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EPS - PROJECT

TITLE: The Modular Design of a Seismic Buoy

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TITLE: The Modular Design of a Seismic Buoy

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Abstract

SARTI (Sistemas de Adquisición Remota y Tratamiento de la Información) are a research group based in Vilanova i la Geltru who are collaborating with an international team of four students for the European Project Semester 2016.

The brief that has been assigned to the team is to redesign a seismic buoy, making it smaller, more compact, lightweight in order to allow for easy deployment.

Seismic buoys are currently very large and consist of several different individual, but connected parts. Ocean Bottom Seismometers (OBS) are much smaller however, they do not allow for the real-time transmission of data.

This was done by researching different buoys and they way that they are currently deployed. The team's first design was evaluated and all of the advantages and disadvantages of the design was taken into account.

This along with taking into account the drag coefficient enabled the team to create a design that was much improved and had more advantages.

The team produced a compact design which solved many of the stated problems. However, more work by future teams will have to take place in order to finalise the finer details of this project.

Keywords – compact, easy to deploy, redesign, seismic buoy.

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1.0 Introduction

The European Project Semester (EPS) and International Design Project Semester (IDPS) are international exchange programs where multi-disciplinary teams work to complete assigned projects. This semester the team are studying at Universitat Politécnica de Catalunya (UPC) on the Escola Politécnica Superior d'Enginyeria de Vilanova i la Geltrú (EPSEVG) campus.

The project that the team have been assigned this semester is to redesign a seismic buoy. Seismic buoys include sensors that are placed on the ocean/sea floor in order to measure seismic activity. The team consists of two design students: Camille Webley and Joey Dunne and two engineering students: Shih-Chun Chang and Victor Reyes. Thier supervisors who are from the departments of applied mathematics at UPC are Enric Trullos and Joana Prat. They are working for the Sistemas de Adquisición Remota y Tratamiento de la Información (SARTI), a research group that develops environmental sensors and instrumentation for industrial and scientific applications to retrieve and record data. They work with digital signal processing, design of electronic data acquisition systems and the automation of complex measurement systems.

SARTI's vision is to be a leader in the creation and development of industrial control systems, the design of electronic communication and virtual instrumentation (especially in the field of oceanography) and transfer these technologies to industries that want to improve competitiveness [1].

The main objective for the project was to redesign a seismic buoy, making it more compact and easy to deploy whilst also enabling the transmission of real time data. This data would be sent back to the laboratory before recovery and provide the technicians with data, showing that the seismometer is still recording. Once recovered this data also provides the laboratory with information regarding the seismic activity in the chosen area. It also gives data on the structure of the Earth's crust in that area.

SARTI have not worked with an EPS group at UPC before and therefore there are no existing or related projects for the team to build upon. However, they have completed many other marine sensor projects. These include: ocean bottom seismometers, an expandable seafloor observatory and underwater vehicles.

Previous designs of seismic buoys are so large and heavy; a large ship is needed to transport the buoy to its predetermined location. On-board this ship is also a large crane. Many designs consist of different components which all have to be deployed separately. The crane lifts the different components into the water sequentially, starting with the surface buoy following with the mooring cable with any extra instrumentation and finishing with the anchor and the seismometer. This means that teams of trained professionals have to be used in order to deploy a moored buoy.

The new design made it much easier to deploy the moored buoy. It would not be necessary to use a team that have been trained in deploying moored buoys as the new buoy self deploys upon entry to the water. It is smaller and lighter; a smaller boat can be used to transport the buoy to the correct location. All of the components can be deployed at the same time, with no need to use the conventional sequential method.

To ensure that the group met their milestones they have used several different project management techniques, but the main tool they used was Trello. Trello is a collaboration tool that organizes your projects into boards. In one glance, Trello tells you what's being worked on, who's working on what, and where something is in a process [2].

The buoy is also able to send data back to the lab before recovery. One of the main deliverables was to discover how to coil the mooring cable inside the body of the buoy. This cable does not only connect the anchor to the surface buoy, it also transmits the data from the seismometer to to the electronics in the surface buoy.

2.0 Seismic Buoys

Seismic buoys are very important in today's world to record and archive the seismic activity in the oceans. The recording of these seismic movements is vital in order to predict any irregularities in our vast and dangerous oceans. The collected information can help laboratories foresee if a tsunami is likely to happen near a specific country's coastline. In the past this has saved millions of lives.

In 2004, an earthquake and tsunami hit the Indian coastline killing approximately 230,000 people and costing billions in damages. This proves the importance of having seismic buoys in our oceans that can transmit real time data.

The signal recordings from the buoy are used to model both the earthquake locations and the crustal structure. This allows gas and oil companies to have precise information on the sea bed structure and stability for the construction of marine platforms, as well as tracking the hydrocarbons in the lower layers of the Earth's crust.

This project model, when completed, will be deployed in the Alboran Sea, which is located between the south of Spain and the north of Africa. The Alboran Sea has had significant seismic movements in recent months. An example of this recent movement occurred in early January 2016, when an earthquake, registering 6.3 on the Richter scale, struck. This Earthquake effected most of Spain, but it had been particularly more destructive in northern Africa. In the aftermath of the earthquake, there was enough damage to cause all technical communications to the city to be cut off. The earthquake had been recorded to of had seven aftershocks, which seriously injured 26 Spanish citizens. One 12-year-old boy died from a heart attack, this was due to the initial shock and surprise of the earthquake. This information highlights the importance of having seismic buoys that can emit real time data. The data is constantly monitored and with the information that an earthquake is coming, the citizens can be quickly and safely evacuated before anyone gets hurt.

SARTI are planning to deploy our buoy design, into the Alboran Sea on the Carboneras fault line. This would be after further development by other teams. All of the details, including the internal electronics, need to be worked on.

3.0 The Previous Design

Traditional seismic buoys consist of three main components.

These are the:

- surface buoy
- anchor
- seismometer

3.1 The Surface Buoy

These buoys were very large and cumbersome. In some models the surface buoy alone weighs 780kg, or more (including the counterweight). These buoys have a variation of diameters, with some being over two meters in diameter and can reach heights of almost six meters. Due to the shear size of the buoy, deploying it into the ocean takes a large highly skilled team of professionals, a large boat and a crane (figure 1). This means that deployment is a slow, labour intensive and expensive process.

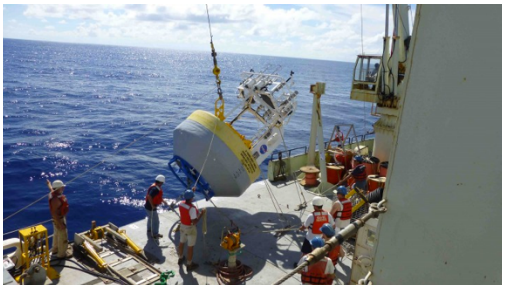


Figure 1: Lifting the buoy for deployment.

However, there are some positive aspects of the previous design that the team could utilise in the new design. On the surface buoy, there is an additional tail section on the underside with underwater fins. These fins provide the buoy with a self-orientating capability towards the wind and the swell of the waves. This means that the buoy responds well to the differences in the surroundings and will always to facing in the correct direction. This is particularly useful when the buoy has to be facing a certain direction in order to connect to a satellite.

3.2 The Anchor

As these buoys are moored, they require an anchor to keep them in the chosen location. The kind of anchor used varies and depends on the design and use of the buoy. Many of the anchors used are solid sections of concrete or scrap cast iron taken from the wheels of old trains. Concreate is easy to manipulate into different shapes and it is also a sustainable material.

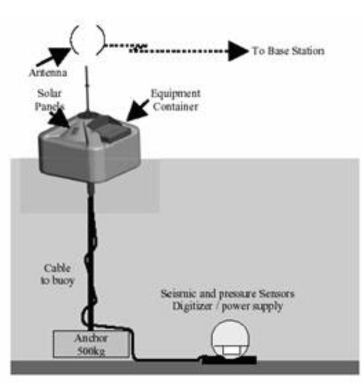


Figure 2: Marine seismic station components.

The seismometer is usually separate to the anchor (figure 2). It is connected to the surface buoy using a different cable than the anchor, however these can be attached or intertwined in some way. This suggests that all of the components have to be deployed separately.

3.3 Hulls

There are many different buoys on the market at the moment which all have different uses.

Looking at the different types of hulls used for buoys will enable the team to see which designs may be helpful when designing our surface buoy.

The different hulls shown below are a small preview of the vast number of different shapes that are currently on the market.

Figure 3: NOMAD Buoy

Boat shaped hulls. E.g. NOMAD

Boat shaped hulls, this buoy, like the one shown in figure 3, has a very low centre of gravity is therefore very stable. There are no known cases of these kind of buoys capsizing. They can be easily transported by truck or by rail and then by ship to the chosen location in the ocean. However, they displace about 10,000kg and are approximately 6m in length.

Toroid

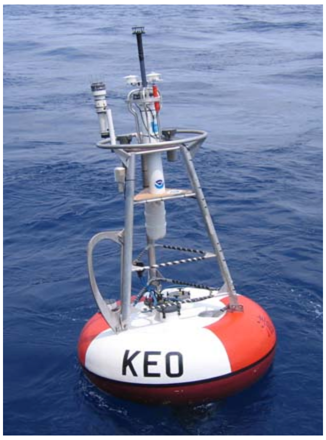


Figure 4: Toroid buoy

The toroid buoy, as seen in figures 4 and 5, is one of the most common shapes for surface buoys. It has a symmetrical shape and a structure on top which can be customised depending on the use of the buoy. Many different attachments can be added, such as solar panels, sensors and cameras. The counterweight is suspended underwater and this makes the buoy very stable. However, these buoys weigh approximately 800kg.

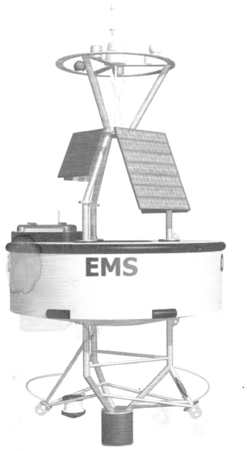


Figure 5: MES Toroid buoy

Discus

Figure 6: Discus buoy

The discus shaped hull is easily transported, like the Toroid buoy it has a symmetrical shape. Foam is used in the buoy for greater buoyancy. This foam is less susceptible to damage and therefore there are reduced maintenance costs.

Conclusion

After the team looked at all of these different hulls, it was decided that the best shape to base the buoy on was the Toroid for one of the first designs. This was due to the fact that the university already owned a buoy of this shape. It also the most common model and also the most stable, whilst being lighter than the boat shape. However, this later changed with the development of the design.

4.0 The New Design

A major flaw in the process of current seismic buoy deployments is how each component has to be deployed separately. The anchor must be deployed first, followed by the seismometer and then the surface buoy. This is one of the reasons why the deployment of the buoy is such a manually intensive task.

