the total net electrical capacity is 1280kW.

This may not seem like much, compared to the  but as the purpose of the generators are to steadily charge the inverter, which will then convert the power to a useful output. this will be enough to last the voyage. As the inverter itself will provide the Power to the motor and other electronics.

## How much power does each component require?

| Component | Calculation/Justification | Power required (kWh) |
|---|---|---|
| HMC | According to Nasa for a four-person mission over a year, the HMC produces 1060 tiles using 2400kWh.Therefore we can conclude that on a six person mission over 50 days, the HMC would use 493kWh. | 493kWh |
| Navigation system | The navigation system will constantly be operational. We estimate the navigation system to use 150W per hour. We would be travelling for roughly 1148 | 172.2kWh |

| | | |
|---|---|---|
| | hours. Therefore we can estimate the maximum power NHF radio would require 172200W | |
| VHF Radio | As we may not always be using the VHF radio, it may be difficult to estimate the kWh of the VHF, but the radio operates at 25W per hour. We would be travelling for roughly 1148 hours. Therefore we can estimate the maximum power NHF radio would require 28700W | 28.7kWh |
| Water Purifier | The water purifier also may not be operational for the whole journey, it has an average power usage of 70W per hour. Therefore we can estimate the total power used by the water purifier is 80360W | 80.36kWh |

Hence we can deduce that our generator provides enough energy to run electronics on the ship with some to spare for emergency electronic installations.

## 2.4 *Vehicle Design*

# Fast Crew Supplier Security 4008

**Structural Features of the FCS 4008**

The structure of the Fast Crew Supplier (FCS) 4008 can be divided into two parts; the substructure and the superstructure. The substructure refers to the supporting structures that create the main body of the ship. The superstructure refers to the extended construction that is built using the substructure as a foundation, it is the part of the ship that is visible from the outside.

The substructure of the FCS4008 is steel, this in in order to provide a hard rigid foundation. The superstructure is made from aluminium alloy, this allows for many advantages;

- Light  - as to reduce structural weight and lower density near the top of the boat, as aluminium is 30% lighter than steel. This in turn lowers the centre of mass and improves the stability of the ship.
- Stronger in colder environments - this property of steel is especially useful for our voyage as we will be starting in the north pole during november , when the sea ice is noticeably prominent. This hardening of superstructure will allow the ship to better cut through the ice.

**Function and Ability:**

The FCS 4008 is able to travel at a top speed of 30 knots, but travelling at this speed consistently could cause possible damage to the ship. Hence, we have resolved to use an average speed of 10 knots. This allows apt time for communication with other ships that ensures we do not cause disruptions in usual sea traffic.

**Staffing:**

The ship can ensure up to 6 crew members and up to 16 personnels on board. This provides enough space  where there will be cabins, mess and sanitary space is provided on the lower deck for members we are looking to hire.

**Food Storage:**

There is a location set in place for food store on the lower deck. The ship is equipped with 2 refrigerators and 2 freezers (where frozen goods can be stored for long periods of time) There will be space for storing MRE in the pantry on the lower deck.

**Costing:**

In terms of costing, (February 2019) currently retails for £7,001,598 for a length of a ship of 51m. We have considered that it is a high value however have agreed to rent the ship out for 60 days. After deep consideration and with limited information we had to work with would would make a deposit of £225,000.

**Lifting Mechanism:**

The forklift is 2m by 4m. The deck is roughly 16m by 8m therefore the deck space is large and where we place the forklift as the floor space upper deck is large.

**Communication Mechanism:**
Even though Nautical and communication is found onboard we will be using the Marine VHF Radio system as researched.

**Waste Disposal Method :**

The HMC (Heat Melt Compactor) is made of 3 components : trash compactor, water recovery system and gas contaminant control. Even though there is a freshwater supply on the lower deck we will be using the HMC as it is more compact.

**Safety:**

A Davit system has been put in place where a crane like devices used on the ship for supporting, raising and lowering equipment such as lowering the emergency lifeboat (safety craft) if there needs to be an evacuation off the ship as we believe the staff's life is the most important at the end of the day.
Fire Extinguishing System (Engine Room)

**Other Equipment and Devices on Board:**

(All other mechanisms researched would be replaced from the original ship which include the water purifier and navigation system)

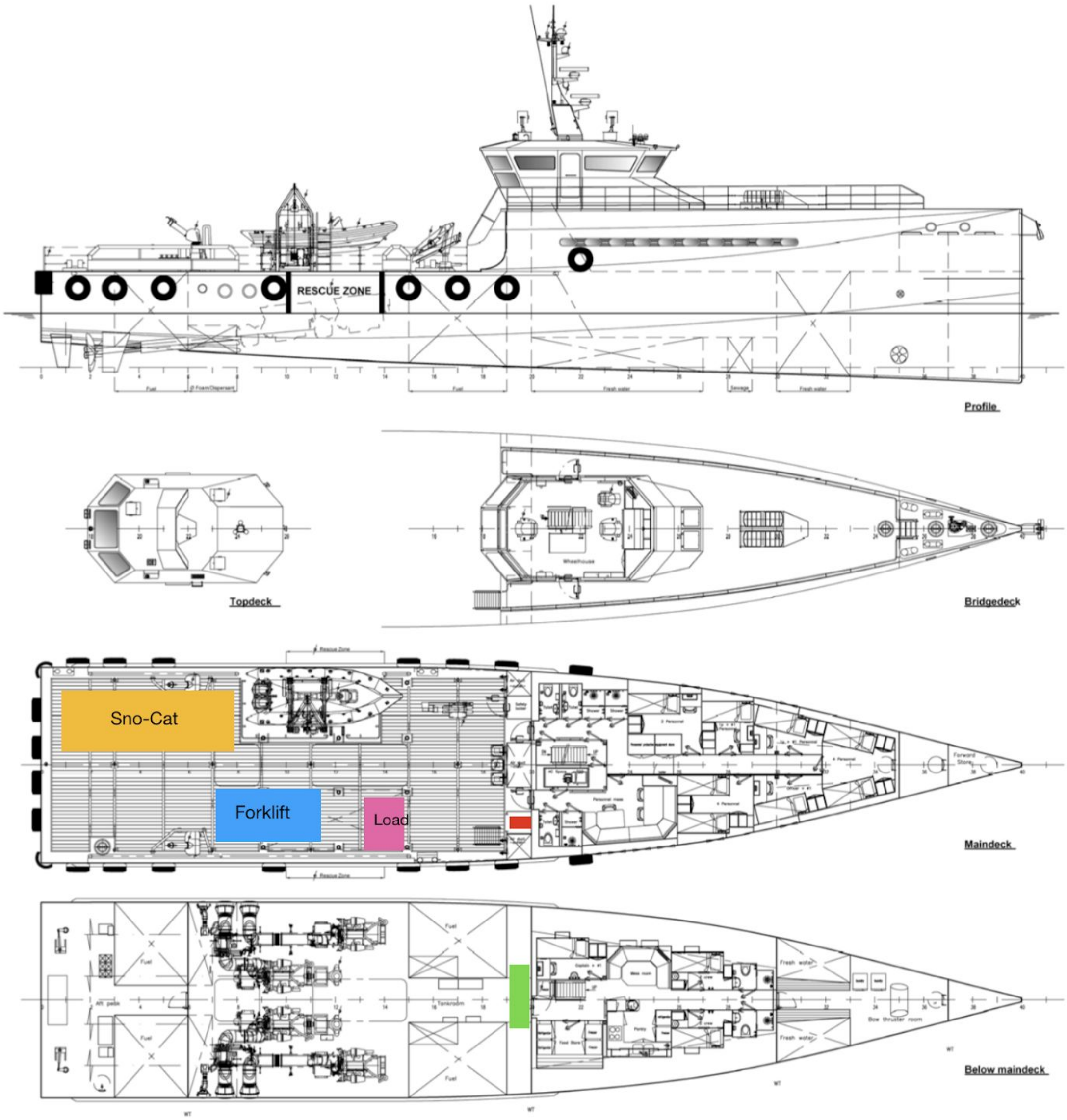
Anchor Equipment (SHHP anchor means a weight reduction of 50% compared to conventional anchor)

**Why did we use this ship compared to other ships?**

Initially we thought of using the Royal Navy ships as they are durable and would be able to withstand damage however the capacity was larger compared to what we needed. Information was limited from research.
Then we decided to look into ships that are on sale, however the capacity was lower than what we needed and they weren't built to travel large distances that we were planning to travel.

Damen is a Dutch defence ship building company. We decided particularly to go for this company as there was extensive information online and was reliable family owned business.

There are 50 Fast Crew Supplier Security 4008 ships that have been built and were perfect for the requirements for our travel from the North Pole to the South Pole and carrying the tonne load.




Red- HMC
Green- Generator

Cargo Deck Area : 140.0m^2

# Model 1643 Tucker-Terra ® / Sno-Cat ®


## Advantages for choosing this Vehicle:

Full Four Tracks- Greater mobility over deep snow.
Lighter, corrosion-resistant fiberglass pontoons. Initially but then updated to a full rubber ‘Terra Track’ system with the multi-ply rubber belt.
Cummins diesel engines range from 160hp to 300hp.
Controlled by pivoting both front and rear axles. Smooth Movement over the rough terrain with minimum destruction to ground cover.
Sidehill ability to prevent side slip on ice or hard faced slopes. The track grouser is provided with ice clears - reducing side slip and provide forward and reverse traction

## Power and Speed

Powered by Detroit Diesel or Cummins 6BT and QSB engines of about 170 horsepower

It is said from unofficial sources that the speed would be 18mph (top speed)
So let's just say the speed is going to be 14mph just to be safe.

The Model 1643 Tucker Terra ® / Sno-Cat ® has a capacity of 50 Gallons.

## Fuel Consumption

1158km on land

14mph -- 22.5 kmh

1158/22.5 = 51.5 hr

1.25 gallons * 51.5 = 64.37 gallons

So basically 65 gallons needed.

