Pole to Pole: Yellow Submarine

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Overview

Basic Design

The very first decision we made as a group was whether we were going to travel via a primarily land or water route. We quickly decided upon travel in the water for as long as possible, as the diverse terrain is difficult to traverse as well as difficult to arrange politically as travel across borders presents lots of challenges. In addition to this a route exclusively on land would not be possible so it would have to be able to travel through the sea also. A sea route has much more consistent conditions, although there is still the issue of travelling across the ice to address. For the first part of the journey, the north pole, the terrain is quite difficult and we would have to make a vehicle that could both change from ice to water and water to ice. This presents many engineering challenge and at the point we considered starting beneath the ice to avoid travelling the first part of the journey on the ice. We emailed the organisers to confirm that it was allowed and it was. By no longer needing to start on the ice the tracks we would use when on the south pole could remain inside the submarine until a waterproof seal could be broken, at which point it would never have to go under water again. As well as bypassing many engineering challenges, by travelling beneath the surface of the water, were able to avoid some of the turbulence caused by the currents. Our general design is based on a traditional submarine whilst incorporating the track design on snow bashers in the form of a Boeing 747 landing gear for the ice based portion of the journey.

Requirements

- Have sufficient space and resources for 1 human to be self sufficient in for 1 year
- Enough food and water to survive
- An antenna for radio communication when near the surface
- An engine and a nuclear generator to power the engine and electrical devices

Route

- The route that we are taking is 20774 km long.
- 20774/365 = 56.92km this therefore is the distance we must travel per day to arrive at the South Pole on the final available day.
- 56.92/24 = 2.37 km/h
- There are larger waves in the pacific but the waves in the atlantic are steeper therefore more likely to cause problems. This is one of the reasons we have decided to travel in the pacific as it makes surfacing less risky.
- Another reason is that the best landing site and the one we will use is easiest to access via the pacific ocean.
- Pacific currents flow at around 0.03 - 0.06 m/s therefore we will lose approximately 0.216 km/h by travelling against them
- Therefore we must travel at a minimum of 2.59 km/h whilst against the current in order to arrive at the deadline.
- We will start under the arctic as due to constant changes in the layout of the ice, maps are unable to accurately stay up to date meaning we would have to rely heavily on the person manning the submarine which creates a greater scope for human error which we want to avoid.
- An additional advantage is that we don't need to stow our tracks as we will only be required to deploy them when we reach the antarctic
- Obviously land travel is unavoidable with the antarctic as it is a continent however as its terrain doesn’t change our maps are much more accurate. Also the terrain is generally flat with relatively small undulations which the tracks that we will use will be able to easily cover.
- The map that we have used to plan the route over the antarctic is the Reference Elevation Model of Antarctica. It was created by the Polar Geospatial Centre and the University of Minnesota and provides the most accurate elevation map of the arctic created. It was achieved by having 2 satellites directly measure the vertical distances between them and the ground over thousands of points.
- A plan of the route including distances between the points is below. (times can be calculated when the speed is known)

At North Pole
2952 km
Exit the arctic by travelling between Russia and US past the Diomede Islands
1241 km
Skirt St Lawrence Island on the US side then pass through the Andreanof Islands
2413 km
Pass Midway Atoll
3103 km
Pass Baker Island
1724 km
Pass Samoa

3517 km

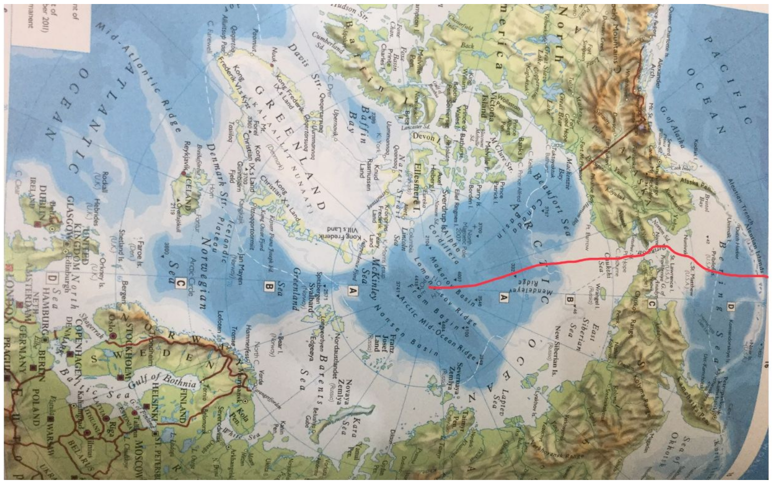
Pass outside of New Zealand near the Chatham Islands

4324 km

Join the antarctic near the Zucchelli station at 75.51912 ,165.22917 degrees and continue to south pole from there avoiding the Ross ice shelf.

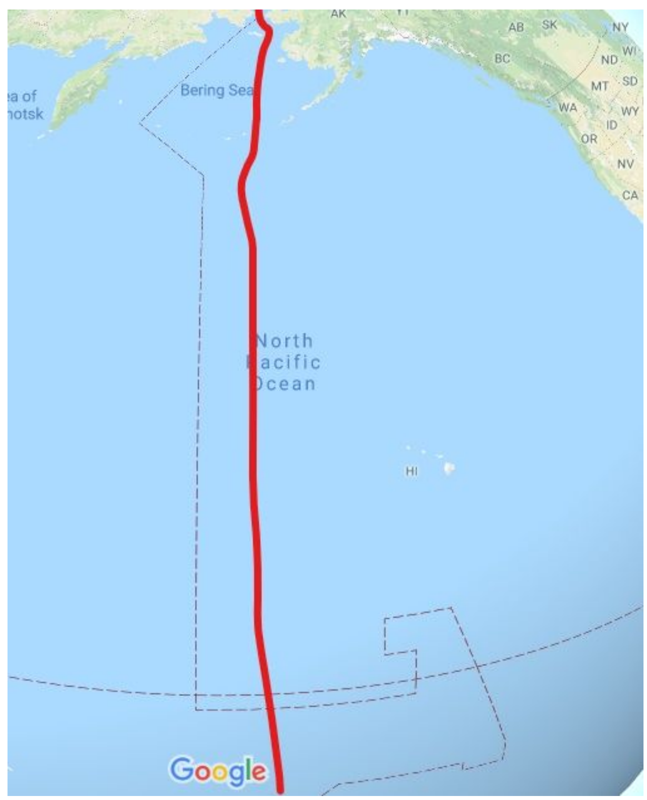
1500 km

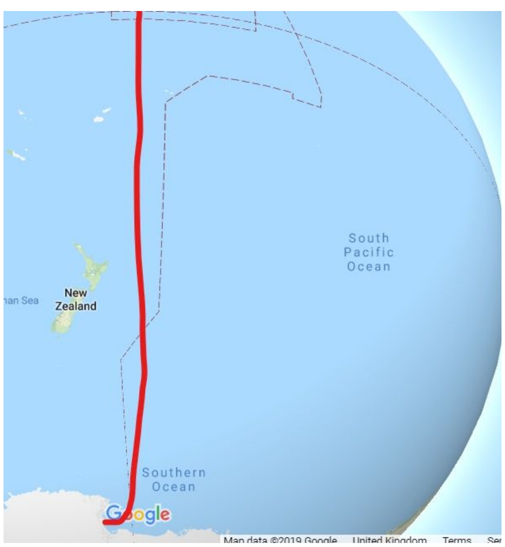
Reach the South Pole



This is a map of the first part of our route, passing out of the arctic circle and into the pacific ocean.

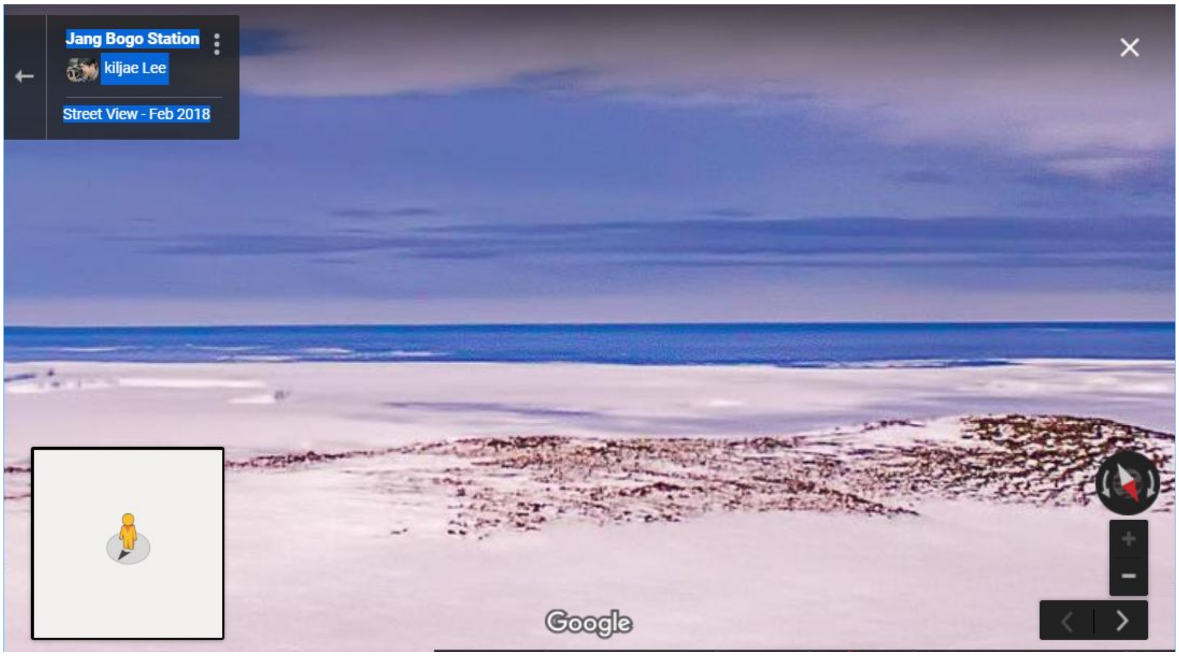
The map to the right shows the route across the North Pacific Ocean. As there are no obstacles we have chosen the most direct path possible.