The team's solution to these problems is to not only make the design smaller and more compact, but to make a design that can be easily assembled and disassembled. The designers started this process by designing the buoy as a single compact unit, which is able to deploy automatically upon contact with the water.

A smaller and more compact buoy will make the deployment process much easier and less labour intensive. A smaller boat and therefore a smaller team will be able to deploy the buoy however, a crane will still be required.

The size and weight of the internal components of the buoy are crucial to the success of the new design.

The internal components include:

- The electronics
- The batteries
- The seismometers
- The steel cable
- The coiled cable mechanism

The steel cable attaches the surface buoy to the anchor on the sea bed.

In order to make the buoy more compact, the seismometer will be part of the anchor. As the seismometer is normally separate to the anchor, this is an innovative design. Below is a series of pictures of the final design of the buoy.

One end of the cable is attached to the seismometer and the other is attached to the electronics inside the electronics compartment. This cable runs through the body of the buoy via small holes. These holes are sealed with silicone so that water is unable to get through. This is the same for the motor. It is sealed with silicone and the cable for the motor will lead into the electronics compartment.

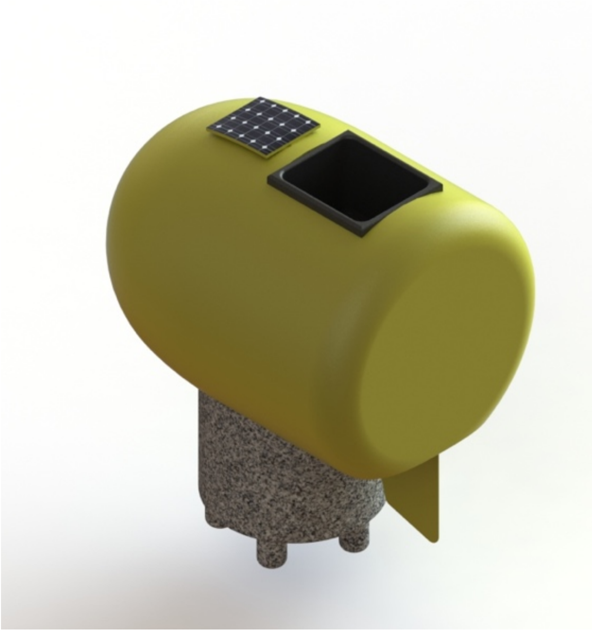
The surface buoy mass: 202kg

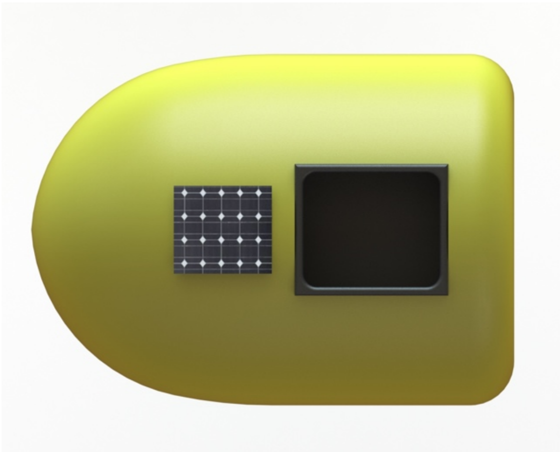
The counterweight mass: 26kg

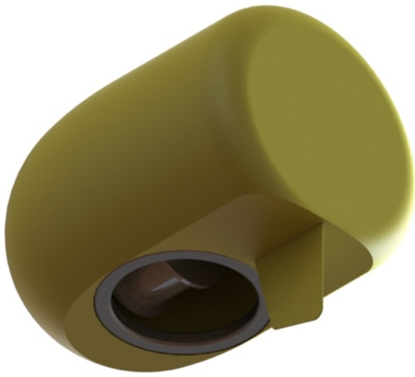
The anchor mass: 186kg

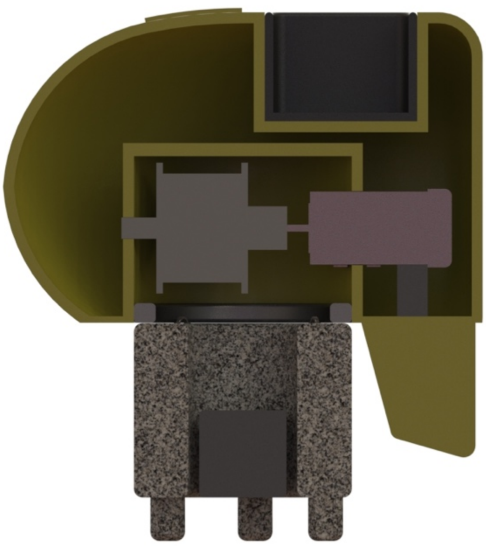
For the calculations see the appendix.

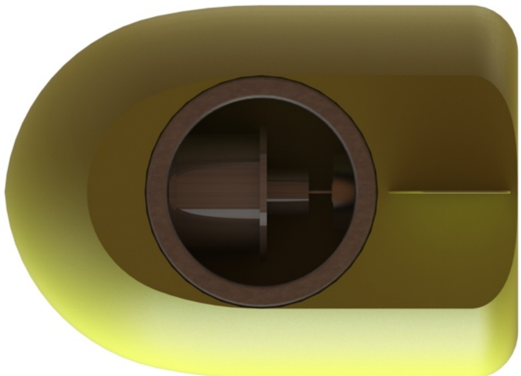
This is a large improvement. This new design of the buoy is approximately 50% smaller and lighter than the buoy currently owned by SARTI.