(Extra refill would be needed roughly $\frac{3}{5}$ of the way there to top up as capacity is only 50 Gallons)

## Advantages of using continuous wheels

We decided to go for the Tucker Sno-Cat ® due to the continuous wheels which is ideal for the type of terrain which we will be travelling on.

- Comparing to wheels, continuous tracks have high performance and optimised traction system
- The traction is high even on slippery surface, which means that it's suitable for ice.
- It can work on rugged terrain, where as wheels can get stuck
- Large surface area in contact with the ground means that it exerts a lower pressure. It has a smaller impact on the ground, especially with our heavy vehicle, so we can reduce the damage to Antarctica
- The weight is spread over the entire surface of the track, so our vehicle can carry heavy load.
- Track grouser is provided with ice cleats which reduce side slip and provide forward and reverse traction

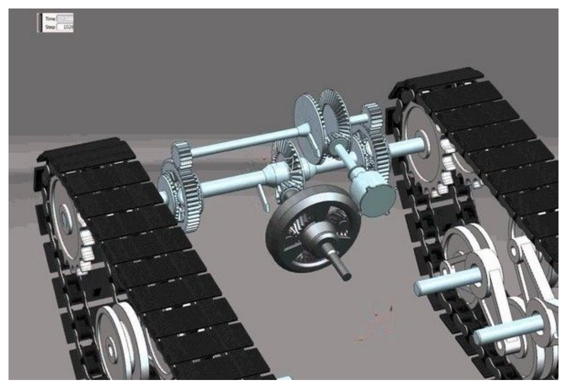
We are also aware of some of the drawbacks of using continuous wheels, but most of them wouldn't have a big effect in the situation that we are dealing with:

- They have a lower speed because of the higher friction and more complex mechanism (this won't be a problem since we have enough time for it)
- difficult to repair (This could potentially be a problem it the continuous track is dislodged or broken. We could possibly carry a set of backup equipment in case of an accident)

## Reasons for choosing continuous wheels:

Advantages of using continuous wheels

- Comparing to wheels, continuous tracks have high performance and optimised traction system
- The traction is high even on slippery surface, which means that it's suitable for ice.
- It can work on rugged terrain, where as wheels can get stuck
- Large surface area in contact with the ground means that it exerts a lower pressure. It has a smaller impact on the ground, especially with our heavy vehicle, so we can reduce the damage to Antarctica
- The weight is spread over the entire surface of the track, so our vehicle can carry heavy load.



We are also aware of some of the drawbacks of using continuous wheels, but most of them wouldn't have a big effect in the situation that we are dealing with:

- They have a lower speed because of the higher friction and more complex mechanism (this won't be a problem since we have enough time for it)
- difficult to repair (This could potentially be a problem it the continuous track is dislodged or broken. We could possibly carry a set of backup equipment in case of an accident)

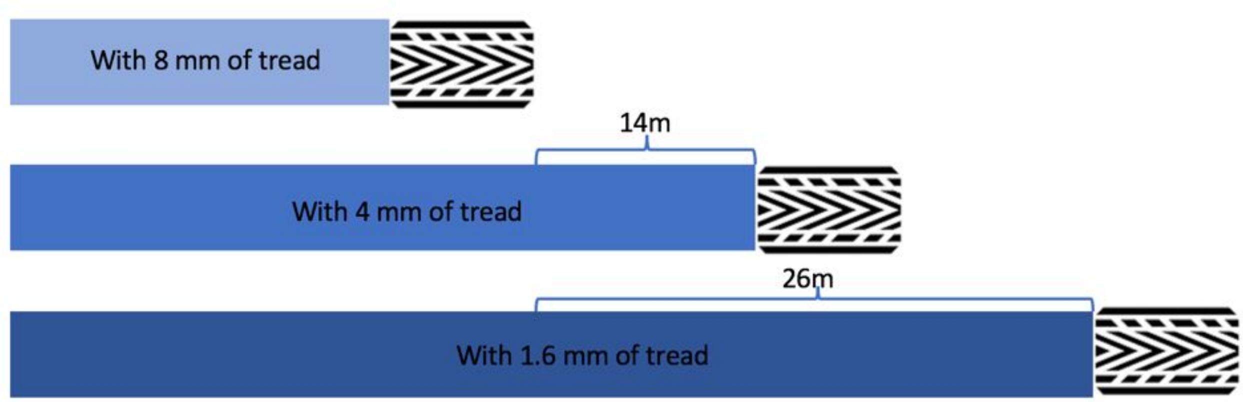
**Tyre treads**

The tyres tread used on ice have some special features:

- **The tread rubber**: Comparing to the rubber of the normal tyres which stiffen at cold temperature, the winter tyres tread a higher natural rubber content, so they can remain flexible in cold weather. In this way, the tyres tread can grip the ground better and provide bigger traction.

- **The tread depth**: the winter tyres tread we use have deeper depth (it has a depth of 4mm whereas 3mm is the recommended minimum depth for summer tyres) which provides a cavity for snow. The compacted snow provide better grip to the ground.
- **Tread patterns**: the winter tyres have thousands of tiny grooves, which can disperse water from underneath the tyre. Compared to normal tread, the tread pattern for winter tyres have wider grooves and narrow slits at the edge of the tread area. It sucks water away from the surface of the ground as it rotates, so it reduces the risk of aquaplaning on the ice.

Braking from 50 km/h to stop on snow with different tread depths:




As shown in the diagram (source: uniroyal-tyres.com), the braking distance increases as tread depth decreases.

Where would we position the Sno Cat?
The Sno Cat weighs 5443kg. Therefore the positioning on the ship will be important so the ship doesn't tip over and there is an even load of both ends. The forklift is roughly 3500-4500kg and load of 1000kg is placed on the other end therefore placing the Sno Cat will

## 2.5 Staffing

- We will need about 4-6 people on board.
- Staff training: we may have to get people from the seal team or train people like a seal team.
    - Physical training, fitness
    - Survival in water eg. saving drowning people
    - Basic first aid training eg. resuscitate
    - We will also need to bring a military doctor on the ship
- Potentially, 4 people with engineering degree (and a biochem ) in case we have to fix the ship in emergency, a nurse/doctor, ZEAL team

**Nurse:**

- Average salary: £50 000 per year→ £4000 per month
- An Army Nurse Corps
- Offers judged by their decision making skills (MMI decision making skills)
- Emotionally Stable - traumatic situations can occur hence instead of hiring a mental health professional, he/she's role can be 2 in one.
- Physical Endurance is needed on this long voyage
- Comparison to **Hazel W. Johnson-Brown**

**MMI decision making skills:**
Many Independent assessments and Presented with several scenarios. (similar to medical interviews)

**Engineers on ship**:

- Mechanical engineer and technician
- Average salaries: £30 000 → £2500 per month
- Things that they must be able to do:
    - Familiar with the spec of the ship
    - Building engine and gears
    - Spot and repair faults and mechanical parts on the ship (people with degree specialised in sea-related transport.)
- NSPE national society of professional engineer: **Engineering Licensure**
    - 4 years degree in engineering from an accredited engineering program
    - Fundamental Of Engineering (FE) exam
    - Complete 4 years of progressive engineering experience under a PE (Professional Engineer)
    - Principles and Practice of Engineering exams
- Why do we need engineer who are PE?

- Those who have earned the qualification of PE are not only highly certified but are responsible for the lives affected by their work and to be a PE one must hold themselves to high moral and ethical standards.

**Conclusion:**
Total staffs: 2 doctor/nurse, 3 Engineers, 1 ship captain (trained for sea travel)
Total mass: 70x6 = **420 kg**

## Clothing and Special Equipment for the Poles

- Antarctica temperature: ~ -20 degree celsius

The appropriate clothing and equipment to bring: (reference: North Face)

- Boots (£140x6 = 840)
    - Double insulated
    - Suitable for hiking the mountains
    - Knee high
    - Waterproof
- Parka (£600x6 = 3600)
- Base layers (£30x12 = 360)
- Long-sleeve shirts (£20x12 = 240)
- Insulation layer (£20x12 = 240)
- Insulated trousers (£540x12 = 6480)
- Thermal socks (SmartWool) (£25x30 = 750)
- Antarctica inner and outer gloves (£70x12 = 840)
- Beanies or headbands (£20x6 = 120)
- Professional EMT medical kit (£250)

Total cost for clothes and essential equipment = £13, 720

These clothes will be provided for the staffs when we are at the north and south pole. However, for the majority of the voyage, the staffs will be wearing their own clothes. Referencing the routing we have planned on section 2.8, when we travel between point 5 to point 14, we will be experiencing tropical climate. Furthermore, as we are travelling during November, when we enters Southern Hemisphere it will be in the Summer.

## 2.6 Food consumption

When discussing how to feed our crew, there were three main methods we considered:

1. Creating a controlled environment in which we grow fruits and vegetables which the crew members cultivate and eat from.
2. Buy MREs from the Military and use them throughout the voyage.
3. Vitamins supplements

| Method | Pros | Cons |
|---|---|---|
| Growing Food on the ship | • Would be good for emotional and mental health.<br>• Food will be tasty. | • As we will only be travelling for at most a year this may not be appropriate<br>• We will not be able to guarantee that the staff will be able to get all necessary nutrients.<br>• Would use valuable resources like space and water<br>• If the crops become diseased our crew members will starve or develop vitamin deficiencies.<br>• Requires one of the crew members to be proficient in gardening. |
| MREs (Meal Ready to Eat) | • Already prepared for hostile environments<br>• Guaranteed to provide necessary nutrients<br>• Is not ethically questionable. | • Would be very expensive<br>• Would take up more space than option three.<br>• Ethically questionable. |
| Vitamins supplemented with astronaut food | • Would be cheapest<br>• Would take up the least amount of space<br>• Is guaranteed to provide the necessary nutrients | • Would be bad for emotional well being of crew members.<br>• Would reduce appeal of position to prospective crew. |

Food packaging: we can adapt the food into the astronauts-type packed food in small packages because they can last very long without getting contaminated and they can take up less space on the ship. Or MREs which come in a full-meal packages.