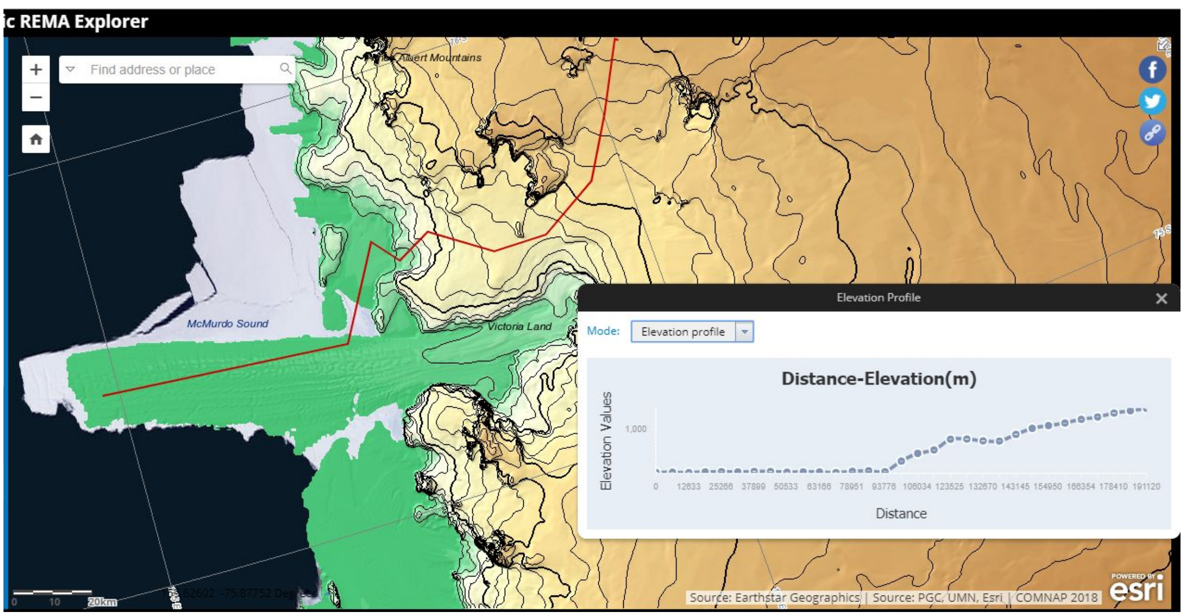




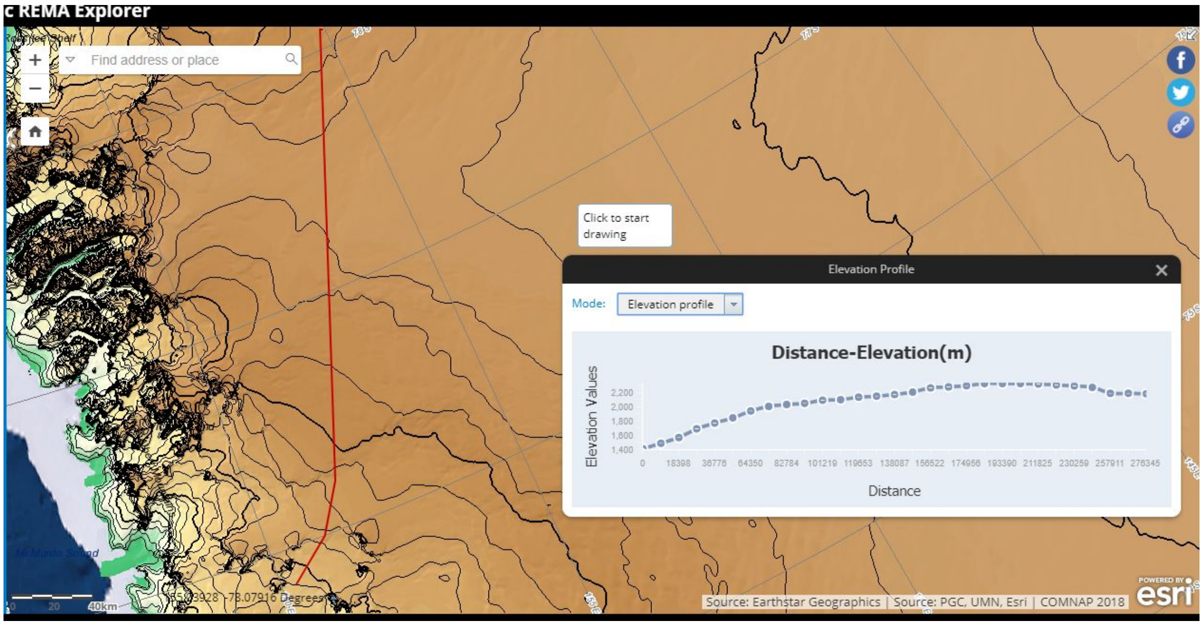
This map above then shows the route through the South Pacific Ocean until the submarine reaches the antarctic.

This is a photo of the terrain near our landing site. You can see that the sea meets the land is continuous way with no cliffs which will allow us to land.

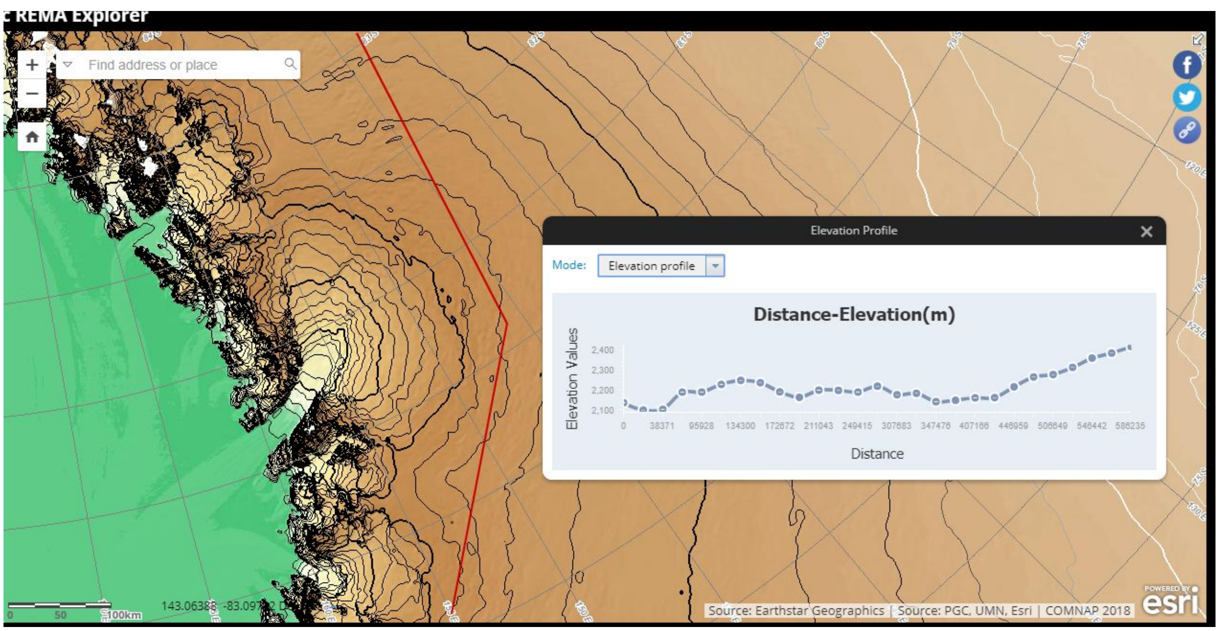




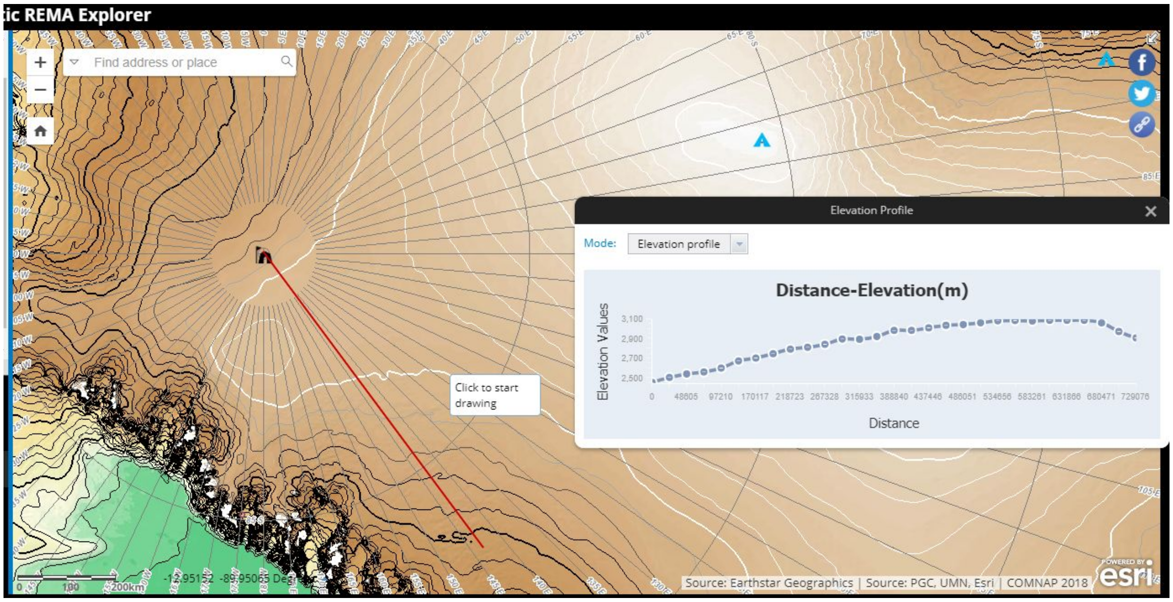
This is a photo of the first part of our journey across the antarctic including our landing site. There is a distance elevation graph included in the photo to show the gradient that we will have to climb. The slopes shown here have a shallower gradient, approximately 2 degrees, than the 5 degrees which we have accounted for which allows the vehicle to easily cope with the terrain. The black lines are contour lines at intervals of 100 meters. The shading is based on the elevation of the piece of land, with the darker the colour representing a higher altitude. The scale in the bottom right corner is for the whole bar 20 km.