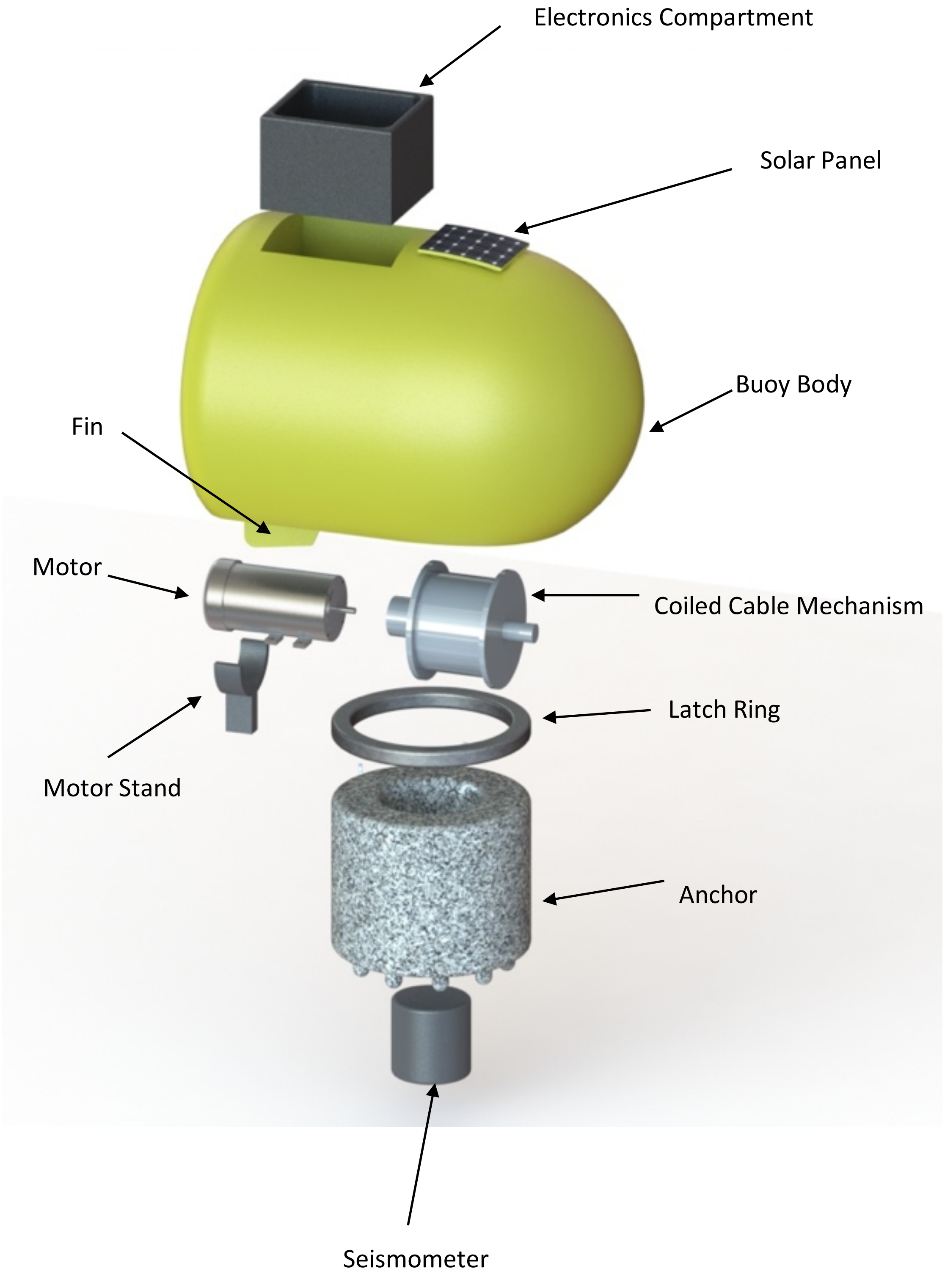




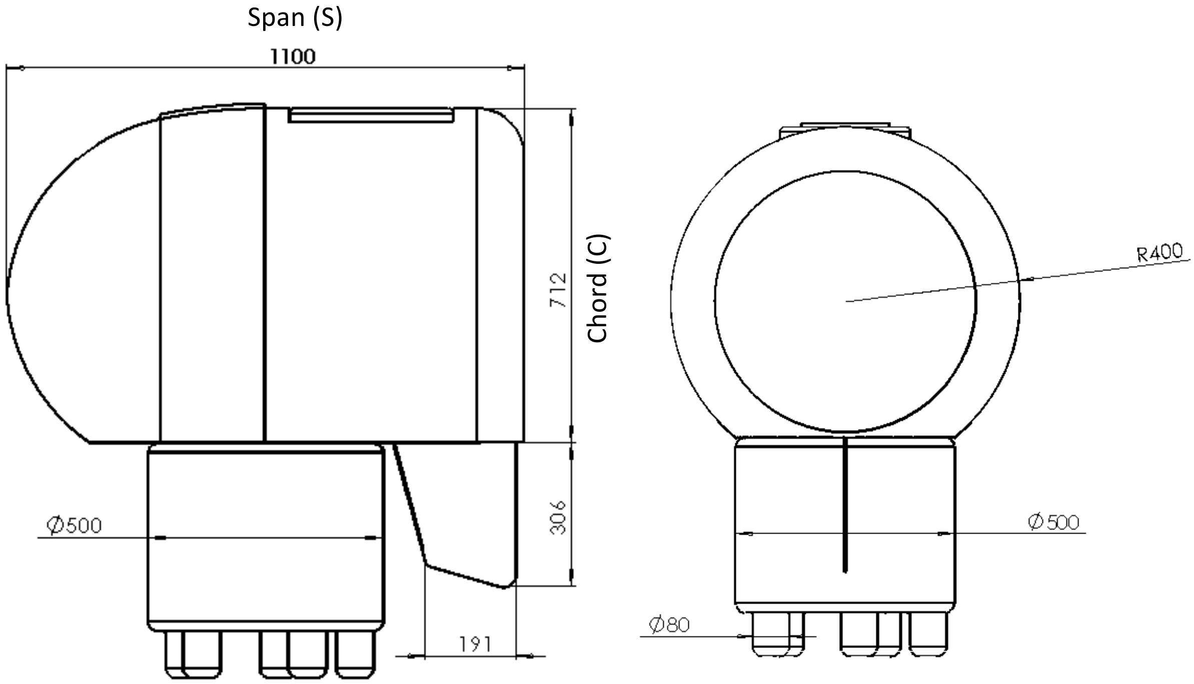


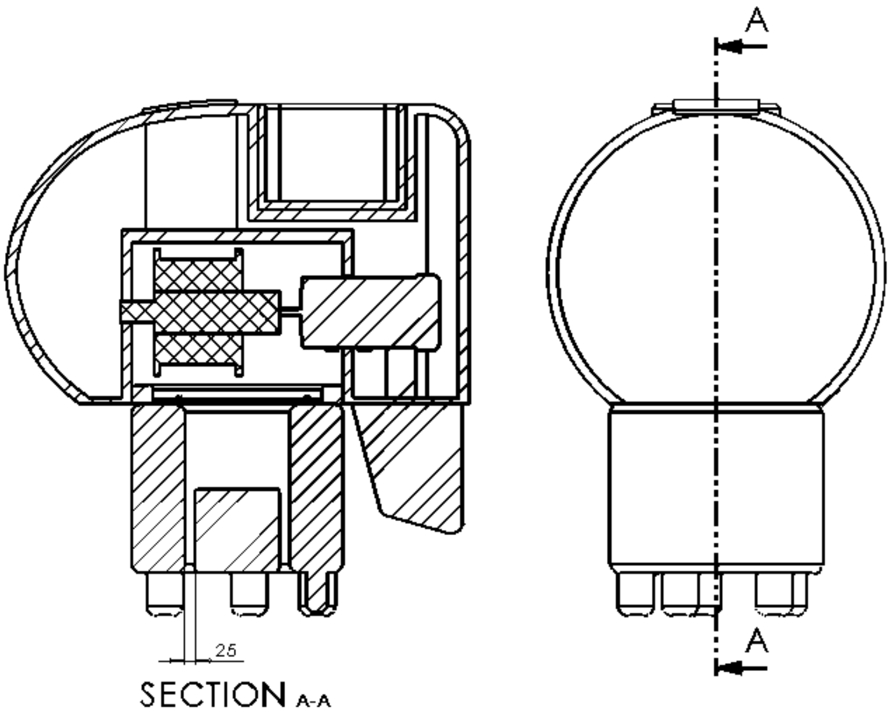





Electronics Compartment
Solar Panel
Buoy Body
Fin
Motor
Coiled Cable Mechanism
Latch Ring
Motor Stand
Anchor
Seismometer

All dimensions are in millimetres unless otherwise specified.





4.1 The Surface Buoy

The design of the buoy has changed over time. Many of the initial designs were based on the the past buoys and the ones that are currently used.

The first developed design (figure 7) was spherical and opened by removing the entire top. This was changed as it was impractical to have to remove the entire top of the buoy in order to fix anything inside. This made it more prone to water intrusion, especially because the handle for the coiled cable mechanism was removable.

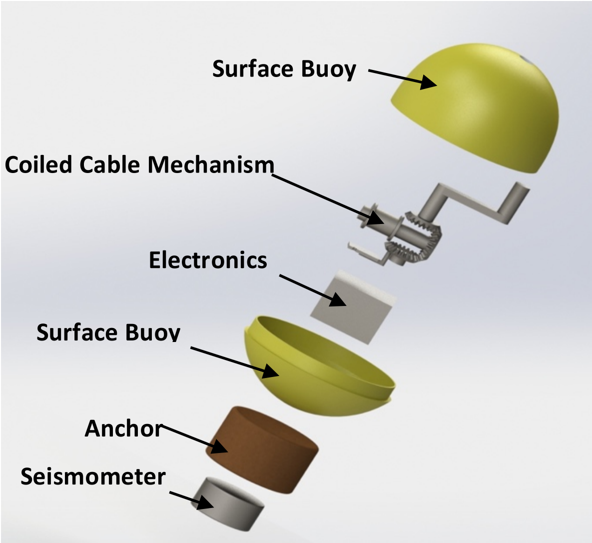


Figure 7: An exploded diagram of the first developed buoy design.

The design then evolved when the team started to look into biomimicry. The goal of biomimicry is to create a product emulating nature's time-tested patterns and strategies [3].

Firstly, sea birds and ducks were used as the animal for the design to based on. These birds sit on top of the water facing the direction of the wind and waves whilst maintaining their direction. The team decided that this would be an appropriate design to imitate as they buoy will have to maintain its direction in the water without capsizing.

However, upon more research it was discovered that the birds maintain their direction due to the motion of their feet in the water. The next animal that was chosen to mimic was a shark. Sharks use their tail fins for movement, but many of their other fins are for stability. The shape of the shark was adapted for the shape of the buoy, utilising the shape of the body rather than the fins.

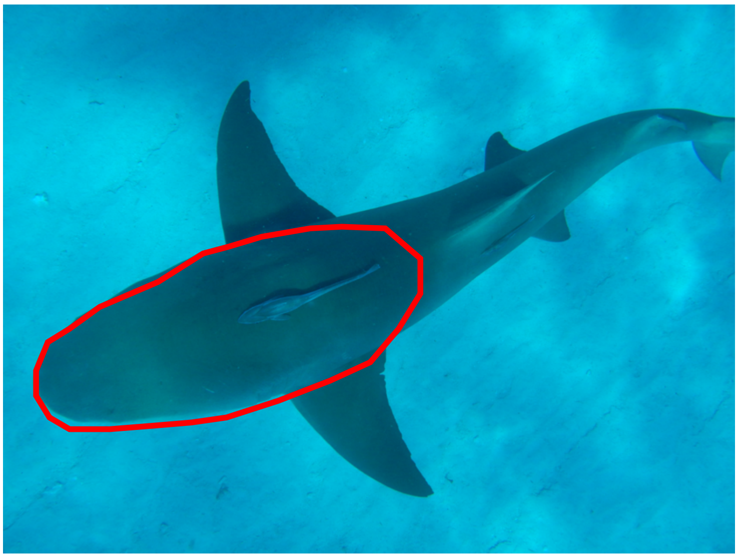


Figure 8: An aerial view of a shark.

The shape of the body had to enable the buoy to maintain a singular direction with help from fins on the underside. Using the simplified shape of the shark, the team developed a design that could be used for the new buoy. Below is an image of a shark which was taken from above. The red line shows the initial shape of the shark, without any fins or a tail, simplified into a single shape.

The idea of fins sparked inspiration in the group and surfboards were looked at next. Surfboards have between one and five fins on the underside of the board. These are for stability and ease of movement though the water. It was seen that this idea could be utilised in our design.

The fins are available in different sizes and shapes and these are chosen based on the weight of the surfer. The different shapes are chosen depending on what kind of board the owner has and what they wish to do with it.

Having a fin which is convex and symmetrical on both sides, called 50/50, is for even distribution and stability [4]. Having a fin which is convex on the outside face and flat on the inside face creates a balance of control, playfulness and speed [4]. Having a curved inside face maximises lift with minimal drag which is perfect for speed and fluidity [4]. Below is a diagram (figure 9) which shows the different profiles a surfboard fin can have.

The buoy that SARTI had previously purchased has simple fins. There are only two fins on the base and these are parallel with one another. These fins do not look life surf board fins at all as they do not have the curl in the tail and are flat. The image below shows part of the underside of the SARTI buoy where the fins are located.

It was decided that the best fins for the buoy to have were the 50/50 fins like the surfboard. They have a streamlined aerofoil shape which makes the resistance to drag low. This is a large improvement on the flat fins from the previous buoy.

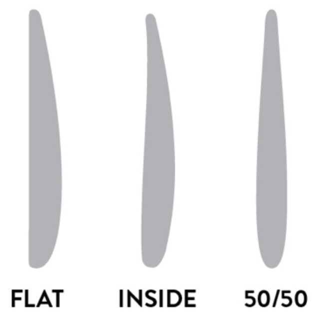


Figure 9: The different profiles of surfboard fins.

Figure 10: The fins on the base of the surface buoy and the profile view of the new fin.

At first it was thought that the best way to encompass all of the electronics into the shell of the surface buoy was to make the entire shell hollow. This would mean that an internal frame would be needed in order to keep all of the different electronics separate. This frame would also enable the electronics to be bolted down so that they do not move in rough seas. Upon further reflection, it was decided that this was no longer a suitable idea and the team decided that the best design was to use the current design of the buoy which SARTI already owns. The original design has all of the electronics encompassed in a small chamber with a waterproof door, as shown the the picture below.

With the current design of the coiled cable mechanism, it is not possible to have any moving parts inside the body of the buoy as they would not be waterproof. This is due to the fact that it would be difficult to create a waterproof seal around these moving parts. To overcome this, the design was altered so that the coiled cable mechanism was in the centre of the body of the buoy, but not inside. This means that all of the parts would get wet. The original materials chosen for the coiled cable mechanism would not function correctly in this new environment therefore, all of the materials were changed.

Figure 11: The top of the surface buoy showing the electronics compartment.

Buoys for scientific uses are classed as special buoys. All of the other buoys in the ocean have navigational or warning uses. These special buoys are all coloured yellow. This indicates that the buoy is not for navigational uses. These special buoy sometimes have a yellow cross on the top or a flashing yellow light. Below is a diagram showing the shapes of different special buoys and the crosses on the top.