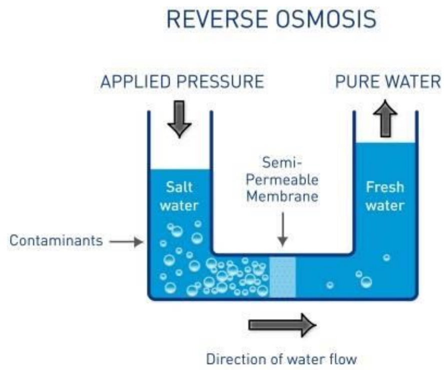


In the end, we have chosen MREs over astronauts-type packed food because MRE comes in full meal and they do not required to be stored in refrigerators. In addition, MREs comes in cardboard boxes, meaning that it will be easy to transfer and stored.

1 packaged meal box is approximately: 0.4 kg (but vacuumed packaging will reduce this mass.)
Mass of food in per day per person: 1.2 kg
Assuming that there will be 6 people on board, total mass of food per day is 7.2 kg.
Total mass of food for the whole travel: 7.2 x 60 = 432 kg→ **500 kg roughly**

Cost of 1 packed meal: £10.00
Total cost: 10 x 3 x 6 x 60 = £10800

- For food consumption, we may need to decide of group of people eg. age, height, weight although it does not really matter.
  - Women food consumption: 2,000 kcal
  - Men food consumption: 2500 kcal
  - Water consumption: 2 litres per day→ we might be able to use sea water and convert it to drinking water because if we have to carry water on the ship, it will be super heavy. Density of 997 kg/$m^3$
    - Reverse Osmosis might be the best thing, weighing around 9 kg




- Produce 190 litre of water a day, membrane can last for 1-2 years
- Dimension: 56.6 x 43.2 x 34.6 cm
- Cost: £90

**Summary:**
Total mass of food = 500 kg
Mass of water: 9 kg (Water filter)

Total mass = 509 kg

## 2.7 Waste disposal

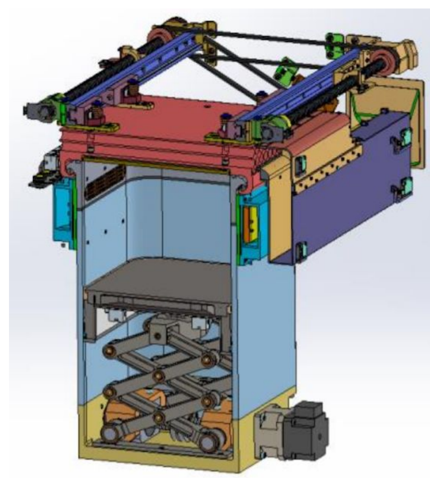
**Waste Management**

On most long distance voyages, the way that waste is dealt with is that it is stored on the vessel and periodically disposed of. Although this could well be done by dumping the waste we produce in the ocean, or storing contaminated material on the ship we found that as a team we would prefer to be more eco-friendly. There is also the fact that dumping our waste invites a horde of opportunities to waste possibly useful materials.

In order to achieve a minimum effect of the environment, and reduce the possibility of disease on our journey; our plan is to use a HMC (Heat Melt Compactor) that has been designed by NASA.

**Heat Melt Compactor**

The purpose of a HMC is to sterilize, compact and recover water from both wet and dry waste. The HMC produces dry, sterilized, plastic encapsulated tiles that may be used as additional radiation cladding for the modified ASRG.

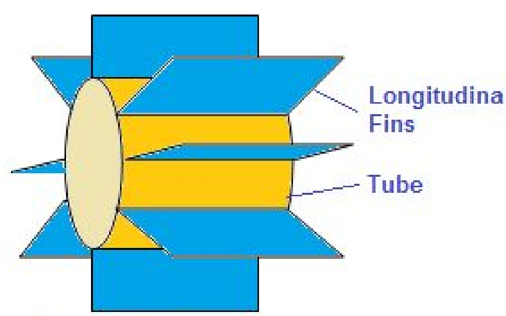


The compactor consists of 3 systems working in tandem to process waste;

**Trash Compactor** (shown to the right):

- Made completely out of stainless steel to provide a strong structure that can withstand a variety of pressures during the compaction cycle.
- All stainless steel surfaces of the chamber that come into contact with waste are coated with a nonstick coating.The coating helps minimize the accumulation of residual food and waste products on the surface, which could otherwise impact the ability of the HMC to maintain a variety high internal pressures.

The compaction chamber assembly uses a scissor linkage and is designed to deliver 379212 Pa of pressure to compress the trash. Heaters on the Ram Head (shown to the right) and the top of the chamber, melt the plastic amongst the waste while boiling off the water. Once the trash is compacted the trash tile is pushed out of the chamber by the ram head and actuator assembly.




**Water recovery system** - The purpose of this system is to capture the water from the waste that has been heated and converted into steam. This is done by partially compressing the waste and heating it using the series of heaters on the ram face, chamber lid, and wall heaters. Steam is ejected through a chamber designed to capture any water droplets that inadvertently get pushed through the vent holes during compaction.

Steam is condensed using a fin tube heat exchanger (shown on previous page). A secondary heat exchanger powered by thermal electric coolers condenses out the remaining moisture and collects it in a separate chamber.

## Gas contaminant control

As the refuse is heated up in the chamber, various gaseous compounds are released including water vapour. These compounds include aldehydes, ketones, alcohols, hydrocarbons and sulfides that are released from waste during heating.

The two primary components of the SCC system (Source Contaminant Control) are the catalytic oxidizer and the adsorption bed. The catalytic oxidizer oxidizes hydrocarbons that are present in the gas stream. The adsorbent bed is located above the catalytic oxidizer primarily to prevent sulfur poisoning of the catalyst. These operate in tandem in order to reduce concentrations of volatile and toxic compounds to acceptable levels.

Step by Step function of the HMC

1. Waste is placed into the compaction chamber
2. The waste is first compacted without heat, during this stage free water may come out of the chamber.
3. Next, the heated surfaces would have reached their set temperature and the trash is then further compacted. At this stage the chamber is exposed to differential pressures or vacuum. This is in order to remove remaining free water by evaporation. In order to minimise chances of encapsulation of wet trash the temperature is kept below the melting point of plastic in the waste.
4. The trash is compacted in order to reduce the volume of the waste and the waste is sterilized by the HMC using heat
5. The temperature of the surfaces is then increased and the melting plastic cools to hold the compressed waste together, stabilising it as a (22.9 cm x 22.9 cm x 2.54 cm) tile.
6. The tile is then removed and stored elsewhere. The HMC compresses waste to roughly about 1/8th of its volume.

Dimensions of the HMC are as follows; (0.75m x 0.40m x0 .75m), this does not include the water recovery system that is adjoined to it that can be rearranged and therefore does not have a set configuration. For the cost, the price for the HMC has yet to be published as the plans for it were only confirmed around October 2018.

## 2.8 Route planning

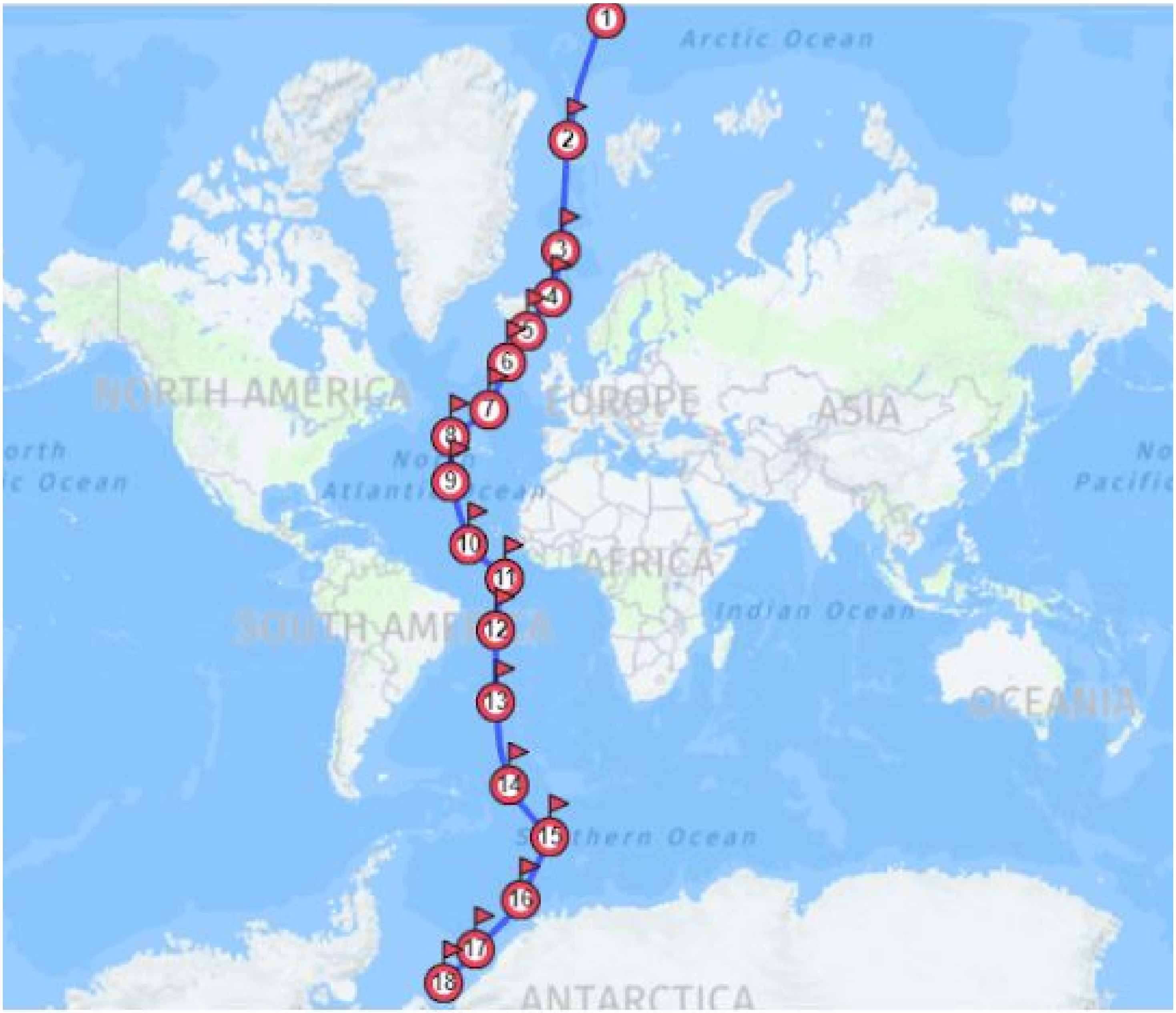
When considering how our route would be planned we were conscious of the fact that we would not be able to use any air travel but especially not use any harbours or ports. As the north pole consists mainly of sea ice and water we decided that it would be easiest to water traversing vessel for our mode of transport; whether that be a traditional ship or not was up to debate at the time.