Our route then continues parallel to the Ross ice shelf further inland with the elevation increasing but at a slower rate than before. The scale of the whole bar here is 40 km.



Whilst in this stage of the journey there appears to be a section of increased gradient early in the graph, this is in fact just a gain of 100 meters in approximately 30 km. The scale of 1 bar here is 100 km.



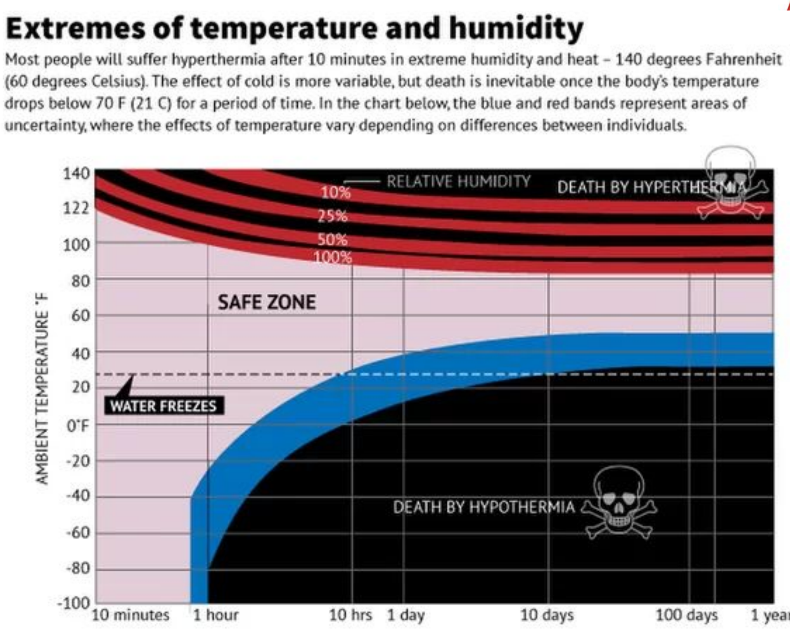
Having now skirted the Ross Ice Shelf we can continue directly to the South Pole as there are no major elevation changes to stop us. The scale of the bar has increased to 200 km.

Operations

We have decided that our submarine will be operated by an (average UK) woman, meaning that we our anticipating her to weigh 70.2kg, need 2,000 calories per day and be 161.6cm tall. This is because the average UK woman weighs less, is shorter, and requires less food than the average UK man, making it more efficient to design it for a woman. The only drawback is the extra sanitary requirements, however we would ensure that she would have an IUD for the duration of the trip.

Heating

Pairing this sleeping bag with a bivy bag like this would create a stable warm environment for a pilot:



S.O.L. Survive Outdoors have a range of exceptional bivy bags for keeping warm. Paired with a small but effective heater, like above, the person could stay warm indefinitely with a small amount of power required. The human can self-regulate the temperature to be an ideal one that doesn't create any unnecessary sweat.

However the use of a heater is not required because part of the method which we are using to produce air and oxygen (See page 34 and 35) gives off excess heat. We are regulating the production of the heat so that it is at 20 degrees for the duration of the journey.

Food

Freeze dried food is the most compact, and there are many readily available to purchase that have the required nutrients for our pilot to survive. The freeze dried option also means that the food is light, which compensates for the tins they are stored in.

Alternatively we could have used army style ration packs, which are already wet, meaning that they don't need rehydrating, and they can be eaten cold. However they are quite heavy due to the water already in the packs, and take up a lot more space than the compact freeze dried option.

We have created a table in order to compare the calories per gram in order to minimise weight on the submarine. Calories are averaged among the various different meals provided by each brand

Product name	Cost (for 3 meals) (£)	Mass (3 meals) (kg)	Calories (3 meals) (kcal)	Calories (kcal)/kg ratio
MX3 Pack of 5 Camping Meals	14.4	0.36	1500	4166
Just in case...® 5 Day Emergency Food Supply (website: Mountain House)	23.4	0.416	1850	4447.12
Fuel your Preparation (tins) (Website: EVAQ8)	11.39	0.28	1388.89	4960

We will use the third option, the brand "Fuel your Preparation" as it has the highest calories/gram, meaning that it would be the lightest, for the same amount of calories.

As the average woman requires roughly 2,000 calories per day, and we must account for 1 year, 2,000 x 365 = 730,000 calories.

This means that 29 sets of food would need to be purchased for the trip, as 730,000/25,600 (calories per box of food) = 28.52. it would cost 29 x 205 = £5,858.

Each set takes 0.49x0.33x0.19m, so 0.031m^3, meaning our total amount of food will take up 0.031 x 29 = 0.899m^3

These tins can be closed, as you can see on the image/website, so storing used tins should cause no health concerns, as the food contamination can be contained in the tin itself.

Drink

According to NAP.edu (National Academies Press), the minimal (obligatory) daily water loss for an adult is at least 1-3 LITRES, which includes losses by the urine, faeces, insensible perspiration and breathing (but not sweating). So, if you are sweating minimally, you would need to drink ideally 3 litres of water per day to keep yourself well hydrated. To act as a safety margin, we will add one extra litre to account for movement around the submarine and the exercise the Pilot will be doing to stay healthy.

To supply this water, we will be using a hand pump called the "Survivor 06 watermaker", recommended personally by the sailing outfitters Force4 Chandlery. They were very happy to help, and recommended us a small and effective hand pump that produces 0.89 litres per hour. It requires no electricity so can work even if there is an electrical failure.

See the email reply and suggested pump below.

FORCE 4 CHANDLERY
The Right Choice at the Right Price
EST. 1977

Dear Harry Baston-Hall,

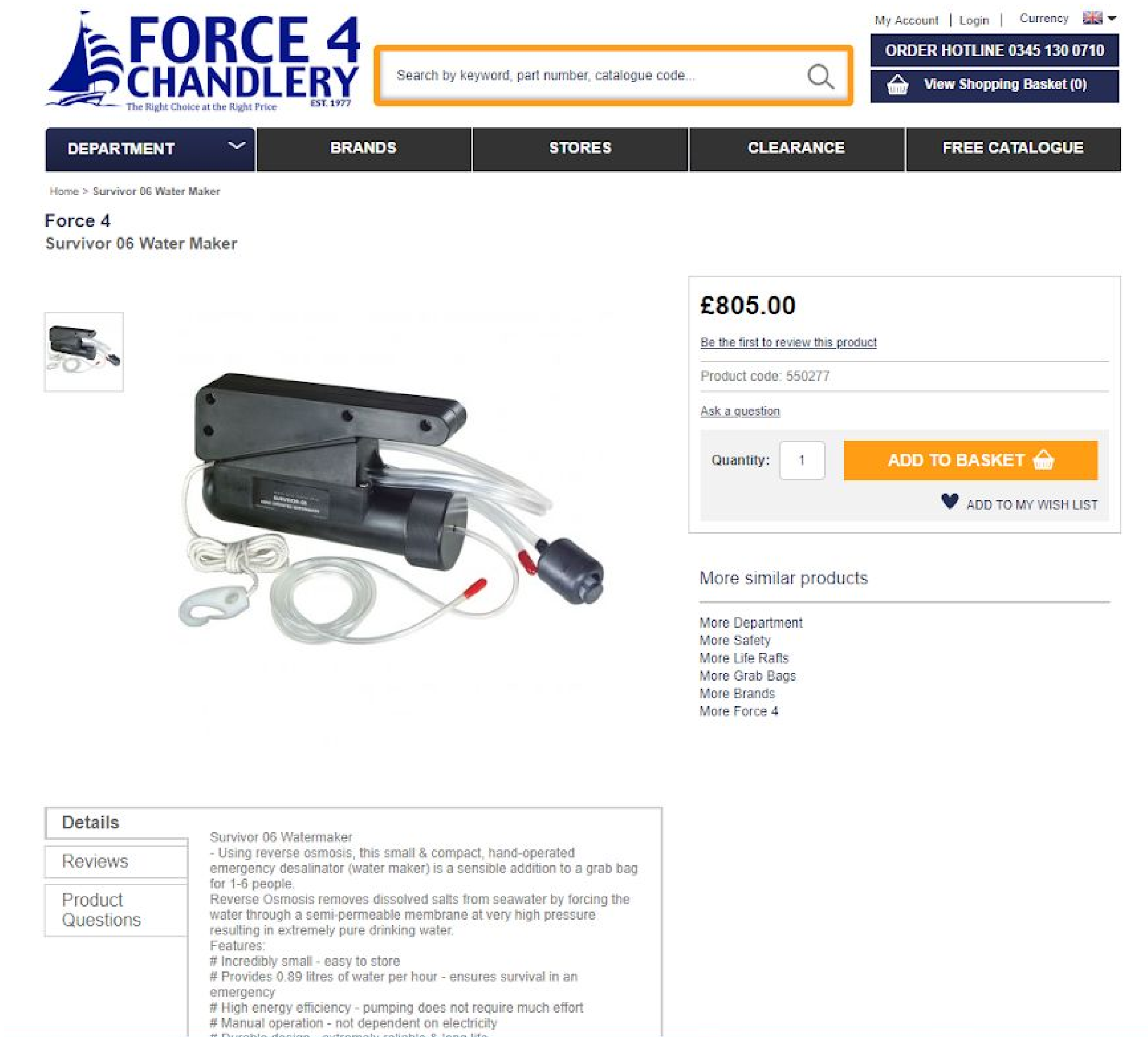
We answered your question

Question: Hi Force4!I am currently involved in an engineering research project that involves a submarine, and I'm currently trying to find the most efficient way to produce drinking water on board. Would you have any products that would theoretically help with that? (im trying to find a pump/water purifier that would work while the submarine is submerged)Any advice on the subject would be hugely appreciated, as this seems to be quite a niche topic of research :)Kind regards, Harry B-H

Answer: Good morning Harry,

The closest thing we would have would be the Survivor 06 watermaker, however this only produces just under 1 litre per hour so may not be large enough scale for you.