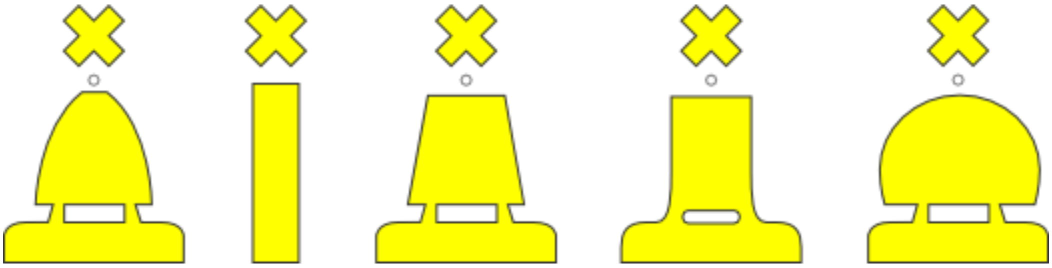


Figure 12: The different shapes of special buoys.

4.2 The Drag Coefficient

The drag coefficient is a value used to discover the value of the resistance an object will have in the air or in water. The lower the drag coefficient the lower the hydrodynamic or aerodynamic drag.

The team have chosen a shape that has not been used for buoys before, therefore it was thought that the drag coefficient should be calculated to show that the new design had less drag.

Having less drag means that the water and the current will flow around the shape with more ease and therefore the buoy should not move as much on the water.

The shape that was chosen by the team was then tested to make sure that it would cause less resistance than the previous buoys. To do this, the drag coefficient was calculated and compared to the previous buoy. The previous buoy was a toroid buoy which means that it is circular in shape with a slightly domed top and bottom. The team's previous designs were also a similar shape to the toroid buoy, but it was more spherical. The closest shape to this on the drag coefficient chart is a sphere. The new buoy shape is a bullet.

From the diagram shown on the right, the following data can be gathered. A sphere has a drag coefficient of 0.07 to 0.5 and a bullet has a drag coefficient of 0.295.

This lower value means that there is less drag on the shape and therefore the water will move around the shape easier and faster. This enabled the team to chose this new, more streamlined shape as the final design.

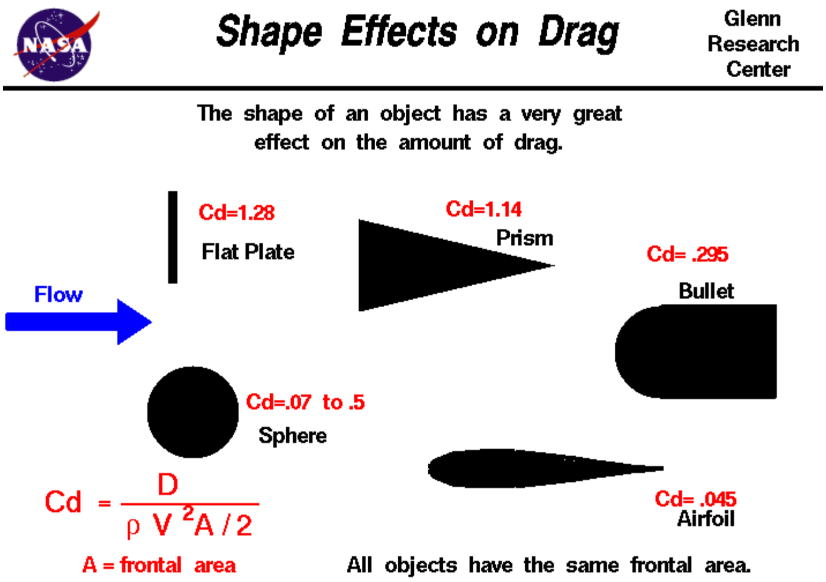
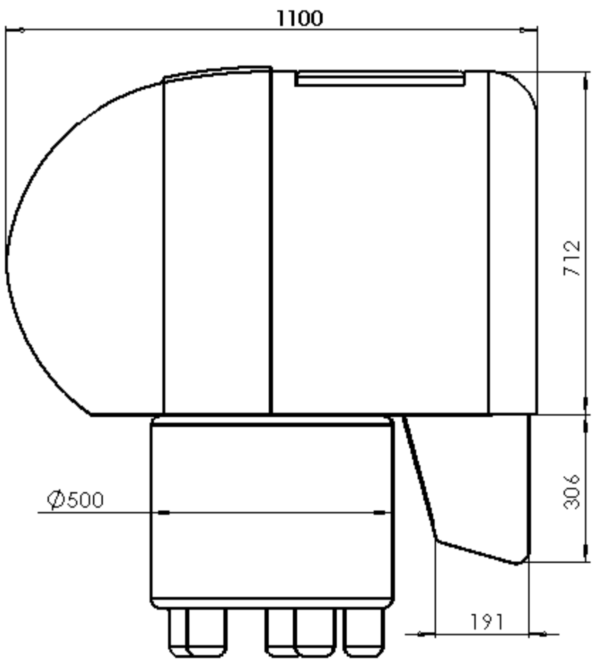


Figure 13: A diagram depicting the shape effects on drag.

Span (S)



Chord (C)

The drag coefficient of a bullet shape (not ogive[i] at subsonic velocity) is: $C_D = 0.295$
This coefficient is calculated in air with velocity $V < 343.2$m/s.
This is valid in sea water if the Reynolds number is equal, assuming the same projected area.

[i] Ogive: a pointed or Gothic arch.

$Reynolds\ number = Re = \frac{V.L}{\nu}$

L = Length of the object. In this case L = S

V = Velocity of fluid

ν= Kinematic viscosity (m^2/s)

The Reynolds number in air equivalent is:

$$Re_{air} > \frac{20 \times L}{1.3 \times 10^{-4}} \cong 0.153 \times 10^6 L$$

$$Re_{air} < \frac{343.2 \times L}{1.3 \times 10^{-4}} \cong 2.64 \times 10^6 L$$

In this equation the team have used a range of values for the velocity: 20 < V > 343.2m/s

In sea water if the main effect over the buoy will be the current with a velocity of: 0.3 < V < 3m/s

$$Re_{sea\ water} > \frac{0.3 \times L}{1.5 \times 10^{-6}} = 0.2 \times 10^6 L$$

$$Re_{sea\ water} < \frac{3 \times L}{1.5 \times 10^{-6}} = 2 \times 10^6 L$$

Therefore, the team can conclude that the coefficient in air can be used in sea water. This number is important as it can enable the team to do dynamic and numerical simulations.

4.3 The Anchor

It was a possibility that by making the anchor lighter, the surface buoy could drag the anchor away from the point at which it was initially deployed. The team decided that the best way to combat this was to place some kind of grip on the base of the anchor. At first it was thought that utilising current designs of anchor was the best method. Anchors that are currently used to moor boats and ships are much smaller than the actual vessel itself, yet they still manage to stop the vessel from floating away. Designs for these varieties of anchors were made and it was seen that these would not work for this use.

Figure 14: An anchor on the sea bed.

In order for these anchors to work, they have to be dragged slightly on the sea floor. This enables them to gain a firm grip on the sea bed and slightly embed themselves into the sand. See figure 14.

These types of traditional anchor would not work for the team's design and therefore could not be utilised. Alternatively, a variety of spike was used. These spikes give the anchor the additional grip that may be needed to enable it to stay in the place of initial deployment.

The anchor is made from concrete, which has been moulded into a torus shape. Due to the compact nature of the design, the seismometer is inside the hole at the centre of the anchor. Upon recovery, the concrete anchor will be left behind and the seismometer and accompanying electronics will be retrieved. The seismometer has to be on the sea bed in order to record data.

The anchor that is attached to the surface buoy is a very important feature for the project team to keep in consideration whilst producing the final design of the project. The anchor is a vital part of every buoys design; it is what the surface buoy in place and stops it from becoming lost or damaged. The anchor is also vital to receive the recorded data as the seismometer is attached to it. The seismometer is a vital piece of equipment used to measure the seismic movements beneath our oceans. For this project, the seismometer is placed inside the anchor, this has never been done before and is new and innovative. The seismometer is being placed inside the anchor in order to make the design more compact and therefore more mobile and easy to deploy.

Making the anchor, which is a large heavy object, part of a more compact design had to be researched and then decided upon by the team. In order for this to work, the anchor and surface buoy need to be deployed as one solid unit. In order to do this, hooks are placed on the top of the anchor that are made for connecting latches on the bottom of the surface buoy. This enables the anchor and buoy to be lifted as one solid unit.

Next the team needed to look into the most suitable material that can be used for making the anchor, old designs of seismic buoys use cast iron scrap metal taken from the wheels of old steam trains. The team decided not to use this material for two main reasons. Firstly, cast iron is not eco friendly and will never degrade in the ocean. It will just be the cause of more pollution and rust in the water. Secondly, the anchors are typically left in the ocean as they are too heavy to retrieve. These cast iron metals can be valuable to people all over the world in need of a strong and durable material. The team thought that it would be better to recycle this iron, rather than just leaving it at the bottom of the ocean.

The material chosen by the project team is high density concrete. Concrete will provide the team with a heavy durable material for its anchor which can be easily manipulated into any shape. The use of concrete will eliminate the worry of leaving a renewable material at the bottom of the ocean. The currents in the sea will be able to eventually break down the concrete as if it were a rock in the ocean.

Concrete comes in two forms, high and low density. For this project the team will be using high density concrete. This is to keep in consideration the importance of a compact design. High density means that you can have an anchor of the same weight in a smaller amount of space when compared to a lower density material.

The weight and mass of the concrete is shown in figure 15.

Bibliographic Entry	Result (w/surrounding text)	Standardized Result
Dorf, Richard. *Engineering Handbook.* New York: CRC Press, 1996.	"The density of normal concrete is 2400 kg/m^3 and the density of lightweight concrete is 1750 kg/m^3	1750 –2400 kg/m^3
Brooklyn Public Library Files; 1999	"Typical density of concrete (2.3 g/cm^3)"	2300 kg/m^3
McGraw-Hill Encyclopedia of Science and Technology.	"Volume generally assumed for the density of hardened concrete is 150 lb./ft^3. (2400 kg/m^3)"	2400 kg/m^3

Figure 15: A table depicting the density of concrete.

As the surface buoy will weigh approximately 200kg the anchor will weigh 450- 500kg. From this the team worked out that the volume of the anchor will be 0.48m3. This decrease in weight is a vast improvement on previous anchors which typically weigh between one and two tonnes.

4.4 The Antenna

The buoy will be fairly close to the shore, so it will still be in sufficient range to use the GSM mobile network. This means that the design did not have to include an external antenna. An internal antenna will work. It is also possible that a signal booster could be used if the signal is not strong enough.

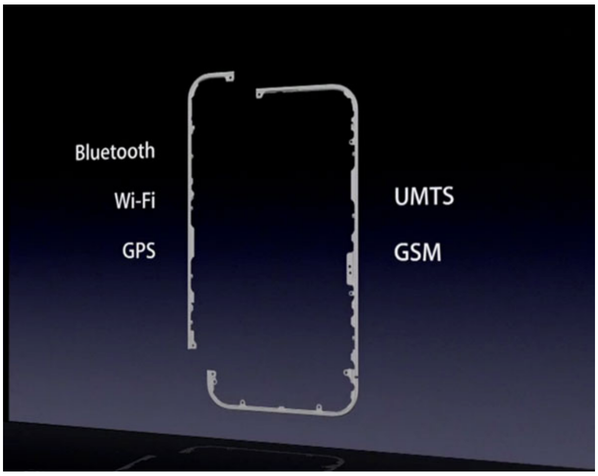


Figure 16: The iPhone 4 antenna.