There were several requirements to take into account when we were designing our route;

- Time - How long will it take
- Practicality - Is it unnecessarily complicated
- Resilience - Are there too many ways it could go wrong
- Flexibility - Do the route and timings leave space for flexibility

Summer in the southern hemisphere, begins 22 December and ends on the 21 March. This lasts 2136 hours. We hope to reach the antarctic continent during the peak of summer, when the majority of the ice will be melted. This is halfway during the summer on the 6th of January. As our voyage is looking to be 49.5 hours before we approach antarctica we will begin the voyage on the 20th of November. Although this does mean that in late November the Northern Hemisphere will have ice, fortunately our ship is designed to break through dense ice without sustaining major damage.

Taking all that into consideration, the route we designed is shown below;


Arctic Ocean
NORTH AMERICA
EUROPE
ASIA
North Pacific Ocean
North Atlantic Ocean
AFRICA
Indian Ocean
SOUTH AMERICA
OCEANIA
Southern Ocean
ANTARCTICA
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

| Point | Co-ordinates | distance (km) | Cumulative distance (km) | Bearing | time between points (hrs) | cumulative time (hrs) | Date |
|---|---|---|---|---|---|---|---|
| North Pole | (90.00000000, 0.000000000) | - | | S (169°) | - | 0 | 20/11/2019 |
| 1 | (84.7060489350415, 10.8984375) | 588 | 588 | SW (203°) | 31 | 31 | 21/11/2019 7 : 00 |
| 2 | (79.71860546904045, -1.0546875) | 579 | 1167 | S (183°) | 50 | 81 | 23/11/2019 9 : 00 |
| 3 | (71.35706654962706, -2.63671875) | 930 | 2097 | S (194°) | 32 | 113 | 24/11/ 2019 17 : 00 |
| 4 | (66.01801815922045, -5.9765625) | 608 | 2705 | SW (219°) | 34 | 147 | 25/11/ 2019 15 : 00 |
| 5 | (61.3546135846894, -13.7109375) | 642 | 3347 | SW (215°) | 36 | 183 | 27/11/2019 3 : 00 |
| 6 | (56.26776108757582, -20.0390625) | 671 | 4018 | S (201°) | 58 | 241 | 29/11/2019 13:00 |
| 7 | (47.040182144806664, -25.3125) | 1087 | 5105 | SW (239°) | 61 | 302 | 02/12/2019 02:00 |
| 8 | (41.11246878918088, -37.08984375) | 1145 | 6250 | S (180°) | 67 | 369 | 04/12/2019 21:00 |
| 9 | (29.84064389983441, -37.265625) | 1252 | 7502 | S (163°) | 117 | 486 | 09/12/2019 18:00 |
| 10 | (11.005904459659451, -31.640625) | 2172 | 9674 | SE (133°) | 90 | 576 | 13/12/2019 12:00 |
| 11 | (0.5273363048115169, -20.7421875) | 1674 | 11348 | S (190°) | 94 | 670 | 17/12/2019 10:00 |
| 12 | (-14.944784875088367, -23.5546875) | 1746 | 13094 | S (180°) | 122 | 792 | 22/12/2019 12:00 |
| 13 | (-35.31736632923786, -23.5546875) | 2263 | 15357 | S (172°) | 112 | 904 | 27/12/2019 04:00 |
| 14 | (-53.85252660044951, -19.3359375) | 2085 | 17442 | SE (145°) | 63 | 967 | 29/12/2019 19:00 |
| 15 | (-62.103882522897855, -6.50390625) | 1183 | 18625 | S (200°) | 52 | 1019 | 31/12/2019 23:00 |
| 16 | (-70.14036427207168, -15.46875) | 977 | 19602 | SW (216°) | 40 | 1059 | 02/01/2019 15:00 |
| 17 | (-74.79890566232939, -29.794921875) | 702 | 20304 | SW (217°) | 37 | 1096 | 02/01/2019 04:00 |
| 18 | (-77.31251993823142, -39.375) | 378 | 20682 | S (180°) | 20 | 1116 | 03/01/2019 00:00 |
| 19 | (-79.33521923837228, -39.375) | 226 | 20908 | SE (153°) | 12 | 1128 | 03/01/2019 12:00 |
| 20 | (-80.54651780307104, -35.595703125) | 154 | 21062 | SE (138°) | 8.0 | 1136 | 03/01/2019 20:00 |
| | **Total distance via ship** | **21062** | | | | | |
| | | | | | | | |
| 21 | (-80.98368830825945, -33.046875) | 67 | 67 | SE (130°) | 3.0 | 1139 | 03/01/2019 23:00 |
| 22 | (-81.41393328285109, -29.53125) | 77 | 144 | SE (137°) | 3.4 | 1142.4 | 04/01/2019 02:24 |
| 23 | (-81.93552563707901, -26.015625) | 81 | 225 | SE (138°) | 3.6 | 1146 | 04/01/2019 03:00 |
| 24 | (-82.4256290002969, -22.67578125) | 7 | 232 | SE (144° | 0.3 | 1146.3 | 04/01/2019 03:18 |
| 25 | (-82.82050417754976, -20.390625) | 55 | 287 | SE (140°) | 2.4 | 1148.7 | 04/01/2019 05:42 |
| 26 | (-83.23642648170203, -17.402343749999996) | 61 | 348 | SE (149°) | 2.7 | 1151.4 | 04/01/2019 08: 24 |
| 27 | (-83.66725589385206, -15.029296875) | 57 | 405 | SE (138°) | 2.5 | 1153.9 | 04/01/2019 09:48 |
| 28 | (-83.97925949886205, -12.3046875) | 48 | 453 | SE (139°) | 2.1 | 1156 | 04/01/2019 11:54 |
| 29 | (-84.26717240431665, -9.7998046875) | 43 | 496 | SE (136°) | 1.9 | 1157.9 | 04/01/2019 13:48 |
| 30 | (-84.55805713644298, -6.85546875) | 46 | 542 | SE (145°) | 2.0 | 1159.9 | 04/01/2019 15:48 |
| 31 | (-84.84608112735175, -4.6142578125) | 40 | 582 | S (180°) | 1.8 | 1161.7 | 04/01/2019 17:36 |
| South Pole | (-90.00000000, 0.000000000) | 576 | 1158 | - | 26 | 1187.7 | 05/01/2019 19:36 |
| | **Total distance via land vehicle** | **1158** | | | total time on land = 51.43 hours | **total 49.5 days** | |
| | | | | | | | |
| | | | | | | **South Pole by** | **05/01/2019 19:36** |

## 2.9 *Lifting mechanism*

### Forklift

**Why we chose to use a forklift:**

- It is one of the smallest drivable piece of machinery, so it saves storing space on the ship.
- It has high load capacity so it is able to carry our 1-ton load easily and safely.
- Things can be moved up and down so that it is easy to transfer the load onto the platform of the land vehicle.

**Why we chose to use an internal combustion forklift:**

- Manual forklifts: they can only lift the load off the ground several inches and they have low capacity (whereas our load is heavy)
- Electric forklifts: they have higher initial cost and the loading capacity is not as high as internal combustion forklifts.
- Internal combustion forklifts:
    - They are ideal for outdoor use – we use it to transfer loads onto and off the ship, so it's mainly outdoor use.
    - They have a higher capacity compared to the other two types – useful in our case since we are transferring a huge and heavy load.
    - However, it requires regular engine maintenance, which our staff onboard are able to do.