Related Product(s) https://www.force4.co.uk/



This also means that we don't have to waste more money and space on adding nutrients to the pure water from the fuel source to make it drinkable, as 100% pure water is rather toxic; it is the most hypotonic solution many studies have said that it strips away nutrients and electrolytes from your digestive system.

Hygiene

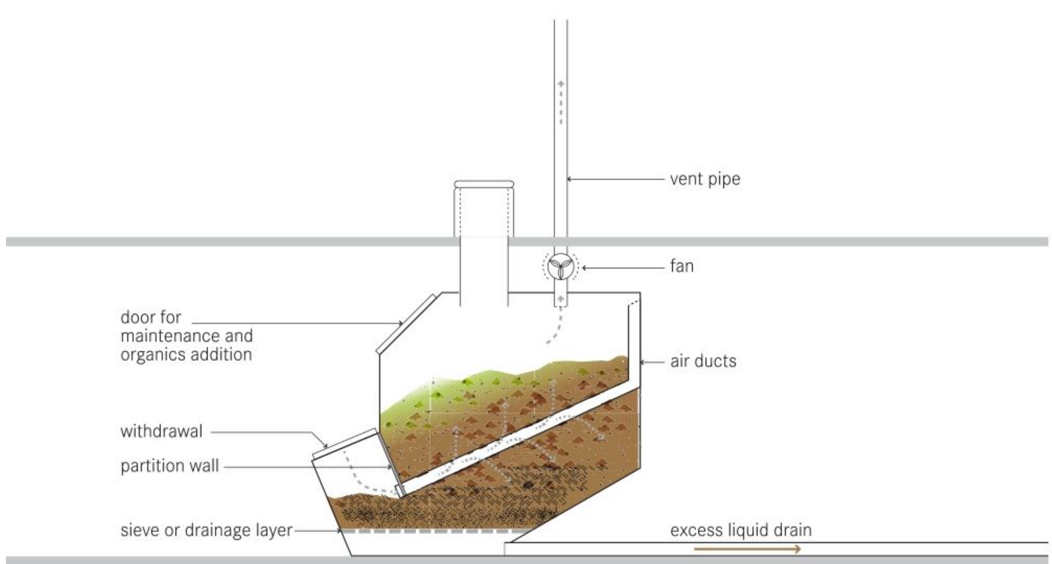
For showering, there are already showers available in most modern submarines that we could use, looking like the one on the right. Having researched recountings of people who have served in submarines, Such as the account by Andrew Karam, MM1/SS (LELT), author of Rig Ship for Ultra Quiet and a previous submariner, the pilot should shower for around 90 seconds, turning off water when not needed. They normally require fresh water stored (heavy and spacious) or a steam supplied vacuum evaporator, to make ready made fresh water. However, we can use the pure water from the hydrogen fuel cells to shower in, which provides 5130L of water in total, so 14.05L per day, and can be diverted from the outlet from the spent cells. Once the shower is finished, the water would drain through the floor into a storage tank for the used water, until released when the submarine surfaces.

For the toilets, we have to seperate what can and can't be released into the sea and then make sufficient storage for the waste that cannot.

The urine is relatively easy to deal with as a normal toilet can be used. It can also be released into the sea as human urine is around 95% water and the other 5% is various elements, include sodium and chlorine. As a result, the shower can be used for urine as it already has a system to remove water after it has been used.

Feces however cannot as, even if it is converted to natural gas and fertilizer using an anaerobic digester, the high levels of nitrogen would cause algae to grow significantly. As they require lots of oxygen, the water may become oxygen deprived and suffocate other marine creatures. As the algae blooms, they also release harmful toxins which can poison marine life. Composting toilets currently simply use gravity and airflow to separate the liquids from the solids. This works by having a pipe for air going in towards the bottom of the pile of feces beneath the toilet. There is the a pipe on the top of the chamber contains a fan in order to create and air flow through the feces, therefore causing them to dry.

There's then a sieve along the bottom for the excess liquids drain off.



The excess liquid would collect with the used shower water and urine and would be released every time the submarine surfaces. The air would constantly circulate to avoid waste, as the air in the submarine is limited so it is important to save where possible.

Calculations:

A human produce 1 ounce of feces for every 12 pounds of their body weight per day. Our pilot would weigh 70.2kg (using the UK national average), which is 154.8 pounds.

154.8/12 = 12.9 ounces of feces per day

12.9 x 365 = 4708.5 ounces per year

However, our feces is only around 25.4% solid, so that reduces significantly once dried:

4708.5 x 254/1000 = 1196.0 ounces = 33.9kg per year

In order to find the volume of the feces, we must use the speed, the diameter and the duration of the average feces, as well as the fact that the typical human excretes once a day.

The average length of feces can be calculated using d = v x t:

2 cm per second x 12 seconds = 24 cm

The diameter is 2 inches (5.1cm) and the equation for volume of a cylinder, V = B x h

24cm x π x (2.55cm)^2 = 490.3 cm^3 per day

490.3 cm^3 x 365 = 178951.1 cm^3 per year = 0.18m^3 per year

However, that is the density of the entire feces, and as the water will be drained off, the total volume of water should be calculated then subtracted from that value to find the storage volume needed for the dry feces.

4708.5 x 746/1000 = 3512.5 ounces = 99.6kg

99.6kg / 997 kg/m^3 (density of water) = 0.10 m^3 of water

0.18 m^3- 0.1m^3 = 0.08 m^3 of dried feces

Therefore, there must be 0.08 m^3 of storage beneath the toilet for the feces.

Fuel and Power

Due to the fact that we were using a submarine this limited some of our options for power as we could not use sources such as solar. However when looking at energy sources our criteria was that it had to be carbon neutral/negative in order to be as eco-friendly as possible.

The main sources that fit into all of these criteria were:

Hydrogen Fuel Cells
Batteries
Biofuel and Alcohol based fuels
Nuclear
Liquid nitrogen
Compressed air

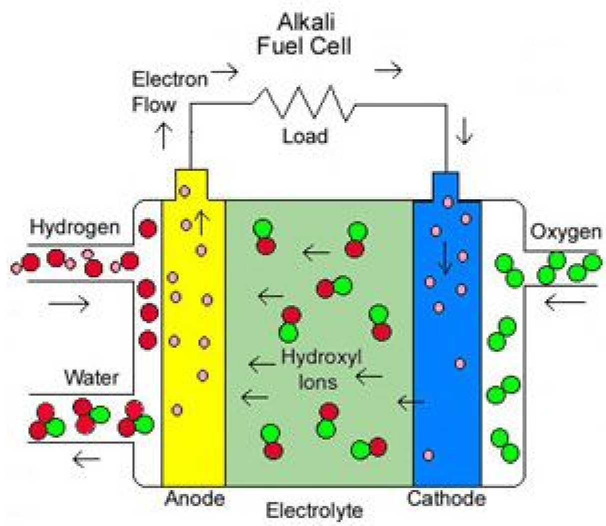
Fuel Cells:

Hydrogen Fuel Cells

These fuel cells are a relatively new technology, however is seen as the future of energy is the transportation industry by many including large corporations most notably Toyota, Although there are many different type of fuel cells Hydrogen Fuel Cells are the most promising one as they have have a high theoretical efficiency of 83% and hydrogen fuel as a source of energy is very energy dense with hydrogen containing as much as 33.3kWh/kg which is more than double that of petrol which comes in at 12 kWh/kg. This type of fuel cell has previously been used in space missions by NASA planned to be used to power vehicles in future Mars missions this is both due to their high energy density but that they also produce pure water as a byproduct. This is very helpful to use in order to provide the crew with enough clean water and is therefore why we decided to use them as our primary power source

How they Work:

In anode H atoms get turned into H^{+} ions and an electron. The H^{+} ions combine with the O^{2-} ions in the electrolyte to form water which is a non harmful byproduct. However the H^{+} ions must pass through a proton exchange membrane in order to reach the electrolyte. This membrane the PEM only allows protons(i.e H^{+} ions to pass through) the electrons are forced to go round a longer circuit in order to reach the cathode. This flow of electron around the circuit is what generates the electricity.



There are many different approaches people have taken in order to store hydrogen on board vehicles however the one we have chosen to use is the hydrolysis reaction of NaBH4, being a solid it has a very high density and therefore a high effective density of hydrogen, the reason we chose this specific one over other metal hydrides is that the conditions necessary for this reaction to occur are much less taxing, as other reactions are well over 100C and require constant pressure. However by using this reaction we avoid these issues at the cost of a slightly lower effective hydrogen density and that we can't Re-hydrise our material although that wouldn't be possible for us anyway.