During the design process, it was thought that the antenna could be built into the internal frame. This would mean that the internal metal frame could act as the antenna. This idea was inspired by the Apple iPhone 4 design. The silver band around the edge of the phone acted as the antenna. The image on the right shows a diagram of the iPhone 4 antenna.

When choosing an antenna, the type that is chosen depends on if the object will be transmitting and receiving data or just receiving. In this case, the buoy will be transmitting data so the antenna that will be used will be one that both transmits and receives data. It will also have GPS so that the buoy can be located by the laboratory/ground station.

Antenna design can be complicated and the team decided that the best antenna to use was the standard antenna that is issued with the buoy that SARTI already own. This is located inside the waterproof compartment with all of the other electronics.

4.5 The Solar Panels

The project team also needs to consider the best choice of power supply while thinking of the design of the surface buoy. Power is needed to keep the inner electronics and equipment working constantly to provide the updates of information that will be processed and recorded. In previous buoys the power sources varied from large internal batteries set to only function for the amount of time that the buoy is deployed for, another popular power source that has been used is solar energy, this left the project team with a choice and research into both options had to be made.

Both options have their own pros and cons. Large pre installed internal batteries have the advantage of being discrete which is useful as in the past external features of seismic buoys with high scrap/recyclable value have had a history of being stolen. On the other hand, with using large internal batteries it is not an eco friendly power source, this is a disadvantage in two ways, by being harmful towards the environment and by being a non renewable source of energy the amount of time a buoy can be deployed or is limited to the size of the battery equipped. Solar power however a completely renewable power source is and will provide our design with more than enough power throughout the night whilst charging during the daytime hours.

There are three common types of solar cells used in marine solar panels sold today, each with their own advantages. Solar modules (solar panels) are very sensitive to shading. Once a solar cell or a portion of a cell is shaded it becomes less effective. The design of some solar modules offers protection from partial shading by including a diode between every string or cell. “Monocrystalline” are single silicon cells grown into larger crystals, then cross-section cut into small wafers to form individual cells that are later joined together to form a solar panel. This cell type has a very high conversion efficiency which means it takes up less space. “Multicrystalline” (Polycrystalline) cells are also single silicon cells constructed by utilizing multiple amounts of smaller crystals to form a cell. This cell type has high conversion efficiency. The final kind of marine solar panel is” Amorphous silicon”, the most inexpensive to manufacture, is produced by depositing an active silicon material on various substrates like stainless steel sheet. The conversion efficiency is not as good as the single crystal type but work better in shaded situations. Shadow protected means that a panel continues to charge when part of the cells is in a shadow, like a stay, which is a great advantage on a sailboat or aquatic object like the seismic buoy.

Solar panels have evolved quite a bit in recent years with popular “Monocrystalline” models being mass produced as portable travel companions. It is this particular type of solar panel (shown in figure 16) that the project team will be using in the final design.

Figure 17: The chosen solar panel.

5.0 Materials

Properties of the materials

For the first design Polyethylene (PE) was used for the shell. This is one of the most popular thermoplastics used in the world. Steel was used for the coiled cable mechanism.

Below is an explanation of the different types of Polyethylene.

- LDPE (Low Density Polyethylene) has a density range of 0.910 – 0.940 g/cm^3. Due to all of its properties it has a lower tensile strength and increased ductility. It also presents unique and desirable flow properties.
- MDPE (Medium Density Polyethylene) has a density range of 0.926 – 0.940 g/cm^3. It is mostly produced by catalysts processes.
- HDPE (High Density Polyethylene) has a density of greater than or equal to 0.941 g/cm^3. Due to its chemical properties, it has strong intermolecular forces and tensile strength.

LDPE Properties:

LDPE is semi-rigid, very tough, translucent, weatherproof, good chemical resistance, low water absorption, easily processed by most methods and low cost.

LDPE Properties	Value
Tensile Strength	0.20 to 0.40 N/mm^2
Notched Impact Strength	No break
Thermal Coefficient of Expansion	100 to 220 x 10^{-6} m/°C
Max. Continued Use Temperature	65 °C (149 °F)
Melting Point	110 °C (230 °F)
Glass Transition Temperature	-125 °C (-193 °F)
Density	0.910 to 0.940 g/cm^3

Table 1.

HDPE Properties:

HDPE is flexible, translucent, weatherproof, good low temperature toughness (to -60 °C), easy to process by most methods, low cost and has good chemical resistance.

HDPE Properties	Value
Tensile Strength	0.20 to 0.40 N/mm^2
Notched Impact Strength	No break
Thermal Coefficient of Expansion	100 to 200 x 10^{-6} m/°C
Max. Continued Use Temperature	65 °C (149 °F)
Melting Point	126 °C (259 °F)
Density	0.941 to 0.965 g/cm^3

Table 2

For the first design of the coiled cable mechanism, stainless steel was going to be used due to its properties. This type of steel does not corrode, rust or stain easily with water, making it perfect for marine use.

Properties (temperature 25 ° C)	Stainless Steels
Density (1000 kg/m^3)	7.75 to 8.1
Elastic Modulus (GPa)	190 to 210
Poisson's Ratio	0.27 to 0.3
Thermal Expansion (10^{-6}/K)	9.0 to 20.7
Melting Point (° C)	1371 to 1454
Thermal Conductivity (W/m-K)	11.2 to 36.7
Electrical Resistivity (10^{-9}Ω-m)	75.7 to 1020
Tensile Strength (MPa)	515 to 827
Yield Strength (MPa)	207 to 552

Table 3

After making some changes to the design, the materials had to change as well. The material chosen for the second buoy design is Polyurethane (PUR) and Polyamide 6 (PA6) for the coiled cable mechanism.

Polyurethane Properties (22.7 °C/73 °F)	Value
Tensile Strength	0.075 to 40.98 N/mm^2
Tensile Modulus	4.82 to 2192.53 N/mm^2
Insulation Resistance	1 x 10^{11} to 2.6 x 10^{13} Ω
Continued Use Temperature	48 to 131 °C (120 to 269 °F)
Melting Point (Extrusion)	80 to 237 °C (175 to 460 °F)
Glass Transition Temperature	-470 to 106 °C (-81.4 to 223 °F)
Density	0.94 to 1.11 g/cm^3

Table 4

For the last surface buoy design Polyamide is to be used for the coiled cable mechanism. Polyamides are a group of plastics and encompass a range of different material types (Polyamide 6,6; Polyamide 6,12; Polyamide 4,6; Polyamide 6; Polyamide 12), providing a range of available properties.

Polyamide 6 Properties	Value
Tensile Strength	90 to 185 N/mm^2
Notched Impact Strength	5.0 to 13 KJ/m^2
Thermal Coefficient of Expansion	90 to 20/70 x 10^{-6} m/°C
Max. Continued Use Temperature	150 to 185 °C (302 to 365 °F)
Density	1.13 to 1.35/1.41 g/cm^3

Table 5

Properties	HDPE	Polyurethane
Density	0.941 to 0.965 g/cm^3	0.94 to 1.11 g/cm^3
Tensile Strength	0.20 to 0.40 N/mm^2	0.075 to 40.98 N/mm^2

Table 6

Properties	Stainless Steel	Polyamide
Density	0.775 to 0.810 g/cm^3	1.13 to 1.35/1.41 g/cm^3
Tensile Strength	515 to 827 N/mm^2	90 to 185 N/mm^2

Table 7

One of the most important properties on which the based their choice for the best materials was the Tensile Strength. This indicates the force supported by the material and the density which indicates the amount of mass contained per cubic unit.

Polyurethane Foam:

The buoy is filled with a Polyurethane foam, which is a type of Polyurethane. This material is appropriate for marine use, because it has a minimum range of absorption to water and support high temperatures. This material is inside the shell of the buoy. It was also used in the buoy that was bought by SARTI.

6.0 Mechanical Aspects

6.1 The Coiled Cable

The team have to redesign the coiled cable so that it can fit inside the body of the buoy. With many of the old designs, the cable is released into the ocean after the anchor. With the cable inside the buoy it will be easier to recover the buoy.

When the first designs were drawn, the coiled cable reel was vertical. This was going to create problems during deployment because the orientation would crate a turning effect of the anchor as it was lowered to the sea floor. The team changed the design of the reel to be horizontal, it this wasn't changed the anchor would spin with aspect to the vertical axis and this would have caused problems with the tangling of the wire. This was much more suitable and caused no problems with deployment.

This was the teams first developed design. The three gears connect each other. The first gear connects with handle. A motor can be used to turn the handle to wind/unwind the cable. The second gear connects with the spindle and the coiled cable cylinder. This is the most important part for coiling the cable. The third gear connects with the link which is in-between the gear and entire thread.

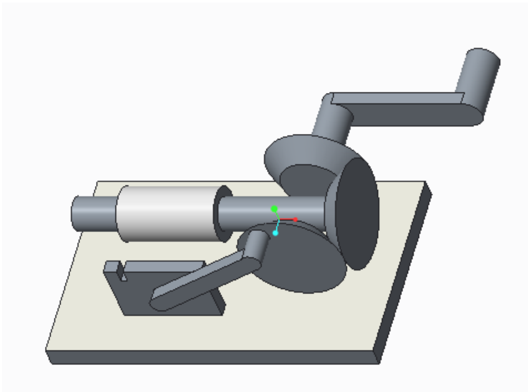


Figure 18: Diagram of the coiled cable mechanism.