**Trunk frame**: all of the key components of the forklift are attached to it

**Counterweight**: it is a cast iron weight attached to the rear of the forklift, so it counter balance the load.

**Internal combustion engine** in our forklift is fuelled by LPG (Liquefied petroleum gas) .

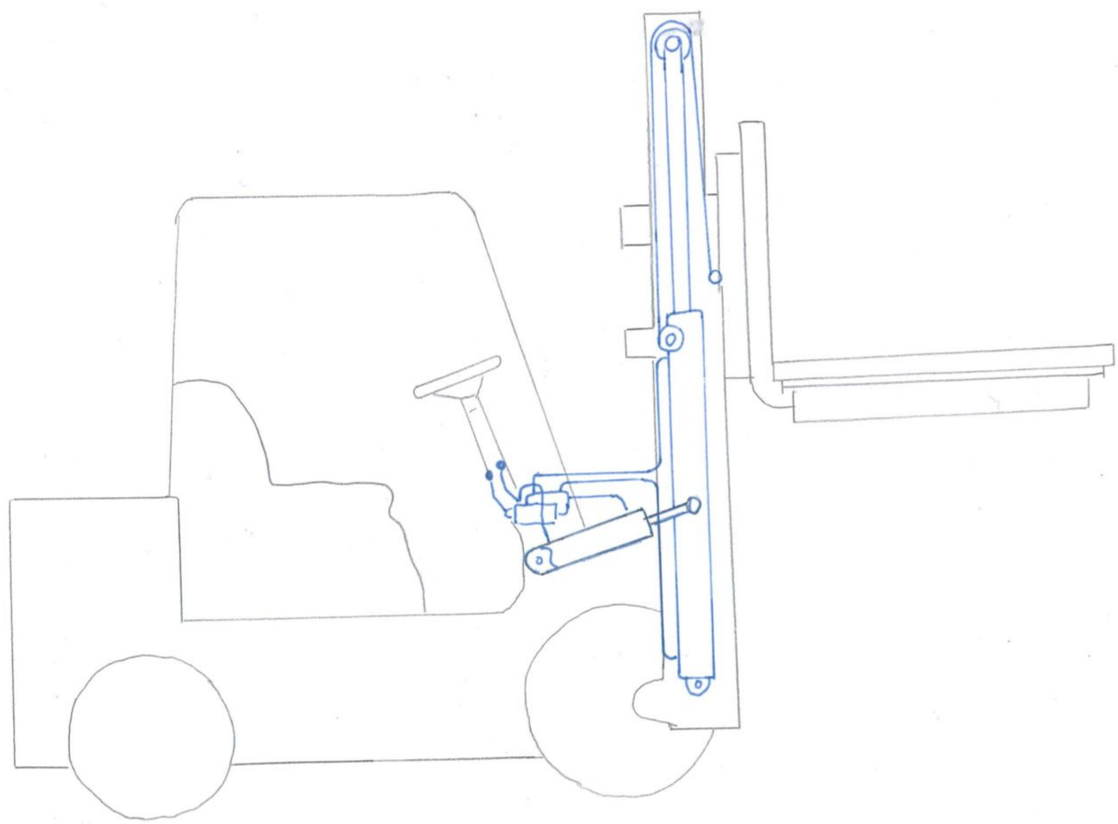
**Why we chose to use LPG**:

- Comparing to diesel and battery-electric forklift, it has a balance between low emission rates and load capacity – it releases less carbon monoxide comparing to diesel fuel, therefore reducing the environmental damage; the load capacity is generally not as high as diesel-fuelled forklift but higher than the battery-electric forklift.
- Maintenance costs are reduced because LPG does not contaminate the crankcase oil.

**How forklifts work?**

Forklift derive its power from two entwining mechanism, which are:

- A Pair Of Hydraulic Cylinders
- A Pair Of Roller Chain Pulleys



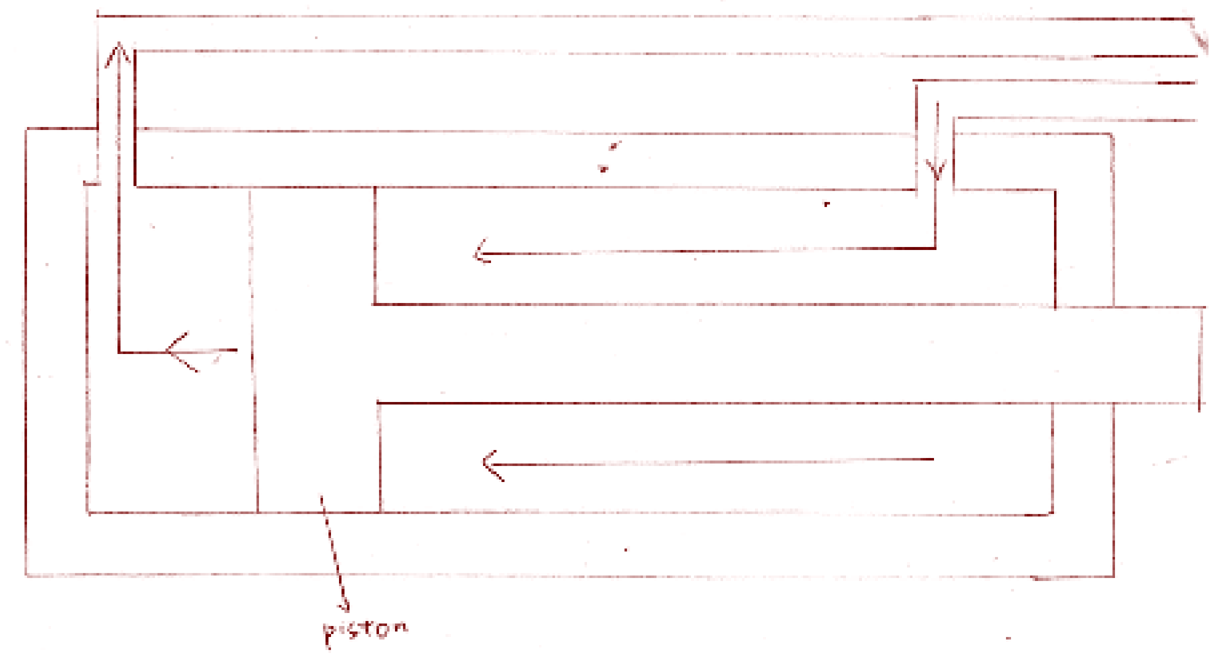
## Lifting mechanism

**Hydraulic cylinder**

When the lift handle is pressed, it draws in the outside air which is forced into the tube reaching to the hydraulic cylinders.

- The hydraulic pistons are attached to the two vertical masts

A hydraulic cylinder is made up of a tube closed at one end and a moving piston fitted into the other. As gas goes into the cylinder, the pressure increases and it generates an force to the piston's head. The force causes the piston to move up. The force from the gas at this point is equal to the weight of the load.




**Roller chain pulley**

The forks are attached to the main body through a pair of roller chain pulleys. As the hydraulic pistons pushes the masts up, the gear on the top of the masts goes up as well. Since one side of the chain is attached to an immobile structure, the chain on the other side pulls the fork up.

Importance of the chain pulley:
- allows forks to go beyond of the reach of the cylinders.
- If taller cylinders are built instead of using the chain pulleys, more building materials will be needed, so the centre of gravity of the forklift would shift forward, causing it more likely to tip.

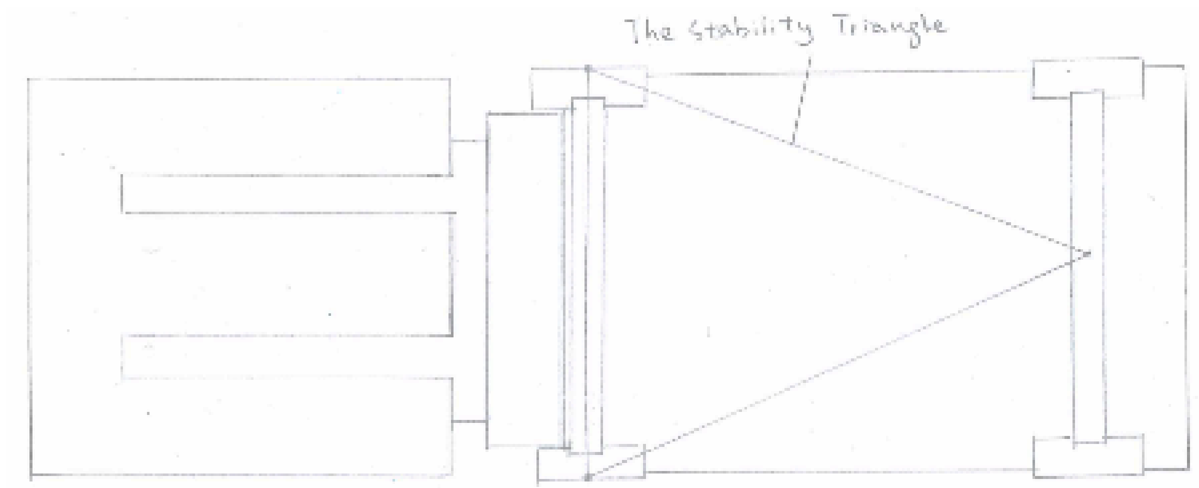
**Controls**

There are two levers in the lifting controls:
- Lifting the block up and down
    - o Handle is moved forward: moves up
    - o Handle is moved backwards: moves down
- Tilting the block back and forth
    - o At the base of the masts, there are two additional pairs of hydraulic tubes which are more horizontal.
    - o Handle is moved forward Þ air is pumped into the chamber Þ the increase in pressure pushes the piston head Þ the masts lean away from the main body

- o Handle is moved backwards Þ air is released Þ air is pumped into the other pair of hydraulic cylinders Þ the masts tilt back towards the main body

**The stability triangle**

The balance point between the centre of gravity of the forklift and the centre of gravity of the load has to stay inside the stability triangle. As you raise and lower the load, make quick turns or tilt the mast, the balance point inside the triangle shifts. The height, weight and the length of the load all contribute to balance point as well. If any of the factors exceeds its maximum, this balance point may move outside the triangle, causing the forklift to overturn.