For the storage of Oxygen we are using liquid oxygen tank known as Cryogenic Storage Dewars these are one of the more efficient ways to store oxygen and using 4x500L tanks we can store enough Oxygen for the entire journey

Batteries:

Lead Acid Battery:
Power output(30-40wh/kg)
Cheapest and most commonly used in electric vehicles and was previously used to power submarines although not the most effective.
These batteries impact the environment on manufacture
Importantly however the efficiency of the battery which on average is 70-75 percent lowers in cold temperatures by up to 40 percent which will be the case in the ocean therefore are not a good option

Nickel-hydride batteries:
Larger energy output that lead acid(30-80Wh/kg) however lower efficiency and much like lead acid perform badly in cold weather

Zebra Batteries:
Uses molten Chloroaluminate sodium(hot salt) high power output and must be heated for use so cold weather has little effect on its performance however due to the fact that it must be heated to high temperatures(270C) the cost of running the battery are quite high reducing the amount of energy which is effectively stored therefore isn't a good option for a submarine

Lithium Ion:
The most viable type of battery, a relatively new technology in the scene of vehicle power sources however it has a very high power output (200+wh/kg) and a high efficiency(80-90 percent) it needs some heating in order to work but not as much as the other batteries and can therefore be heated by the heat produced by the hydrogen fuel cells which have an operating temperature of 100C. This wont be our main source of power however is a useful source to have for powering the support systems of the submarine, and due to their recharability and excess power generated from the hydrogen fuel cells can be stored in the batteries for later use, it also provides the energy necessary to begin the reaction in the hydrogen fuel cells

Biofuel and alcohol based fuels:

Biofuels are currently being researched as an alternative source of fuel in aviation. There have been multiple tests using pure biofuel and a mix of biofuel and normal blends of jet fuel and results have shown almost no difference in the performance of the engines showing that it is a reasonable alternative fuel source for transport purposes, most biofuels are compatible with most petrol diesel and jet engines therefore not increasing the cost by needing to get a special engine. Some biofuel can suffer at very cold temperatures but this won't be a problem as the temperature which our submarine will encounter will not be cold enough

Nuclear:

Used in submarines due to the fact that it does not require Oxygen to produce power, this means that the submarine doesn't need to surface frequently in order to replenish oxygen needed for crew + power generating process.
Submarines using nuclear power also never need to be refueled even in their usual 25 year lifespan making it easily sufficient to supply enough energy for the journey

The downside with nuclear power is that it is very expensive so much so that some countries don't field nuclear submarines for that reason. Also depending on the size our our submarine a nuclear engine might be too large therefore it might not be the best of options as we are trying to minimise on our size, However it was an alternative to consider for if we had chosen to go for a larger scale submarine

Liquid nitrogen

By using a heat exchanger to cause heat to be extracted from the ambient air using liquid nitrogen as a coolant will result in forming a pressurised gas(the air) which can then be used to turn a motor to generate electricity or propel the submarine. This type of propulsion is often used in conjunction with batteries or fuel cells as these(the batteries and fuel cells) often have low battery lifes or provide an insufficient power output. If we decide to go nuclear this will not be necessary however using this in conjunction with hydrogen fuel cells is an option.

The problems with this source of power is that the costs of production of the liquid hydrogen are quite high, although the costs of maintenance are quite low but that is relevant for our relatively short time of use. There are multiple safety hazards involved in the use of liquid nitrogen as a source of power, as it has risks of increasing nitrogen levels in air which would cause the crew to suffer asphyxiation furthermore condensed oxygen can violently react with organic materials and the tanks of nitrogen if kept improperly can violently explode

Although the process of using liquid nitrogen to generate electricity or turn a motor does not produce any greenhouse gases the production of liquid nitrogen does making it surprising not anymore eco friendly that most other power sources

Compressed air:

Compressed air has been used to power vehicles in the past being used for braking in railway and also to power some vehicles. This works by use of an air motor which expands the pressurised air and uses it to generate mechanical work which can then be used to turn a motor or propeller. The advantages of this is that its very low cost (1/10 of fossil fuel prices)

However it is inefficient and storage is an issue. This will only work for very small subs where we can minimise weight to the extreme and make it as hydrodynamic as possible in order to require the minimal amount of energy but even then for this long of a journey there are better options

Solar Power:

How they work; they make use of n-type materials which have an abundance of electrons and therefore conduct well and p-type which are the opposite and conduct badly by forming layers of these materials. When photons hit the surface of the solar panel it

knocks off some of the electrons which are collected by conductive materials(usually metal plates) and this flow of electrons if converted into usable power
The most recent advances in solar technology show 2 main options

Light sensitive nanoparticles this is a new technology which is currently under development. They use new nanoparticles called quantum dots these replace previously use n-type materials which binds with oxygen in the air and turned them into p-type materials which are less conductive. The new n-type quantum dots do not bind with oxygen and are therefore more usable outside and result in the solar panels being more flexible. On top of this advancements have been made to improve efficiency using this technology,
They also have lower cost of production than other solar panels due to the fact that they don't require high temp vacuums to manufacture

Gallium arsenide
This is a slightly more mature technology but has only recently been attempted to be used in thin film solar panels which are the type of solar panels which we would most likely use due to their flexibility and lightweight design. Although these solar panels are definitely more expensive than other models they hold the world record for efficiency and are only becoming more efficient as the technology is explored.

However in the end we have decided to not use solar panels as the costs outweigh the benefits most due to the fact that we will not be surfacing too regularly as all of our oxygen for hydrogen fuel cells in stored on bored

Final Decision Specification

We decided to use hydrogen fuel cells for the journey as at the slow speed it makes it very energy efficient, also as it is a technology that is expected to have breakthrough in the coming years and although we are not relying on this it shows a lot of promise in the future of the technology which we hope to prove can be a viable option for journeys like these

On top of the Hydrogen fuel cells we have a stack of Lithium ion batteries, these are for powering the support systems of the submarine and due to their recharability and excess power generated by the hydrogen fuel cells can be stored in the batteries with losses as little as 2% of charge a month.

As for our motor we are using a ABB low voltage AC motor due to their high efficiency(95%) and reliability of the brand, with a power output of 100kw and a squirrel cage design.

Hydrogen Fuel Consumption(km/kg)(on	7.6

land)	
Power output(max)	100kw
Voltage	600V
Mass	1650kg
Dimensions(m)	1.65x1.25x1.5
Start up time(s)	90

Fuel Calculations:

For Ocean Part of the Journey:

Time taken: 315 day = 27216000s

Distance travelled= 19274000m

Speed = 0.714(accounting for currents flowing against us)

$Cd = 2fD/\rho v^2 A$

Initial Impluse:

KE= $1/2mv^2$
=17842.86

For Journey:
(this is assuming a Reynolds number of approximately 1.5x 10^7
And a reference area of our sub being 78.5 m^3

Resistive Drag(F) = $1/2 Cd\rho v^2 A$
= 112.05N

Work Done = Force x Distance
= 112.05 x 19274000
= 21597126215J
Total Energy required:

Initial impulse + continuous travel
=21597126215 + 17843
=2159730464J

Efficiency(motor + inverter
=0.99 x 0.95
=0.9405

Therefore Total Energy required
=2159730464/0.9405
=2296364130

Power Required:

=Energy transferred over time
=2296364130/27216000
=84.376Kw

Land Section

Using experimental results from the Railway Technical Research Institute

Fuel consumption= 7.6km/kg

For 1500km Land segment:

Amount of hydrogen necessary ~ 200kg

Total amount of Hydrogen required for journey

~ 300kg
Adding 50kg for redundancy and to power support systems of submarine power can be stored in lithium ion batteries when excess is generated

=350kg

Hydrolysis(chemical decomposition with water) of NaBH4
$NaBH_4 + 2\ H_2O \rightarrow NaBO_2 + 4\ H_2$

Moles = Mass/Molar Mass
Moles of NaBH4 in 1 Kg = 1000/37.832 = 26.433 moles
Moles of Hydrogen = 26.433x4 = 105.731
Mass of Hydrogen = 105.731 x 2.016
= 213.15g = 0.2131kg

Therefore: if 350 kg of Hydrogen is necessary
Amount of NaBH4 needed:
350/0.2131 - 1632.42kg

Density of NaBH4 = 1.07g/cm3
= 1070kg/m3

Therefore 1.535m3 required,

Hydrogen produced from reaction can be pumped to the PEM fuel cells using a system similar to that of a Direct Borohydride Fuel cell which is currently being researched as an alternative to Hydrogen Fuel cells as they do not require as much O2 however the downside is that their power output is considerably lower and the technology is much less mature than that of PEM fuel cells

Oxygen requirements:

$2\,H2 + O2 \text{ --> } 2\,H2O$

Moles of Hydrogen:
= mass/molar mass
= 350000/2
=175000

Moles of O2
= 175000/2
=87500
Mass of O2
=moles x Molar mass
= 2800000g
=2800kg

Navigational Systems

Reasons for needing RADAR/Sonar

- Safety
    - Avoidance of other sea craft
    - Avoidance of land obstacles
- Navigation
    - If bad conditions or no visibility
    - Works together with other navigation systems such as GPS, marine radio, sonar, and emergency locators
    - Bearings are changed based on land / ice information

Radar works by emitting microwaves from a rotating antenna horizontally over the water surrounding the craft. If waves are bounced back, they are received and the position of any obstacles is shown on the radar interface or integrated into the GPS.

Radar

Radar does not travel far enough underwater to be very useful, so sonar will be used mainly instead for this section of the journey however it will be useful when the submarine surfaces and when we are travelling over land.

For a radar unit we will use the Raymarine Quantum 2 Q24D. it has a 24 mile range. Its dimensions are 541 mm width x 209.5 mm high so relatively small. It is waterproof and can withstand -10 C temperatures.

Sonar

It works with the same principles as RADAR, but using sound waves, and works much better underwater. It can be passive or active and our sonar system will have both options.