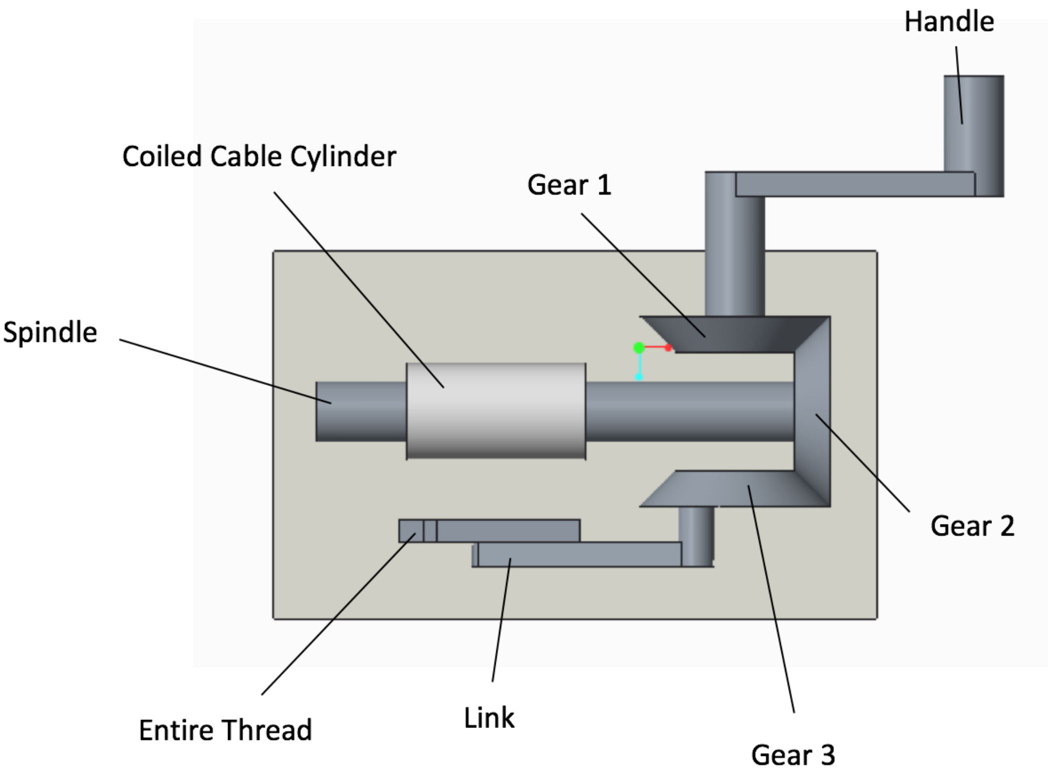


Figure 19:Labelled diagram of the coiled cable mechanism.

When the motor drives the first gear, the second gear will start to turn. This will make the coiled cable cylinder start to turn and the third gear will also turn. Using the slider-crank mechanism, the gear will turn and make the entire thread move around. The purpose of this mechanism is to make sure that the cable evenly distributed on the coiled cable cylinder.

The handle is only for use in emergencies. There will be a cylindrical motor inside the spindle which will turn the gears and therefore move the link and thread.

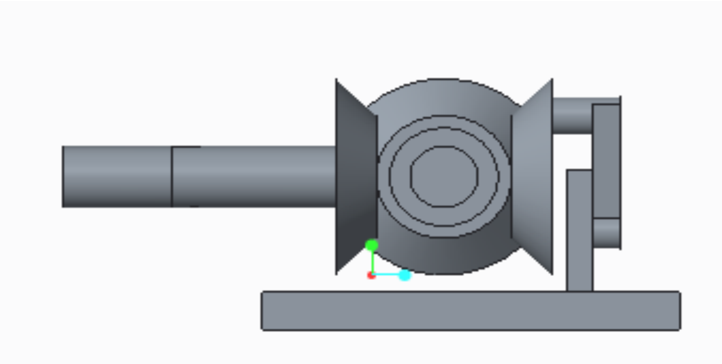


Figure 20: Top view of the coiled cable mechanism.

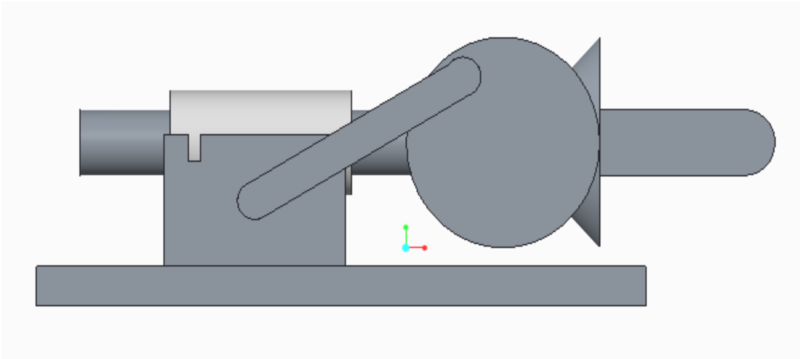


Figure 22: Side view of the coiled cable mechanism.

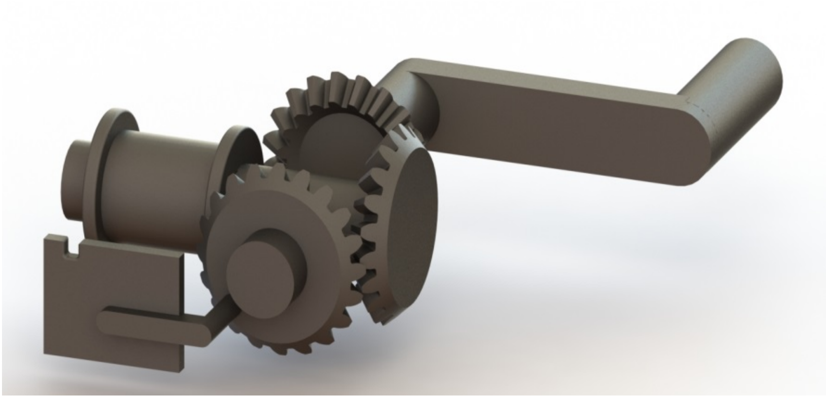


Figure 21: A rendered CAD drawing of the coiled cable mechanism.

This coiled cable mechanism had a problem. When the handle was turned once, the coiled cylinder also turned once. Therefore, the entire thread only moved one cycle. This means that only one loop was created on the coiled cylinder. This is very inefficient and to combat this the team changed the design.

The slider-crank mechanism converts the rotational motion into linear motion. This is shown in the figure 23 below. When the crank (2) rotates once, the link (3) will make the slider (4) move left and right.

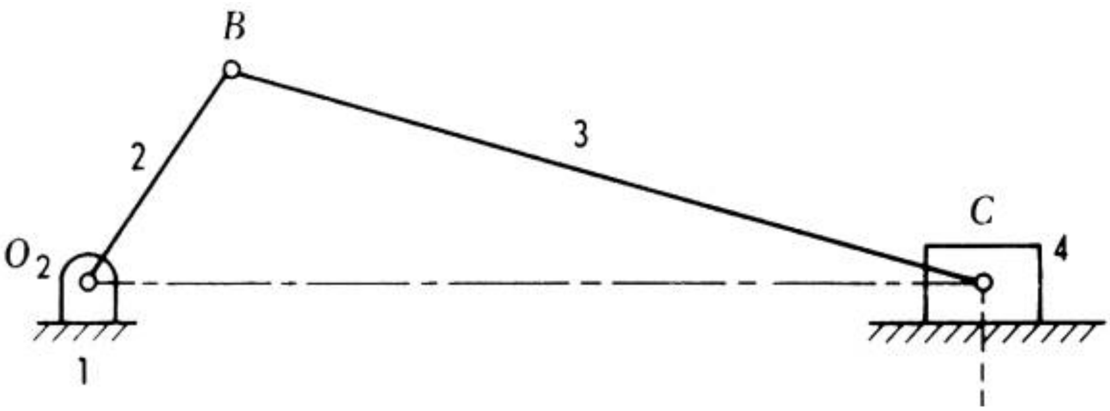


Figure 23: The slider-crank principle.

Figure 24 is the team's second design. Here the three gears are connected to each other, but the slider-crank mechanism was changed to the Geneva mechanism. This means that the entire thread was changed to the rack. Both of these functions are the same. They enable the cable to be evenly distributed on the coiled cable cylinder. However, there are some differences.

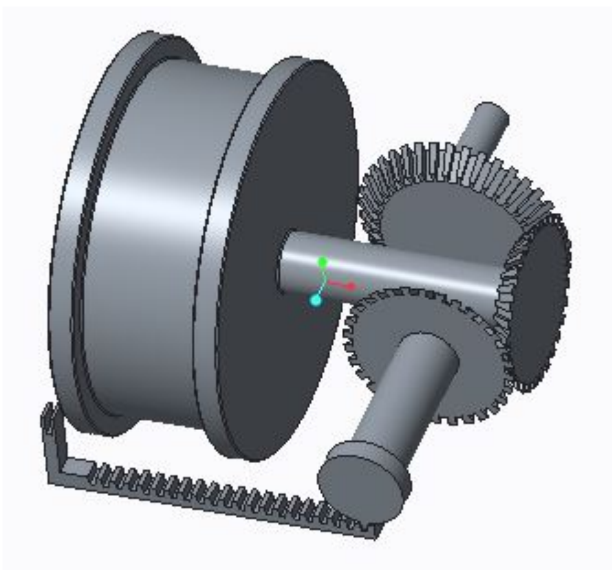


Figure 24: The second coiled cable mechanism.

Geneva mechanism

This mechanism translates continuous motion into intermittent motion. Figure 25 on the next page is an example of how this works. The Capstan (2) with a pin on the top continuously rotates, this causes the rack (1) to move with an intermittent motion.

Using the Geneva mechanism this enables the the mechanism to have more loops on the coiled cylinder in one turn. The green component is like the gear and the yellow component is like the rack.

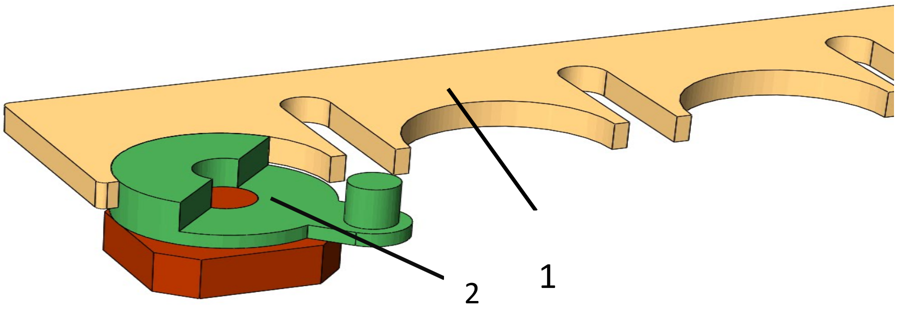


Figure 25: The Geneva mechanism.

However, there was problem with this due to the use of the rack. It takes up too much space when the rack moves in one cycle. It would need to have a space double the length of the rack. This would increase the dimensions of the team's design by two.