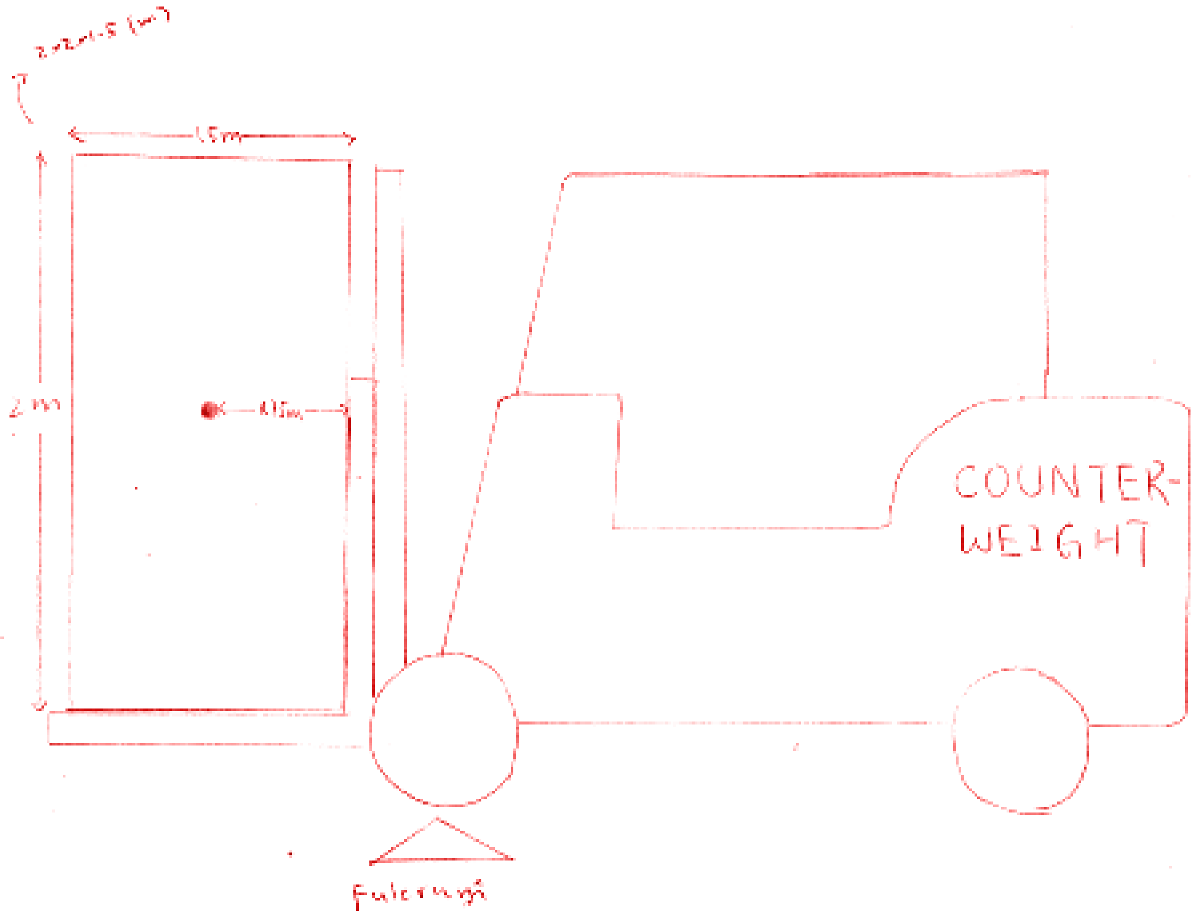

**Load centre and calculation**

Load centre: the distance from the vertical face of the fork to the centre of gravity of the load

As shown in the diagram, the load should be placed in a way that its centre of gravity is as close to the front wheels as possible, so it can minimize its load distance and reduce the load moment. The load moment can be calculated using:

$$\textit{load moment} = \textit{weight of the load} \times \textit{load distance}$$

E.g. a forklift with 1500kg capacity at 0.7m load distance means the load moment cannot exceeds 10300 newtons. However, if the capacity is reduced, the load distance can increase to make up the same amount of load moment.




$$0.75 \times 1000 \times 9.81 = 7357.5 \text{ Nm}$$

Hence, our forklift needs to handle turning moment of 7357.5 Nm.

## 2.10 Tracking system

### 2.10.1 GPS

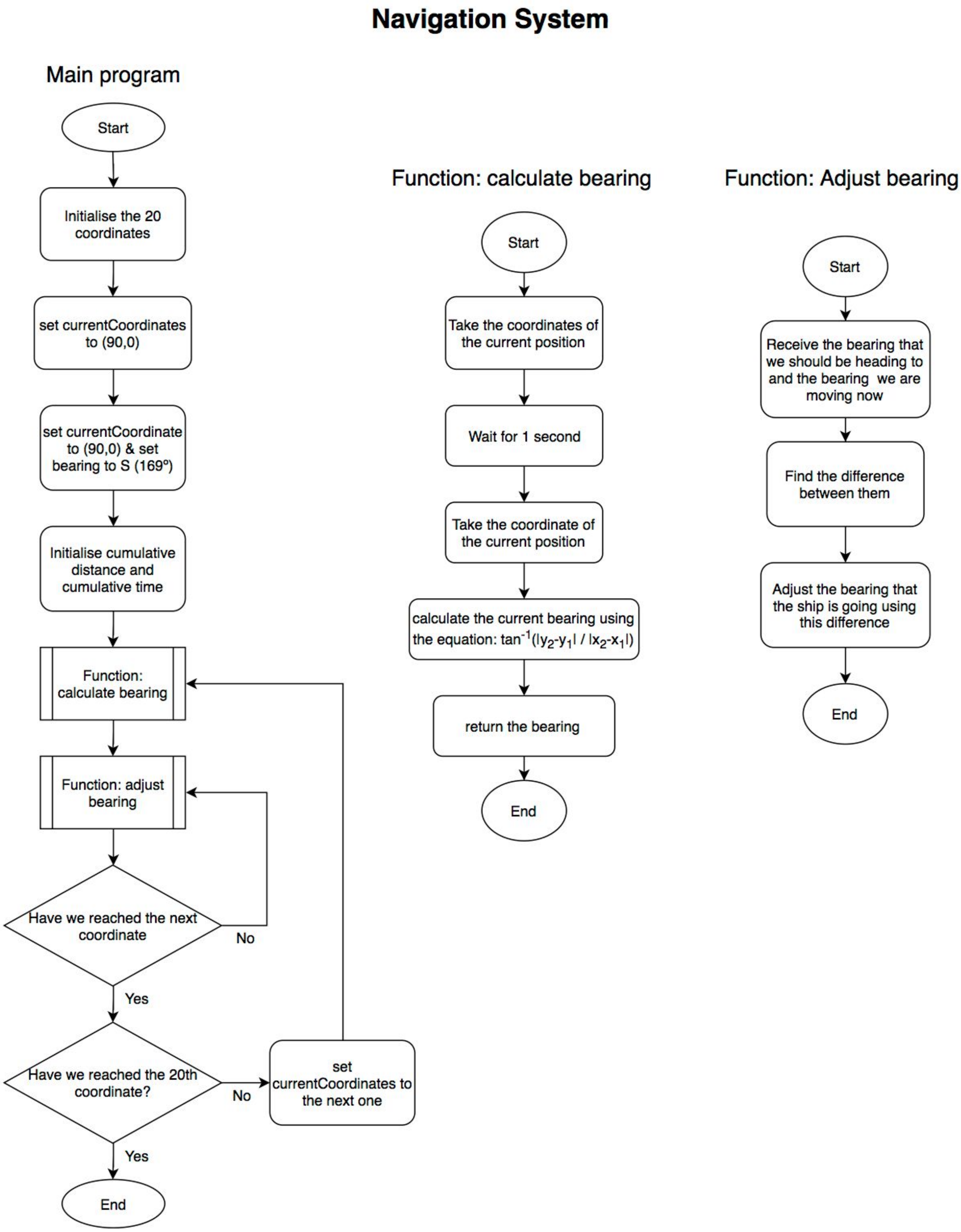
It is a network of satellites that allow for the most accurate positioning, even in the extreme weather conditions in Antarctica.

There are 24 satellites and each satellite circles the globe twice a day. For each satellite, the sphere that this satellite can detect, intersects the sphere of the Earth in a circular area.

With only one satellite, the receiver can only determine the area of the circle, not its exact location within this circle. With two or more satellites' signals, the area of the location is narrowed down, thus pinpoint the location.

The coordinates of the position will then be sent to the ship and this will be used in the algorithm

## 2.10.2 Navigation Software



## 2.10.2 Communication System

**Avoiding Collisions**

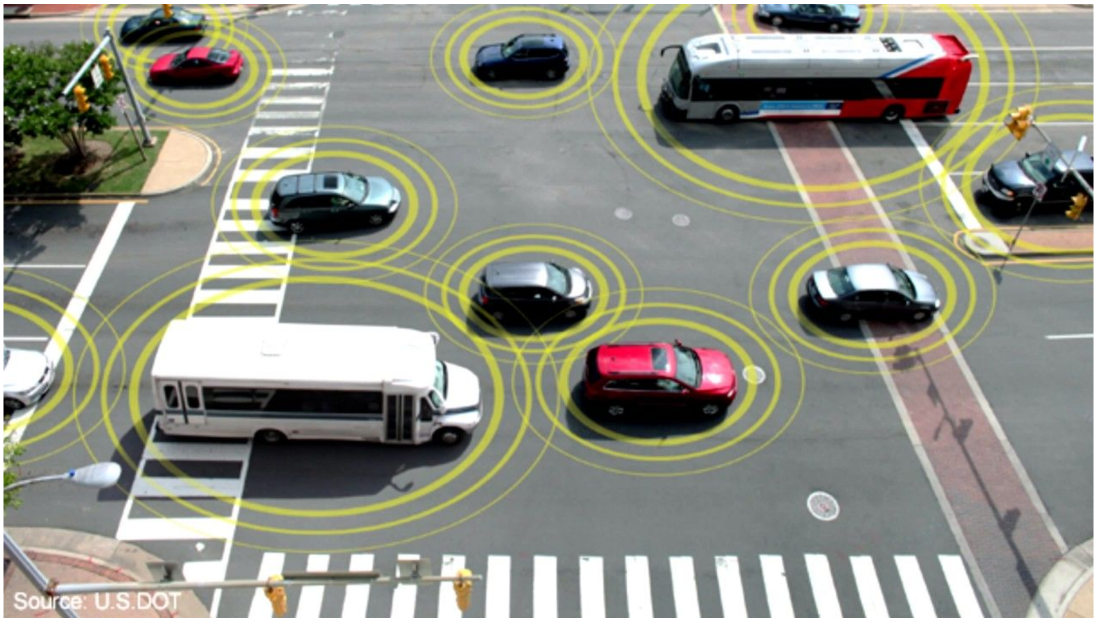
Whilst navigating the ocean for such a long time, we found it was of the highest importance that we did not collide with other ships. Accordingly, we found it was important to communicate with other ships whose routes may intersect with our own. This is especially important as our trip is irregular, therefore ships would not be expecting us.