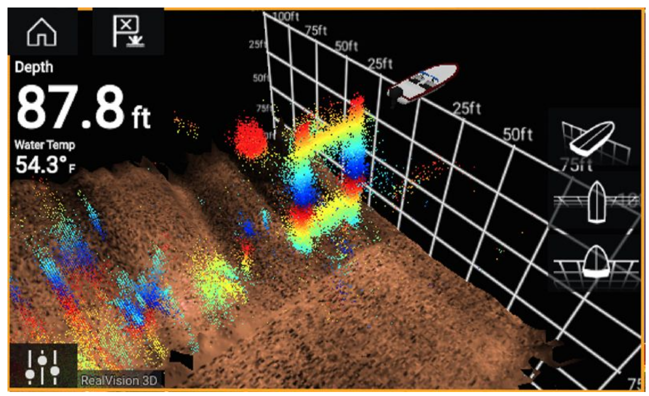
The sonar that we will use is the RVX 1000. It has:

- CHIRP sonar - This stands for Compressed High Intensity Radar Pulse. Whilst traditional 2D digital sonar sends out continual pulses, 200 kHz in shallow water and 50 kHz in deep water, it sends out a single pulse a 160 kHz then at 161kHz continuing to 200 kHz when it repeats the process. This creates a much more detailed and precise image of the surrounding area or object than digital sonar, though the radar is equipped with that as well.

- DownVision, SideVision. These provide a sonar created picture below, to the side and the rear of the boat. This means we will be aware if there is a risk of the submarine grounding as well as allowing the pilot to be aware to obstacles around them. This is obviously in addition to sonar providing pictures to the front of the sub.
- RealVision 3D. This incorporates all of the different views of the sonar into one model which can be panned, tilted and zoomed making it even easier to see every angle around the submarine and thus detect obstacles the size of a fish with clarity.

GPS

We will require a GPS unit for the submarine to navigate effectively on land and when on the surface of the ocean. We will use GA 150 antenna.



Interface

All of these units will be managed from 1 device. This is the Axiom XL 16". Its dimensions are 395 x 78 x 249 mm and weighs 5.9 kg. It can withstand -25 C temperatures and is fully waterproof. Its display resolution is 1920 x 1080 FDH and has 24 bit colour resolution. Being able to manage all of these navigation systems from one device will make it easier for our pilot to make swift informed decisions.

Conclusion:

We will have a basic radar system for when under the ice and when approaching the water exit point, but we will use sonar for when travelling through the sea. Owing to the simplicity of our route when at sea we will navigate as follows. Obtain an initial bearing when we begin using a compass then when we surface along the route we will use the GPS to obtain our current location which will allow us to take another compass bearing so that we continue on the correct path. When we exit the sea we will be able to constantly check our position via GPS and thus navigate accordingly.

General design

Materials

Although not many merchant submarines have been created, as they are typically only used for smuggling illegal goods, recreation and war, there are a few notable exceptions. However, these were mostly used to transport several hundred tons of goods while we only need to transport one ton that takes up 2m x 2m x 1.5m. This means we will essentially have to start from scratch.

The two most essential parts of a submarine is the outer hull and the pressure hull. The outer hull would be made out of aluminium honeycomb. This is because, first and foremost, the outer shell is designed to be waterproof, which aluminium honeycomb is. Although aluminium does not rust, it is prone to corrosion, so it would have to be coated, have a sacrificial anode or a different method to prevent corrosion. The aluminium honeycomb is often used in heating and air conditioning due to the fact it is excellent at changing turbulent flow into laminar flow. This is very helpful for us as, along with it's very low weight, reduces drag, meaning less energy has to be produced and therefore less environmental effect. The pressure hull (inner hull) is intended to allow the pilot to breath as well as not being crushed by the water pressure. For this reason, we initially wanted to use a nanocrystalline alloy, developed by North Carolina State University and Qatar University, combining lithium, magnesium, titanium, aluminium and scandium to create an alloy with a comparable density to aluminium but also stronger than many other titanium alloys. After contacting the developer of this compound regarding an estimate for the price of it, he explained that the scandium is far too expensive to be commercially viable and he had sought after funding do continue developing it, however he had had no success.

Dear Professor Koch,

I am currently involved in a (theoretical) engineering challenge in which we have to transport a one tonne mass from the north pole to the south pole and we are looking into designing a submarine. We came across a fascinating article from 2014 on the alloy you developed at North Carolina State University. We were looking into using it for the inner shell of the submarine because of it's high strength to weight ratio, meaning that we can significantly reduce the weight and therefore the power needed to travel. We were wondering if you would be able to give us a (very) rough estimate for the price per metres cubed as we need to include such information in our final document.

Many thanks and regards from the UK,

Jake de Jongh

Carl Koch <cckoch@ncsu.edu> 31 Jan 2019, 15:29
to me

Dear Dr. de Jongh,
The low density high entropy alloy (AlMgLiScTi) I assume you are referring to is not commercially available. I have tried, and am still trying to get funding to study it in more detail. Unfortunately it contains Sc which is very expensive and would make the alloy not commercially viable. We will try to substitute for Sc if we get the funding to pursue this. Your company is called Abingdon School. We stayed in Abingdon many years ago when I was at Harwell Lab. on exchange from Oak Ridge National Lab where I was then working.
Best regards,
Carl Koch

Instead, we settled upon using titanium for the pressure hull due to its excellent strength to weight ratio, as well as the fact that it is commonly used for the inner hull of submarines. Steel is also commonly used, however its strength to weight ratio is inferior.

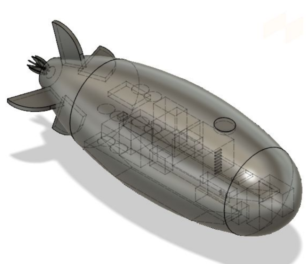
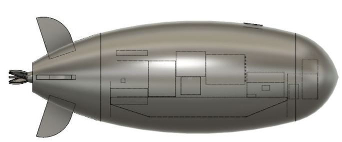
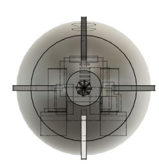
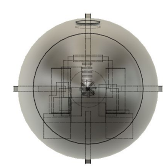
Once these two key parts are created in an aerodynamic and lightweight shape, the interior then can be filled with sufficient accommodation and resources for the pilot, as well as the nuclear generator, the engine and an area to operate the submarine. The radio can be connected to an ariel on the top of the submarine that extends when near the surface of the water.

Size/Surface Area:

The vessel is 16.9m long, 6m at its widest point while in submarine mode and 6.7m tall with the tracks extended. The surface area of the outer shell titanium is 236.847m2.

Shape:

Aerodynamic or hydrodynamic performance of basic geometric shapes are known.
aerodynamic and hydrodynamic testing shapes like the sphere, cone, cylinder, cube, ellipsoid, rectangular plate, etc. .. have provided tables and calculation formulas linking their dimensions to their Cd (drag coefficient for predicting the resistance force of the form immersed in a fluid stream).
The traditional design has very little room for improvement the only thing that we can see as being a way to cut down on water resistance is that of taking the top mast section out of the design effectively making it a bullet with a propeller.

Breathable Air:

Typically oxygen is supplied in pressurised tanks, the electrolysis of water or from a form of oxygen canister creating a hot chemical reaction much like the ones that caused issues on the MIR space station. As the trip is much longer than any stored form of oxygen can sustain we must use the electrolysis of the ocean water to form H2 and O2 after being purified and then vented into the submarine's air circulation system (the hydrogen can't be used for fuel with our current technology so is just expelled out the rear of the submarine for extra thrust). CO2 also has to be removed and the most used and developed form of doing so is venting it after collecting it with a CO2 scrubber. They work by reacting the CO2 with soda lime (a mixture of chemicals including calcium hydroxide, sodium hydroxide and potassium hydroxide) or amines (a derivative of ammonia).

We will use a combination of compressed air canisters and releasing oxygen from sodium chlorate.

Amount of air required per day = 11000 litres

Amount of air required per hour = 458.3 litres

Assuming an oxygen content of 20%

Amount of oxygen required per day = 2200 litres

Amount of oxygen required per hour = 91.6 litres

This is the equation for the decomposition of the Sodium Chlorate.

$2\ NaClO_3 \rightarrow 2\ NaCl + 3\ O_2$

This produces heat which we will control to be 20 degrees and we will use this heat to warm the living quarters.

A that heat it will release 29.8 litres of oxygen per hour and to sustain this production we will require 43.6kg of the compound.

458.3 - 29.8 = 428.5 litres of air

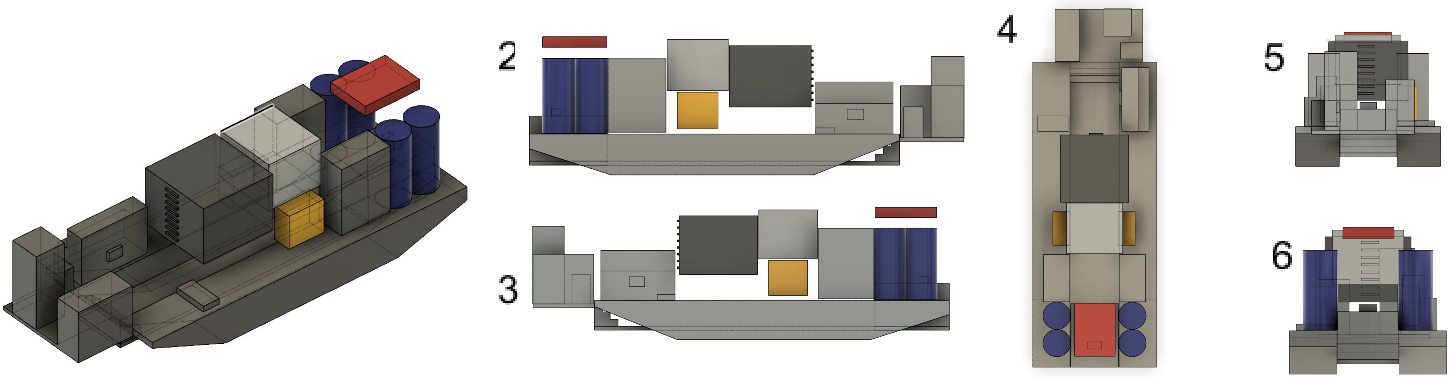
The compressed air cylinders which we are using contain 7020 litres of air each

7020/428.5 = 16.4 hours of air from each tank.