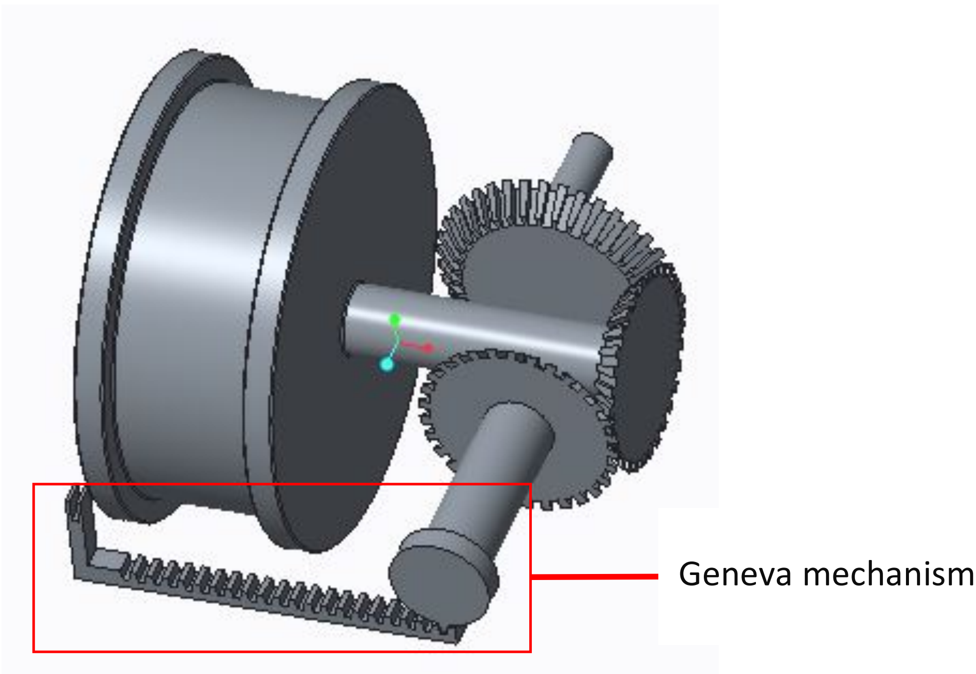


Figure 26: The Geneva mechanism shown on the coiled cable mechanism.

Figure 27 is the team's final design of the coiled cable mechanism. This is a much simpler way to distribute the cable evenly on the coiled cylinder. This device connects with the motor.

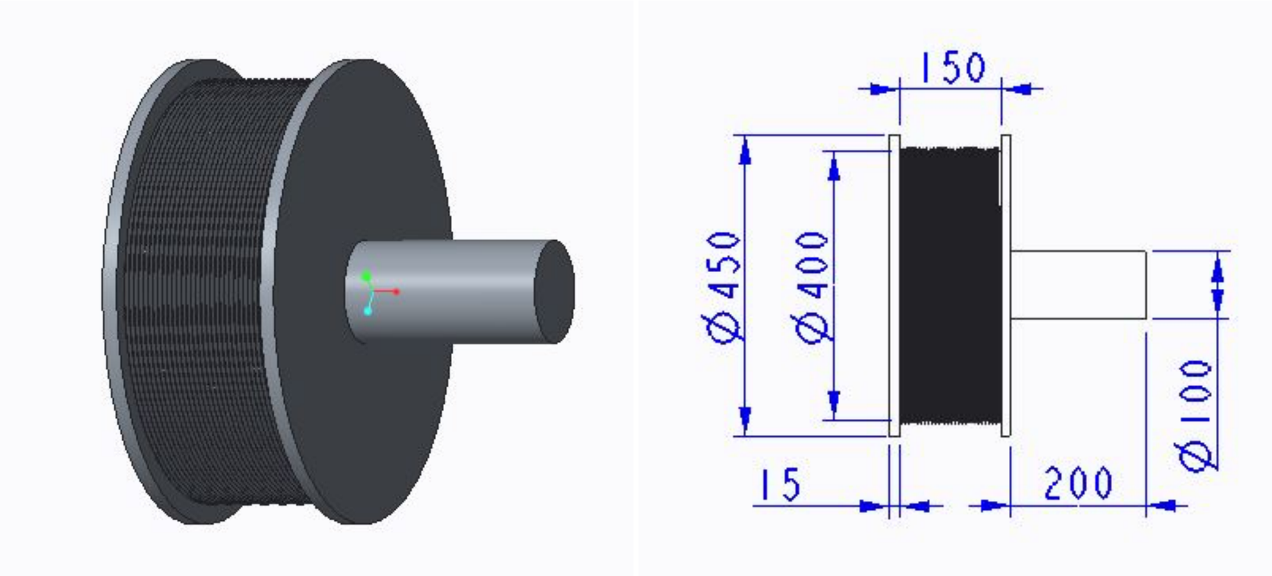


Figure 27: The final coiled cable mechanism.

This design resembles a screw thread. As it turns the cable rolls into the spaces between the peaks.

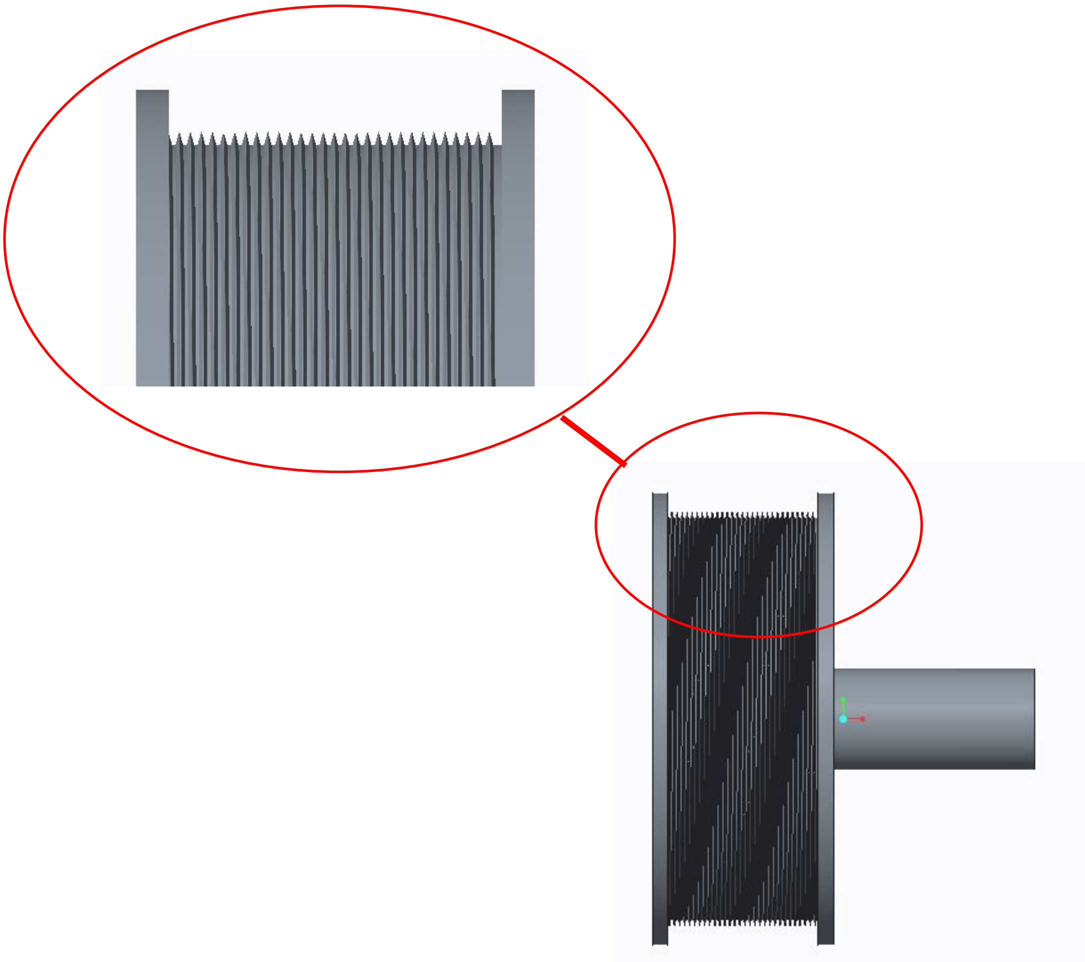


Figure 28: A diagram showing the detail of the coiled cable mechanism.

6.2 The motor

As the motor will not be inside the watertight, sealed compartment it will be exposed to the sea water. This indicates that the motor will exposed to the sea water and therefore will need to be waterproof and corrosion resistant. The first thing that the team had to decide was which kind of motor would be required. There were three choices. A brushless, specifically a stepper or an AC motor. Solar panels generate DC current unless an inverter is used to convert the DC current to an AC current.

Type of Motor	Advantages	Disadvantages
Brushless Stepper	Motion control. Can be used in steps and can hold the mechanical load at one of the steps. Smooth motion. Applied current always generates maximum torque. More efficient – if less torque is required current is reduced.	Bigger in order to accommodate the additional heat of operating at maximum current all the time.
AC	Robust and sturdy – can last a lifetime. Cheaper. Low maintenance. Does not require complex circuitry. Can be used underwater as they do not produce sparks like DC motors.	Low starting torque and therefore cannot be used for traction and lifting loads.

After looking at the advantages and disadvantages of the two different motors, the team decided that the best motor to use for our application is the AC motor. This is because it is low maintenance, does not produce sparks and can last a lifetime. The motor will be powered by an external source of energy upon recovery. The motor will not be used during deployment. Solar panels produce DC current and would therefore need an inverter. This would create extra weight which is not needed.

6.3 Deployment

In order for the buoy to be automatically deployed upon entry to the water, the team had to identify a suitable method to attach the components together. The following latches are only for use during deployment.

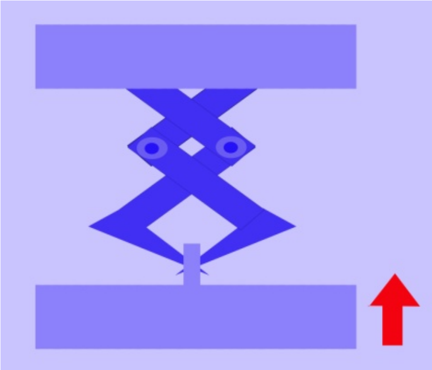


Figure 29: Latch design 1A.

The latch design in figure 29 will be strong, but it depends on the amount of pressure being applied from below. It is only as strong as the amount of force pulling it down.

The pressure can be released by simply moving the bottom object upward, with the initial impact of the buoy on the waters surface.

The latch design in figure 30 shows that once the buoy has hit the water, the hinged latch will move upward and release the anchor.

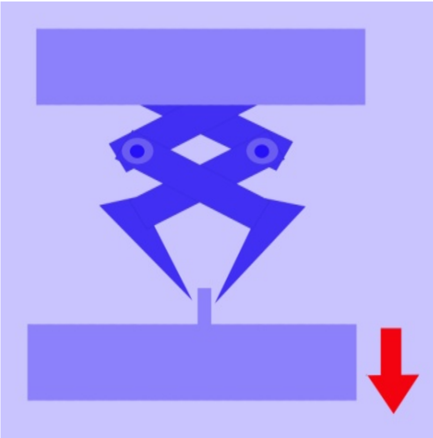


Figure 30: Latch design 1B.