Looking at the map above showcasing the world's shipping routes, it is clear that the area our vessel passes through is abundant with traffic. Thus we discussed several ways that our ship could communicate with other vessels long distance.

**Inter-ship Communications**

DSRC, stands for Dedicated Short-Range Communication, is currently being used in the development of autonomous vehicles (self-driving vehicles). DSRC enables communications between vehicles in a given range.

The two types of communication which the ship will required--Vehicle to Vehicle Communication (V2V) and Vehicle to Any Communication, V2X. The V2X will enable the ships to be able to communicate with any infrastructures nearby, such as safeguard towers, etc.




The DSRC works in a way in which a vehicle broadcasts its location, direction which it is travelling, its speed, etc. through radio waves to others. Once the nearby vehicles pick up the information, they will be able to are able to send messages including GPS location and warnings. Then, the computer system would be able to calculate its distance from the obstruction and notice the captain to steer away.

DSRC offers low latency, meaning that it will enable the ship to achieve near real-time decision after receiving warnings. This factor is very important as the DSRC only has a range of 1000 m. Therefore, in order for the ship to create a response on time before it crashes, the latency must be as low as possible.

**Why DSRC?**

DSRC is suitable for this expedition because it continues to have strong performance despite the terrible weather we could potentially be facing during the journey. Although many has debated that 5G, once it is applicable to commercial uses, would be the better alternative, but the strength of 5G connection will be interfered by the number of connections and the weather conditions.

Furthermore, 5G requires connection between vehicles and a server. Unfortunately, that will be impossible for the journey as we will not have access to any server while in the ocean. On the other hand, DSRC does not require any interaction with an infrastructure.

Also, the technology was developed specifically for V2V applications that require critical latency of ~100ms, very high reliability and security authentication with privacy safeguards. DSRC was established in 2009, meaning that the technology has been tested thoroughly for almost 10 years.

When working together with LiDAR sensor (Light Detection and Ranging), the system will be able to detect the obstructions nearby quickly enough to steer away from them. The LiDAR sensors fire pulses of infrared radiation to the surroundings. When the radiation bounced back off a surface back to the receiver, the computer system would be able to calculate the distance between the obstruction and the ship.

**<u>Marine VHF Radio</u>**

After many discussion among my teammates in addition to further research, we have decided to consider the Marine VHF radio system. This is because the DSRC only works when the vehicle you try to communicate with has DSRC. There is no confirmation that in ten years' time all of the ships would have DSRC. So, it might not be suitable to use it.

The VHF radio is simple, easy to use, and cheap. Its power can be adjusted to be able to receive signals at different distances. Also, most commercial vessels are equipped with VHF. So, in emergency situations, VHF would enable you to contact lock keeper, port control, coastguard and other vessels. In addition to being able to contact others



for help, you can also listen to information from other ships, such as where they will be going, the estimated time they will arrive at a location, etc. This will avoid multiples of ships stuck in a traffic waiting to pass the same passing point.

Conclusion:

We have decided that we will use the marine VHF radio instead of the DSRC because in order for DSRC to work, all the ships would have to be equipped with the system. And, marine VHF radio also offers many channels.

## 2.11 Project plan and Gantt chart

# GANTT CHART

| | | | |
|---|---|---|---|
| PROJECT TITLE | Pole 2 Pole solution | COMPANY NAME | Badminton School |
| PROJECT MANAGER | Aaliyah Adesida | DATE | 13/11/18 |

PHASE ONE · PHASE TWO · PHASE THREE · PHASE FOUR · PHASE FIVE

*Christmas Break. (as we live in different continents it will be difficult to collaborate during this time)*

| Task | TASK TITLE | TASK OWNER | START DATE | DUE DATE | DURATION | PCT OF TASK COMPLETE |
|---|---|---|---|---|---|---|
| **1** | **Phase 1** | | | | | |
| 1.1.1 | Write up our goals from the project | ALL | 19/11/18 | 25/11/18 | 6 | 100% |
| 1.1.2 | Create Google Docs and Gantt Chart | Aaliyah | 19/11/18 | 19/11/18 | 0 | 100% |
| 1.2 | Research Fuels | Aaliyah | 19/11/18 | 27/11/18 | 8 | 100% |
| 1.3 | Research cargo and staffing | Artie | 20/11/18 | 01/12/18 | 11 | 100% |
| 1.4 | Types of Vehicles | Havra | 20/11/18 | 22/11/18 | 2 | 100% |
| 1.5 | Look into routes and timings | Aditi | 20/11/18 | 25/11/18 | 5 | 23% |
| 1.6 | Navigation and communication | Cathy | 20/11/18 | 28/11/18 | 8 | 100% |
| 1.7 | Research and reach out to NASA and British Antartic Survey | Aaliyah | 03/12/18 | 05/12/18 | 2 | 100% |
| **2** | **Phase 2** | | | | | |
| 2.1 | Look into Sustainable food and write up. | Aaliyah | 01/12/18 | 07/12/18 | 4 | 100% |
| 2.2 | Finalise means of transport | ALL | 03/12/18 | 08/12/18 | 5 | 100% |
| 2.3 | Finalise Fuel Source | Aaliyah | 03/12/18 | | | 100% |
| 2.4 | Establish sea or land route requirements | Erin | 03/12/18 | 08/12/18 | 5 | 100% |
| 2.5 | Establish method of navigation | Cathy | 08/12/18 | 01/12/18 | 8 | 100% |
| 2.6.3 | Create FFBDs to direct used technology | Cathy | 09/12/18 | 09/12/18 | 0 | 100% |
| 2.9.1 | Finalise travel method | ALL | 12/12/18 | 12/12/18 | | 100% |
| 2.9.2 | Set Tasks to be done during Christmas Break | ALL | 12/12/18 | 12/12/18 | 0 | 100% |
| 2.8 | Comprehension and Analysis of Mechanics that contribues to the movement of the load | Cathy | 18/12/18 | 20/12/19 | 2 | 100% |
| **3** | **Phase 3** | | | | | |
| 3.1 | Review work done over Christmas | ALL | 14/01/19 | 14/01/19 | 0 | 100% |
| 3.2 | Discuss requirements for staff onboard | ALL | 14/01/19 | 14/01/19 | 0 | 100% |
| 3.2.1 | Look into possibile food sources | Aaliyah | 14/01/19 | 16/01/19 | 2 | 100% |
| 3.2.2 | Establish main food source | Artie | 14/01/19 | 17/01/19 | 3 | 100% |
| 3.3 | Establish source of drinking water | Artie | 17/01/19 | 20/01/19 | 3 | 100% |
| 3.3.1 | Establish requirements for power source | Aaliyah | 23/01/19 | 23/01/19 | 0 | 100% |
| **4** | **Phase 4** | | | | | |
| 4.1 | Confirm staffing and salary | Artie | 27/01/19 | 31/01/19 | 4 | 100% |
| 4.2 | Compare and confirm power source | Aaliyah | 27/01/19 | 02/02/19 | 6 | 100% |
| 4.3 | Establish in detail the land vehicle for the south pole | Havra | 27/01/19 | 29/01/19 | 2 | 100% |
| 4.3 | Research possible waste disposal methods | Cathy | 27/01/19 | 31/01/19 | 4 | 100% |
| 4.3 | Detailed design of genertpr | Aaliyah | 06/02/19 | 11/02/19 | 5 | 100%% |
| **5** | **Phase 5** | | | | | |
| 5.1 | Confirm waste disposal method | Cathy | 30/01/19 | | 0 | 100% |
| 5.2.1 | Confirm and establish land vehicle | Havra | 31/01/19 | 03/02/19 | 3 | 100% |
| 5.2.2 | Lessons learnt | ALL | 04/02/19 | 06/02/19 | 2 | 100% |
| 5.3 | Future development | ALL | 06/02/19 | 06/02/19 | 0 | 100% |
| | Progress Check-up | ALL | 06/02/19 | 06/02/19 | 0 | 100% |
| 5.5.1 | Compile, edit and proofread report | Aaliyah | 24/01/19 | 10/02/19 | 17 | 100% |
| **6** | **Submission** | | | | | |
| 6.1 | Send off report | Ms Wheeler | 21/02/19 | 2102/19 | 0 | 100% |

# 3 Solution and Evaluation

## 3.1 Solution Summary

## 3.2 Design Validation

### 3.2.1 Cost and Finances

| Items | Cost (£) |
|---|---|
| Food<br>(for 3 meals, 6 people, for 2 months) | 10,800 |
| Water Filter | 90 |
| Total salary | 51,000 |
| Fast Crew Supplier 4008 | 225,000 |
| Forklift | 8,800 |
| Diesel Fuel for Sno-Cat<br>(70 Gallons~320 Litres)<br>£1.29/litres | 412.80 |
| Sterling ASRG | 102,452 |
| Microturbines | 4400 |
| Waste Management | TBD |
| Sno-cat | 135,000 |
| Special clothing and equipment | 13,720 |
| Liquefied Petroleum Gas for forklift<br>(8 Gallons)<br>£1.83/gallon | 14.64 |
| Fuel for MTU and Caterpillar | 148.84 |
| Total Cost: | £551,921.44 |

Reducing Total Cost of Voyage

As we only plan on using the Sno-cat once, we thought it would be more cost-efficient to resell the sno cat after its use. The original price of the Sno-cat (similar model we have selected ) we would use is £135,000. This sno-cat was manufactured in 2016 , earlier models of the sno cat manufactured in 2012 have lower prices, averaging around £126,000. Assuming that the decline in price can be modelled exponentially we can approximate a resale price for the 2016

Tucker Sno Cat as such:

From the website, we know that none of their models sell for less than £76,000, therefore we set 76,000 as a constant minimum price

Given that in 2016, the price of the sno cat was 135,000 and in 2012 the average price of the snow cat was 126,000. We can create a simple linear model based on this.

$$Resale\ price = Old\ price \div ta$$

*Where t=time passed and a is a constant*

*Hence:*

$$126,000 \ = \ 135000/4a$$

Therefore a = $\frac{15}{56}$

We can check this value by comparing the value a model gives us to an the actual price of an old sno cat.

