Wave Energy Conversion on Shallow Coast

James Bevan

Eivind Hammersland

Bachelor's thesis in Subsea Technology

Bergen, Norway 2020

Høgskulen på Vestlandet

Jamen Bevan, Eivind Selvik Hammersland

Wave Energy Conversion on Shallow Coast

James Bevan

Eivind Hammersland

Department of Mechanical- and Marine Engineering

Western Norway University of Applied Sciences

NO-5063 Bergen, Norway

IMM 2020-M90

Jamen Bevan, Eivind Selvik Hammersland

Høgskulen på Vestlandet

Fakultet for Ingeniør- og Naturvitskap

Institutt for maskin- og marinfag

Inndalsveien 28

NO-5063 Bergen, Norge

Norsk tittel:	Konvertering av bølgeenergi ved langgrunn kyst
Author(s), student number:	James Bevan, 571706
	Eivind Hammersland, 181753
Study program:	Subsea Technology
Date:	May 2020
Report number:	IMM 2020-M90
Supervisor at HVL:	Saeed Bikass
Assigned by:	Waveco
Contact person:	Inge Bakke
Antall filer levert digitalt:	1

Preface

This assignment was given to us by Inge Bakke, the CEO of Waveco AS. It is the bachelor thesis for the Subsea technology – Operation and Maintenance study program. Our supervisor for this assignment is Associate Professor Saeed Bikass. This assignment is the fifth that has been done at HVL for Waveco AS

The main motivation for choosing this assignment was to work with product development, with potential to combine theoretical and practical work.

We would like to thank Inge Bakke for his guidance and input, and for being there to answer any questions we had regarding the assignment. We would also like to thank our supervisor Saeed Bikass for his support and guidance during this assignment.

Jamen Bevan, Eivind Selvik Hammersland

Abstract

As the world's population is increasing, as well as our energy needs, the world is constantly looking for alternatives to fossil fuels to meet this high and increasing demand. Wave energy is an emerging method for creating sustainable energy that has gained increased interest in recent years. There is great potential for energy production using waves but is currently not being utilized to its full potential, due to a lack of research, development of concepts, and willingness to invest.

In our project we look at potential concepts for converting wave energy. Our project also had the aim to create a concept for a wave energy converter specifically for shallow ground shores, with the aim of replacing diesel generators in emergencies. It is therefore needed to be easily transported and installed, with the ability to run with little to no maintenance for about 30 days.

We explored two possible concepts, one for using wave energy for converting saltwater to freshwater using reverse osmosis, and a concept for converting wave energy into electrical energy. These concepts were used to create 3D models with the intention to 3D print and test them. However, due to unforeseen circumstances a more theoretical analysis was performed. A six-hats analysis was used to determine which of our designs had the most potential.

Our analysis showed that the shortcomings of the reverse osmosis design outweigh its benefits. We found that using wave energy to create freshwater from saltwater using reverse osmosis, although having potential, requires further development for this concept to be ready for testing. This would involve improving the mechanical energy transfer from the turbine to the pump and developing turbine further.

We determined that the idea of converting wave energy into electrical energy had the best potential, and our design was based on using a rotating generator positioned inside the turbine to convert the rotation to electrical energy.

Further testing needs to be done on the use of a turbine on shallow coasts for electricity generation. This should include performance testing a 3D printed prototype in a wave tank to determine the designs ability to capture energy from the waves. This can be done using a mechanical brake test to find the rpm and torque, to determine the efficiency. Using the efficiency, the viability of the design can be decided.

Further development should also include testing the anchoring system to determine its usability in a real-world situation.

Sammendrag

Ettersom verdens befolkning øker, øker også energibehovet noe som gjør at vi stadig ser etter alternativer til fossilt brensel for å møte verdens energibehov. Bølgeenergi har fått mer oppmerksomhet de siste årene på grunn av dette. Bølgenes potensiale er veldig stort, men vi klarer ikke å utnytte dette potensialet på grunn av manglende forskning, liten utvikling innenfor sektoren og mangel på investorer.