There will be several of these hinged latches around the bottom of the surface buoy. They will hold the weight of the anchor when the buoy, as a compact unit, is lifted upward with a crane.

As the buoy is being held over the water, the impact of both buoy hitting the ocean's surface will generate enough force to push the anchor against the buoy momentarily. This action will lead to the pressure on the clamp holding the anchor to disappear allowing the anchor to release and fall safely to the ocean floor keeping the surface buoy at the surface.

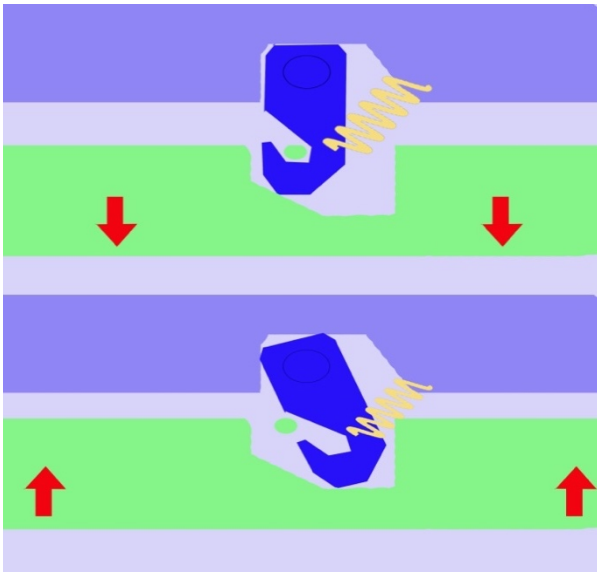


Figure 31: Spring loaded latch design.

This design was changed after further study into this process. It was seen that the weight holding latches could be unreliable. Whilst keeping the main design concept of them, it was adapted slightly.

It was decided that the latches would be more reliable if an automatic spring mechanism was built in. This would ensure the release of the anchor to the ocean floor. The design chosen is shown in figure 31.

Here is is shown that the anchor (green) is attached to the surface buoy (blue) by a latch that is holding the weight due to the direction of force that the anchor contains.

In the top half of the image, it shows that the force of gravity pulling the anchor downward is what holds the two parts together, making it an assembled unit. However, upon impact with the water the direction of force changes and the anchor is pushed upward causing the surface buoys latches to release the anchor. This process is helped with the use of a spring (yellow) that can ensure that the latch doesn't return to the previous position. These latches are crucial to ensure to the design of a smaller more compact design as it releases the anchor upon deployment, which was one of the team's main criteria.

To help spread the weight of the anchor evenly across the bottom of the buoy the latches are equally spaced on the underside of the buoy. This decreases the pressure on each latch in order to hold the heavy anchor in position. To further help distribute the weight of the buoy the latches are screwed into an internal frame (see figure 32 below) that is attached to the underside of the buoy. The material of the frame is cast iron which is a very strong and heavy metal. The frame will have the double purpose of acting as the counter weight for the surface buoy. This will help to keep the buoy in an upright position.

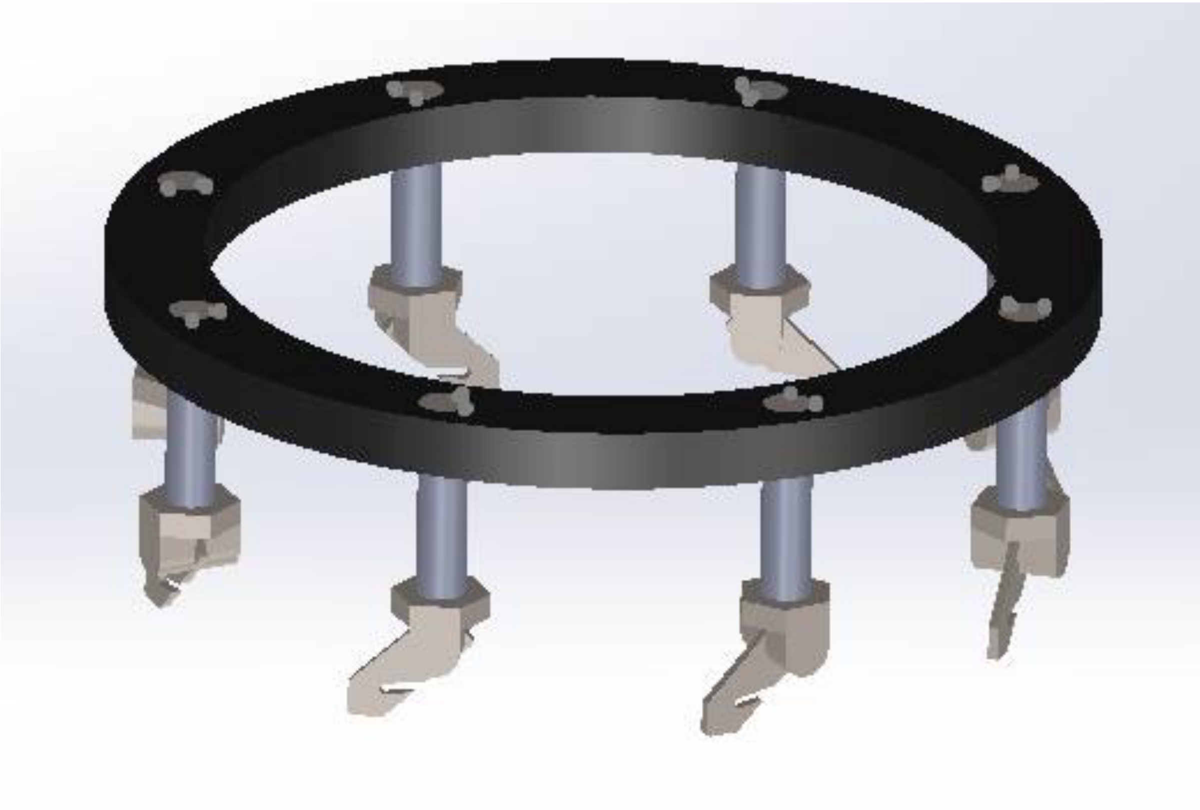


Figure 32: The final latch design.

6.3 Recovery

When recovering the buoy at the end of its life, it is important to recover the seismometer. This is because the main bulk of the anchor will remain on the sea bed after recovery. In order to do this the team had to find a way to release the seismometer from the anchor. This will be achieved by using an acoustic release (shown in figure 14 below).

Figure 33: An acoustic release.

An acoustic release is a remote controlled latch that can be controlled from distances of up to 6000m. The standard release is motor actuated, alternatively a relay output may be provided to energise an external mechanism.

The battery life of the package is dictated by how often the latches are used. The mechanism only draws power during the attachment and release when the motor is driven.

The transponders have a single-chip microcontroller at their heart for timing and control functions. The transponder remains in a low power sleep mode until commanded by the Transponder Control Unit. This means that the battery life of these mechanisms can last anywhere from three months to ten years depending on the size and use of the attached batteries.

However, as the project team will be using an innovative new coiled cable the remote controlled acoustic release will not be necessary in this design. The team will use mechanical release clips that will function on command by sending an electromagnetic current down to the clips releasing the seismometer from the surface buoy. This is shown in figure 34 below.

Figure 34 shows the coiled cable from the surface buoy attaching to both the anchor and seismometer at the bottom of the ocean. The seismometer will still be connected to the anchor, but won't have the ability to float away. This relieves the tension between the surface buoy and the seismometer through the steel coiled cable and also allows for more accurate data. This is due to the fact that there should not be any interference from the anchor in the data.

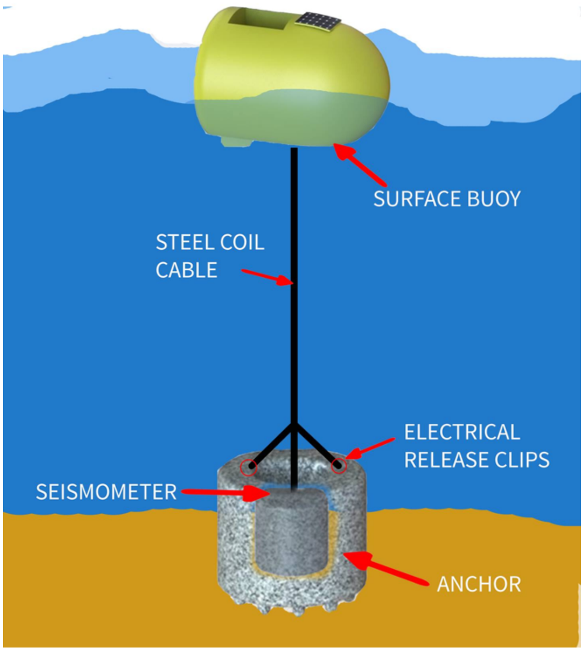


Figure 34: A diagram showing the position of the mechanical release clips on the buoy.

Appendix

In order to calculate the mass of the counterweight the following equations were solved.

Where:

F = buoyancy (N)
V = volume of buoy below water (m^3)
ρ = density of sea water (1025 kg/m^3)
g = gravity (m/s^2)
m = mass of surface buoy (kg)

The neutral buoyancy line is assumed to be in the middle of the buoy (in the chord direction).

Buoyancy Force = Weight

$$F = mg = \rho V g$$
$$\therefore m = \rho V$$

In order to calculate the volume of the buoy below the buoyancy the following equation was used. This is an approximate value.

$$V = (400)^2 \times \pi \times \frac{1}{2} \times 700 + \frac{1}{3} \times \pi \times (400)^3 - 250 \times 88 \times 950$$
$$V = 222049832\ mm^3$$
$$\therefore V = 0.222049832\ m^3$$

$$m = 1025 \times 0.222049832$$
$$\therefore m = 227.6kg$$

The sum of the following components is equal to the mass of the surface buoy without the counterweight.

Mass of:

Electronics compartment = 9.877kg
Coiled cable mechanism = 10.423kg
Coiled cable mechanism core = 2.808kg
Motor = 57.959kg
Fin = 0.409kg
Buoy body = 119.330kg
Motor stand = 0.883kg

$$m = 9.877 + 10.423 + 2.808 + 57.959 + 0.409 + 119.330 + 0.883$$
$$\therefore m = 201.689kg$$

Therefore, the mass of the counterweight is as follows:

$$m = 227.6 - 201.689$$

$$\therefore m = 25.911kg$$

In order to calculate the mass of the anchor the following equation was solved.

ρ = density of concrete (2300kg/m^3)
V = volume of anchor (m^3)
m = mass of anchor (kg)

$$m = \rho V$$

$$V = \pi \times (0.25)^2 \times 0.4 + 5 \times (0.04)^2 \times \pi \times 0.1$$
$$\therefore V = 0.08105 m^3$$

$$m = 0.08105 \times 2300$$
$$\therefore m = 186.415 kg$$

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