E.g The 2010 Tucker Terra compared with the most recent price we have, the 2016 Tucker Terra.

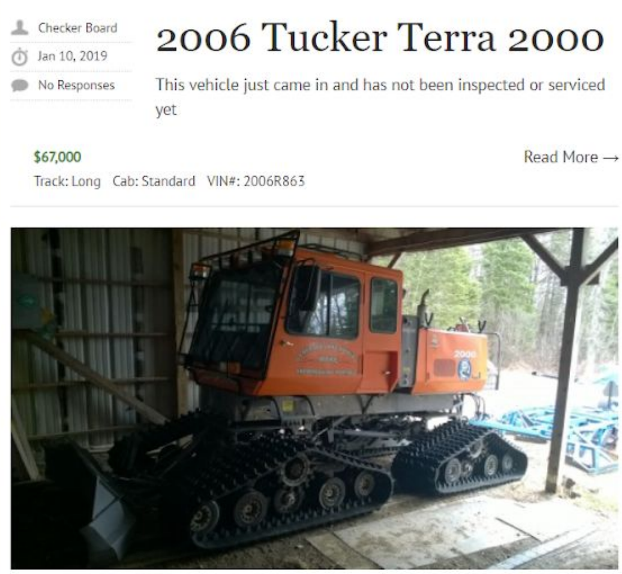

The 2008 Tucker Terra has a Price of £88,700.

When we use our model to estimate the price we get;

$$P \ = 135000/6(15/56)$$

$$P \ = £84,000$$

We can do this again to estimate the accuracy of our model using the 2006 Tucker Terra listed for a price of £51,700




Using our model:

$$P \ = 135000/10(15/56)$$

$$P \ = 50400$$

*With this information we can confirm that our model has an uncertainty of around -£5000* *(negative as the value calculated tends to be below the actual value). Keeping this uncertainty in mind we can calculate the maximum and minimum resale price for our sno cat within the next 10 years.*

*Assuming the voyage is undertaken in 2019:*

$135,000 = N/3(15/16)$

Therefore - $N = 108,000\ (3.s.f)$

*This means that if we resell the vehicle in 2019 we can resell it for a maximum of £113,000 and a minimum of £108,000.*

*Although this model cannot be used for differences in time that are more than or equal to 4.*

### 3.2.2 Energy Effectiveness

#### Environmental

Environmental wise, we believe as a team that we have made very little negative effect on the environment during our voyage, as our generator is nuclear powered, no greenhouse gases are emitted. The waste we produce has very low volume, due to the nature of the HMC and does not require much space for storage or for us to dump waste in the ocean.

Due to the nature of nuclear power, our power source has a low efficiency, but in other aspects the efficiency and streamline of the voyage is significant. We carry what we believe to be the minimum number of staff, whilst accounting for the possibility of illness or injury.

Our food carries the necessary nutrients, and we are using gastronomy that is trusted. Due to the specific nature of MREs we can account for food on a meal to meal basis. We designed this voyage pessimistically, accounting for the worst possible environmental factors.

#### Job Allocation

*Whilst conducting this project we were aware that there were only* four of us, even though we planned the completion of tasks in advance and had roles. These roles were flexible and it meant one task could be supervised by up to three people, simply because the fluidity of the roles meant that whomever was the most qualified to fulfill that element of the task would do so.

### 3.2.3 Durability

Even though this journey had specified that it was a one-way trip, we believe that it could be possible for us to make this trip multiple times, with the same plan.

### 3.2.4 Safety

On such a long voyage, we found it was vital to have planned in the case of an emergency;

Food

Even though the voyage will only take 50 days we model resources as if the voyage would take 60 days in order to give leeway to any mishaps or delays.  This allows a minimum of 10 days during which we could request assistance.

Radioisotope

We have accounted for possible issues caused by radiation exposure by cladding the radioisotope with a thin layer of iridium followed by a thick layer of lead. As well as the additional cladding-suitable material that it produced by the HMC.

In the event of damaged equipment

Illness

We have also accounted for the possibility of illness by having staff that are qualified to treat others on the ship, and have prepared by having more than one person to fill each major position.

Fire and Accident

In the case of the ship being unable to continue, the Ship is equipped with an abundance of lifeboats. In the case of fire, several fire extinguishers have been placed throughout the boat.

### 3.3 Future Development

We all very much enjoyed this project but even though the time limit made the challenge much more engaging, it stopped us from pursuing certain possibilities we would have liked to include in the project.

Firstly we would look at increasing the efficiency of our power source, radioisotope technology is cutting edge and we feel that it is an integral part of the future for sustainable long term energy. We would have liked to looked further into the engineering required to build a generator and why exactly the majority of generators have low efficiencies.

Throughout this challenge we developed a vested interest in software and remote tracking. If we had more time, we would look at creating an interface using software that would allow those in remote areas (remote meaning far from the ship) to access how much fuel we have used and how far the vessel has travelled. This central system would allow those maintaining and refuelling ships seamless access to useful information. This would be done using trauma vast networks of satellites around the world and could possibly be lifesaving in a situation where a vessel is under threat. Whether that be from damage to it's components, passengers or something more malicious.

We would more thoroughly research prices regarding the renting of the ship and hopefully seek out the lenders of the ship to access a more concrete price. Our ship contains many amenities, some of which we did not take into account when designing our own versions, therefore if we were to do this again we would consider more thoroughly how we would replace the systems on board the ships with our own systems that are more suitable for the voyage, and whether or not this is necessary in the first place.

These are but a few of the things that we would do in hopes of further developing the quality of the voyage in the future, but unfortunately we did not have time for.

## 3.4 Sources & References


- https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140011480.pdf
- https://www.thereadystore.com/mre-self-heating-emergency-meal-case-of-12
- https://www.nspe.org/resources/licensure/what-pe
- http://www.daviddarling.info/encyclopedia/R/AE_reaction_turbine.html
- http://www.wbdg.org/resources/microturbines
- https://hypertextbook.com/facts/2008/AndrewMorel.shtml
- https://www.searoutes.com/routing/
- http://www.sno-cat.com/performance.html
- https://www.turbinegenerator.org/steam/types-steam-turbines/reaction/
- http://www.wbdg.org/resources/microturbines
- https://products.damen.com/-/media/Products/Images/Clusters-groups/High-Speed-Crafts/Fast-Crew-Supplier/FCS-4008-Security/Downloads/Product_Sheet_Damen_FCS_4008_Security_08_2018.pdf
- 
- https://apps.dtic.mil/dtic/tr/fulltext/u2/729021.pdf
- 
- https://aister.com/en/maritime/superstructures/
- http://scaluminum.com/2017/06/the-cold-temperature-advantages-of-custom-aluminum-extrusion/
- https://www.yachtworld.co.uk/boats/2010/damen-sea-axe-2849700/?refSource=browse%20listing
- https://en.wikipedia.org/wiki/Davit
- https://en.wikipedia.org/wiki/Maritime_Vsat
- https://atomicinsights.com/rtg-heat-sources-two-proven-materials/
- https://www.uniroyal-tyres.com/car/tyre-guide/tyre-knowledge/difference-summer-and-winter-tyres


- https://products.damen.com/-/media/Products/Images/Clusters-groups/High-Speed-Crafts/Fast-Crew-Supplier/FCS-4008-Security/Downloads/Product_Sheet_Damen_FCS_4008_Security_08_2018.pdf
- https://apps.dtic.mil/dtic/tr/fulltext/u2/729021.pdf
- https://aister.com/en/maritime/superstructures/
- http://scaluminum.com/2017/06/the-cold-temperature-advantages-of-custom-aluminum-extrusion/
- https://www.yachtworld.co.uk/boats/2010/damen-sea-axe-2849700/?refSource=browse%20listing
- https://en.wikipedia.org/wiki/Davit
- https://en.wikipedia.org/wiki/Maritime_Vsat


- https://www.youtube.com/watch?v=MZ6GCH2nLy0
- https://sciencing.com/forklift-works-5398671.html

- https://www.proliftequipment.com/blog/forklift-hydraulic-systems/

## 3.5 Lessons Learnt

**Aaliyah Adesida** - We learnt a lot throughout this project individually and as a team. Before the challenge as a team our strengths and weaknesses were varied and now, after we have completed the challenge I'm sure we all still have our own individual talents and failings. But, I know for a fact that we all gained something from this project whether it was an improvement of an old skill or the acquiry of a new one.

Personally I found that I improved my skills of time management and learnt a lot regarding nuclear and mechanical engineering. I hope to develop these skills as I continue onward through the world of physics, up to and even after I reach my goal of becoming an engineer.

**Cathy Ding-**

This challenge enables me to apply and develop my skills and knowledge to a real-world problem. It gives me an insight into how the physics theories we learnt in school lessons can be used when studying the mechanical structure of the machines. Furthermore, working in a team to complete this big project has improved my communication and collaboration skills.

**Artie Techaposai -** This challenge enables me to develop many skills, especially teamwork. I have learnt to listen and work collaboratively as a team, accepting each other's opinions and expressing my thoughts. I have improved the ways I manage my time, completing the project as well as maintaining my academic performance.

In addition, I have learnt a lot about the lifestyles and the difficulties of living in both long voyages and extreme conditions. I am glad that I could use some of my knowledge from EPQ about autonomous vehicles on this project. I hope to continue to develop my skills in the future

**Havra Adamali -** Through this task I have learnt to resolve problems that I found and take criticism from the team members and improve the vehicle research.

I also learnt about the sorts of vehicles for transportation and how to tailor it to fit our requirements. I became more adaptable throughout this challenge and really learnt to listen to team member's feedback.