(41 days * 24)/16.4 = 60.0 this is the number of tanks required for 41 days of air which is the longest amount of time which we will be required to spend underwater.

When we this supply of air is running low the submarine will surface on the hatch will open to allow the surrounding air to be compressed by an air compressor which for ease of use will be attached directly to the canisters meaning it just has to be turned on and supplied with the uncompressed air from the atmosphere.

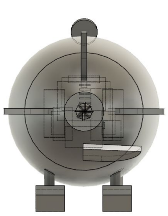
Layout:

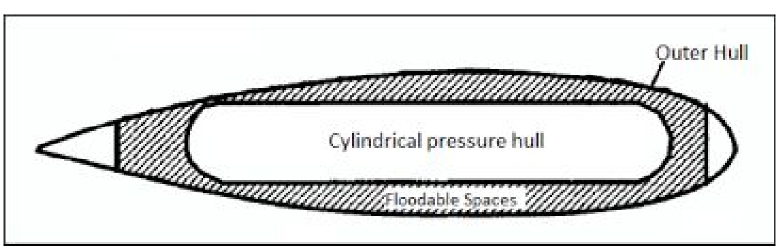


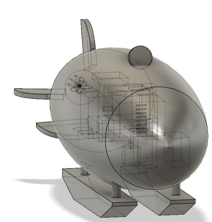
In the very front section of the submarine (top of figure 4) lies the pilot's sanitary systems, bed, control systems, self powered treadmill for fitness, oxygen generator, carbon dioxide scrubber and water dispenser from the hydrogen fuel cell. Behind this living space is the 1 ton block above the gangway with a ladder attached to block the noise from the engine and act as an exit. Behind that are two stores of food, one on each wall, and the lithium ion battery attached to the ceiling to allow the gangway to pass underneath. Further behind that are two stores of NaBH4 on either wall in separated compartments so if one is damaged the other is still usable and behind that are the four oxygen tanks on the walls for the hydrogen fuel cell which is attached to the ceiling with the engine underneath so everything is accessible.

Landing Gear Design Overview:

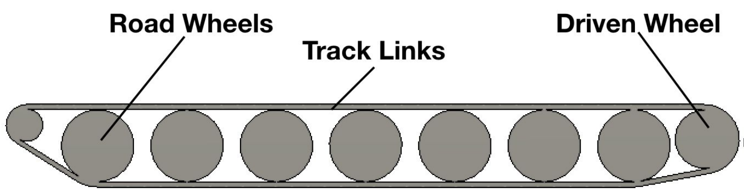
- Using continuous tracks
    - Craft will be heavy, so will spread out weight, good for travelling, but also in thin ice situations
    - Has very good off-road potential, which is important due to rough terrain in antarctica
    - Hard - wearing (cannot tear or puncture)
    - Simple to maintain and fix
    - Easier to store during sea part of journey
    - Very good maneuverability
    - Good ride (will not damage cargo or passengers)
    - Can handle heavy loads well
- Will only have one long track per side, as this will make mechanics simpler, turning easier and will mean that we only require two storage bays.
- Water-tight seal will be formed from solidified silicon around the edges of hatches that give access. When the hatches are opened the seal will be permanently broken, which is not an issue for us as landing gear will never have to be retracted since we are starting underwater.
- Bottom surface of craft will have to be strengthened to avoid damage from raised terrain that fits between the tracks.
    - Suspension / chassis will connect through inner skin to tracks
    - Compartments will take up ‘floodable spaces’ (see diagram) at the bottom, so will not affect structure or useability of the interior of the craft too much.





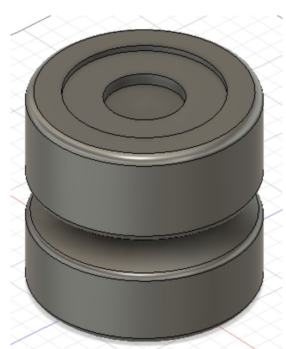


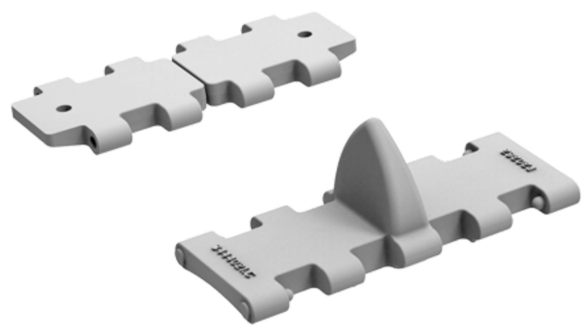
The Tracks:



Track dimensions: 8000 mm long, 1000 mm high, 1100 mm wide. Links are 150 mm thick.

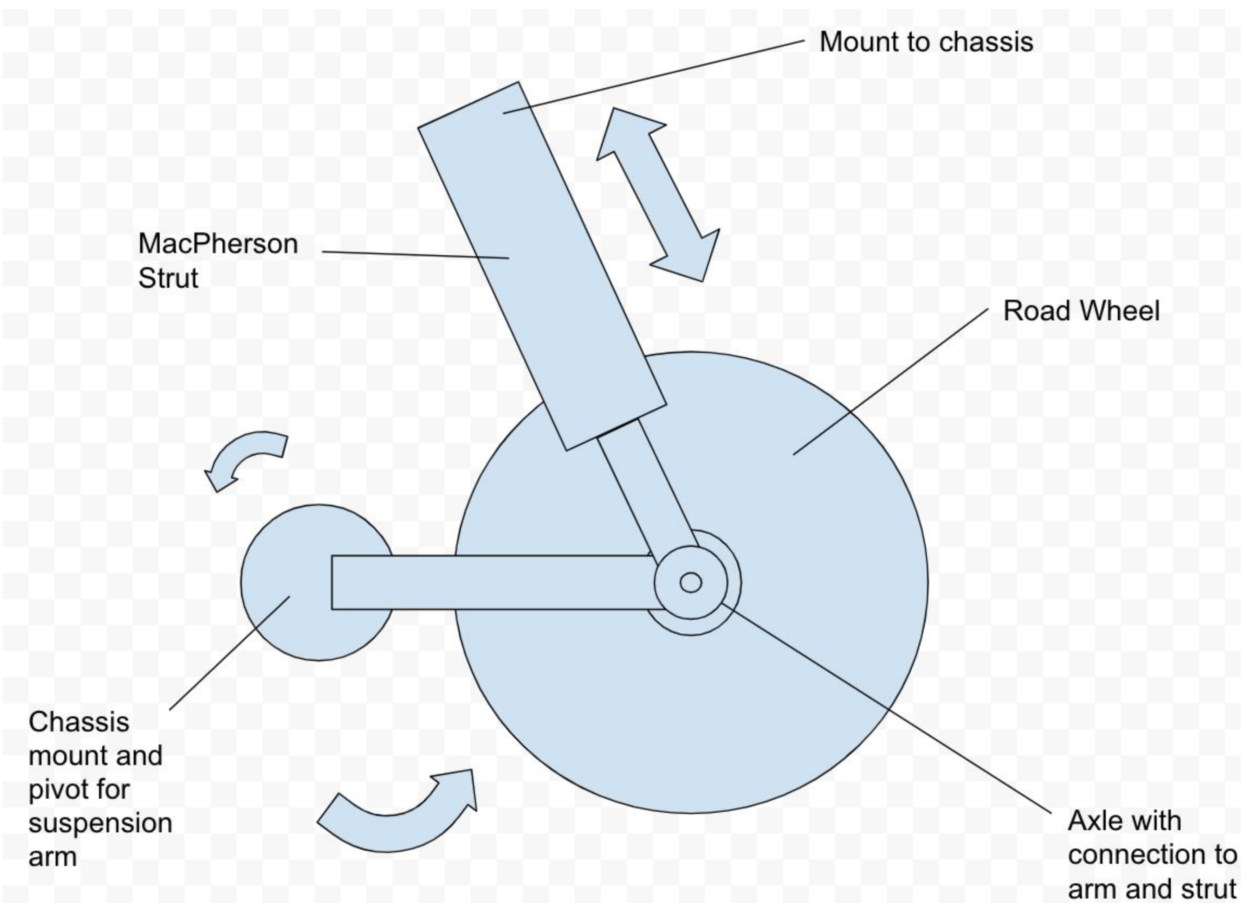
This track design is influenced by the track designs of most snowcat vehicles as well as some medium weight tracks. Above is shown a simple 2D drawing showing the road and drive wheel configurations (direction of travel is left in the drawing). The craft has two tracks - one per side, with each one having one drive wheel, located at the back. This is best, as the power source is located at the rear of the craft, so this makes drivetrain design simpler. Each track has 7 road wheels, which are not powered, and serve to hold the weight of the craft and allow the tracks to move freely. Track links feature internal fins located centrally in every second link. Along with the wheel design, this means that the track stays in place around the wheels, and this also provides lateral stability as well as better control. To attach the links together, long pins are used the length of which is equal to just lower than the width of the track links. The width of these tracks is 1100mm, and although this is very large compared to other tracked vehicles such as tanks, the weight of our submarine is also larger, to an extreme degree. Therefore it is important that the area of contact with the ground is larger, to avoid too much pressure on the ground, possibly resulting in loss of movement or control. The external faces of the track links have grooves spanning the complete width of the tracks, so ensure grip on most likely loose or slippery ground conditions. The internal wheel design features a groove down the middle of each wheel, corresponding in size to the fins on the inside of each link. The wheels have a 150 mm thick solid reinforced rubber coating. This insures grip on the inside of the track links, in the same way as a tyre, except without being pneumatic. The material of the track links is also reinforced rubber (although a much harder version). Using this rather than metal helps reduce weight. The weight of the submarine will also ensure grip between the wheels and the links. Below are shown the designs of wheels and track links.





The Suspension System:

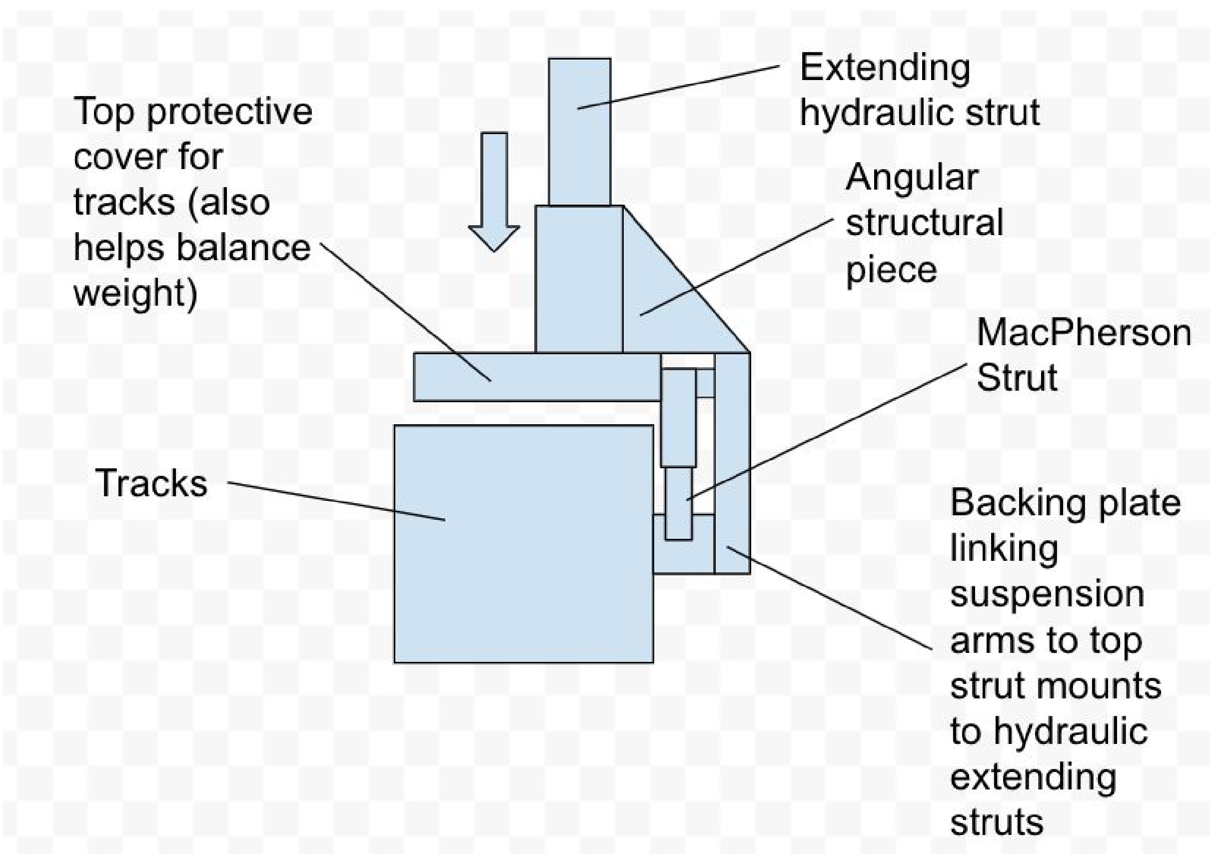
Each road wheel has its own spring and shock absorber, in a MacPherson strut configuration, with one end attaching to a suspension arm and another to the main structural support, connected through the gear deployment system. The google drawing below shows the system involving the MacPherson strut, pivoting arm and showing where it mounts to the chassis. Note that when I say chassis, I mean one of the solid, locked main structural components of the gear deployment system. No suspension is needed on the front or drive wheels, as they are raised off the ground level. This also means improved



drivability on rougher terrain. Having a suspension system for the drive wheel would be complicated, as power has to be given to it, as well as the transmission moved into place when the tracks are deployed.

The Deployment System:

During the sea journey, tracks will be stowed. This is to avoid drag as well as damage to the tracks themselves, which will mean that the travel is less efficient either way. Just before we reach the land/ice of the south pole the tracks will be deployed from the storage compartments and locked into place. Since the tracks do not have to be retracted at any point, the mechanism can lock without need to unlock. To design this system, I looked mainly at aircraft main landing gear systems for influence, however, after realising that the space available for track storage was very small, I decided to have the tracks extend downwards out of the hatches rather than pivot out. Another added complication with our design is that the tracks need to be powered, which is not needed in any aircraft designs. Below is a cross-section drawing from behind of the mechanism for extending the tracks out of the storage compartments to underneath the craft. Note that drive linkage is not included in this.



The system to extend the large strut is hydraulic. This means that a hydraulic pump is needed onboard to work the struts. This is located near to the engine. Pumps and systems of this nature have been designed many times for different uses and different loads. We will use a heavy duty one, similar in design to that used in aircraft, as the function is very similar. A hydraulic system has another benefit which is that it can lock in place but can be unlocked, all with no large and breakable components. There will be two main struts per track, each to support the weight of the submarine.

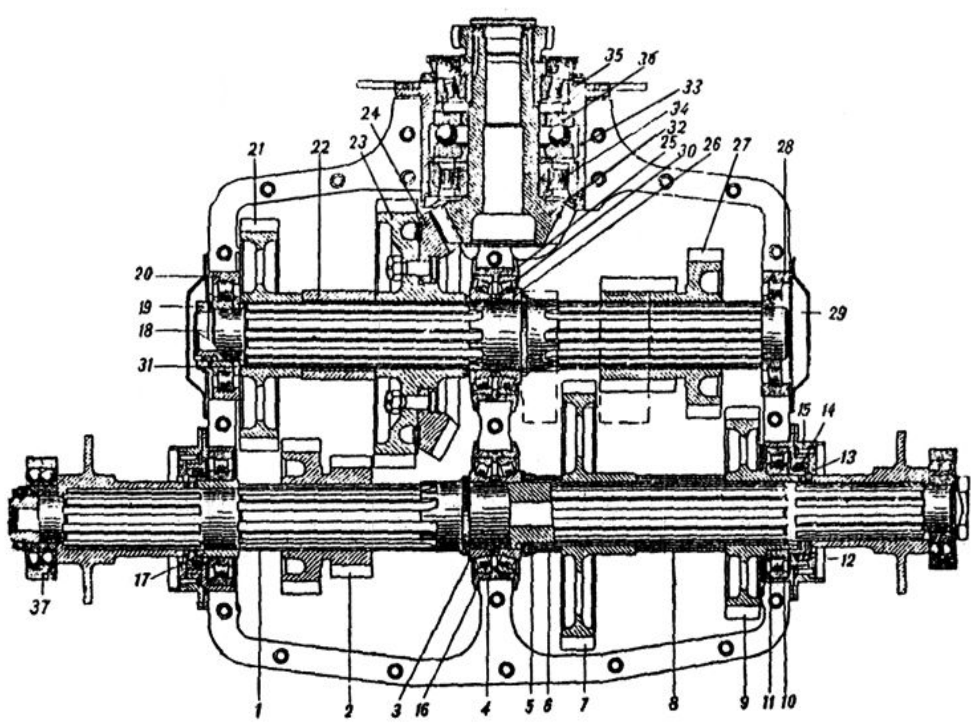
The Storage Compartments:

The compartments for the stowed tracks are composed of a single door, but with openable gaps for the hydraulic struts. The doors will open using the sam hydraulic system as the struts. There are four main design features of the compartments:

- The tracks will be kept away from any water for the duration of the sea journey, so the compartments will be sealed and watertight. The seal will be silicon, which will form a temporary bond around the edges of the doors. When the doors are opened, the silicon seal will be permanently broken, but since the tracks never have to be stowed again, this is not a problem.
- Before the doors are opened, the compartments will be filled with water. To open the doors with all of the water pressure from the outside would be nearly impossible. If there is equal pressure on both sides it will be much easier. To fill up, there will be many smaller holes along the top of the compartments so that the water pours in.
- To avoid interference with the buoyancy and control of the craft, the compartments will be depressurised for the sea journey. This will also make filling them with water easier.
- So that the doors can be closed while the tracks are deployed, in the places where the hydraulic struts are, the door will include another hatch, which folds back when closing the main hatch so that the struts can fit through the gaps made by those hatches.

The Transmission/Drive Linkage:

The engine is located at the rear of the submarine, just above the drive wheels. Since a driveshaft can come out of both sides of the engine, the rear one will go to the propeller, and the front one will be for the track power. Both will have clutches to disengage the power when only one is needed. On the track driveshaft will be a gearbox. This will be very similar in design to tank gearboxes. The difference will be in the gear ratios themselves and the strength of the components. Below is shown an example of these gearboxes. These connect to the controls, which work by engaging and disengaging each track. The clutches for this are included in the gearbox design. This design also turns the driveshaft so that it is parallel to the axles of the driven wheels when it exits the transmission. To connect the drive wheels to the power, a system will be used like that associated with the gearbox shown below.



Shown on the left, an application of the gearbox can be seen. To connect from the gearbox to the drive wheels, containers formed of two merged circles can be seen inside these covers are gears to transfer the power. Our design will feature longer versions of these, which will rotate down with the deployment of the tracks to mesh with the gears of the drive wheels and provide power.

Manufacturing:

The hull is simply constructed from titanium plates that are cut to size and curved by rollers and high pressure. These plates are then placed over a wooden template and welded and strengthened by ribs and bars. The inner hull is constructed in the same way and placed inside at the time of construction. The tracks are installed before the outer hull has been completed so as to make a watertight yet breakable seal around them within the hull. Large equipment is placed within the inner hull and attached as it’s being built while smaller equipment that is bought in is brought inside but not fitted. Once the submarine has been launched, the engine and vital electrical equipment are fitted. Once the vitals have been tested, smaller equipment and comfort for the crew is installed. Once they have all been tested and fitted, the manufacture process has been completed.

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