Vårt prosjekt går ut på å lage et konsept for en bølgeenergikonverter til langgrunn kyst som kan erstatte et dieselaggregat dersom en naturkatastrofe skulle oppstå. Den skal være lett å transportere og installere, og den skal lage strøm eller vann i 30 dager med lite til ingen vedlikehold.

Vi har sett på to mulige konsepter hvor den ene bruker bølgeenergi til å lage ferskvann fra saltvann ved hjelp av reversert osmose og den andre lager vanlig strøm. Disse konseptene blei tegnet i 3D med en intensjon om å bruke 3D-printing til å teste begge kandidatene i en bølgetank. Dette blei dessverre ikke mulig grunnet en uforutsette hendelser og det blei istedenfor gjort flere teoretiske analyser. En «seks tenkehatter» analyse blei brukt for å finne ut av hvilket design som hadde størst potensiale.

Vår analyse viser at designet med reversert osmose har flere problemer enn fordeler. Vi fant ut at å bruke bølgeenergi til å lage ferskvann ved hjelp av reversert osmose har et stort potensialt, men mer utvikling trengs før denne ideen kan testes. Dette inkluderer å finne en mer effektiv måte å overføre den mekaniske energien fra turbinen til pumpen og utvikle turbinen videre.

Vi fant ut at ideen om å konvertere bølgeenergi til elektrisk energi har størst potensiale, og vårt design er basert på å bruke en roterende generator plassert på innsiden av turbinen til å omdanne turbinens rotasjoner til elektrisk energi.

Videre testing må gjennomføres for å se hvor godt en elektriskbølgeenergikonverter fungerer på langgrunn kyst. Dette burde inkludere testing av en 3D-printet prototype i en bølgetank for å se om designet har de egenskapene som trengs for å danne energi fra bølger. Dette kan gjøres ved å bruke en mekanisk bremsetest for å finne turtallet og dreiemomentet og bruke disse til å finne turbinens effektivitet. Ved hjelp av effektiviteten kan vi finne turbinens levedyktighet og avgjøre hvilket design som er best.

Videre utvikling burde også inkludere testing av ankringssystemet for å sjekke at det funker i virkeligheten og ikke bare i teorien.

Table of contents

1. Introduction

1.1 Background

With the growing awareness around climate change, an alternative to diesel generators for emergency backup energy would be desirable. Diesel generators are generally used in areas without a connection to a power grid, or as an emergency backup if problems with the power supply from the grid arise. Another use is to produce clean drinking water in areas lacking infrastructure, for example parts of Africa. Typically, the diesel generators and water producing equipment are provided by charities [1]. These generators consume diesel to produce electricity, which in turn produces carbon dioxide, which is a greenhouse gas. To reduce these greenhouse gas emissions other energy sources such as solar, wind, and wave energy could be used. Of these options, wave energy has the highest energy density and provides a more consistent energy supply when compared to solar and wind [2]. Oceans cover 2/3 of the planet, making wave energy a huge resource that could be taken advantage of.

However, wave energy is not without its flaws. Waves are complex and create issues with the designing and production of devices that effectively and efficiently convert wave energy into a usable form. Waves are mostly caused by winds, the friction between the wind and surface water disturbs the surface, creating a wave crest. Waves can also be caused by the gravitational pull of the sun and moon; these waves are called tidal waves (or tides). Wave energy also has problems connected to generally requiring some or all the installation to be in the sea, Seawater contains salt and microbes that can lead to corrosion and/or growth forming on the equipment. Being in the sea also means the equipment may be in proximity to marine creatures such as fish, shellfish, seals, or even whales depending on the location.

Shallow coastlines make the installation and retrieval of temporary installations for emergency energy more viable and the short distance to land means less cables (less loss due to impedance and less production cost). On the other hand, coastal water flow is highly turbulent and factors such as long-shore drift, rip currents, and riptide come in to play and can make installation of WECs difficult.

The provider of this assignment, Waveco AS, is a technology innovator dedicated to providing alternatives to make the global green energy transformation possible. This assignment is based on an America-based challenge, called waves to water, which is a 4-stage contest with a prize pool of $2.5M. The contest aims to accelerate technology innovation in wave energy powered desalination systems, as these technologies have the potential to deliver clean water to communities for disaster relief purposes [3]. This goal of the assignment is to design a Wave energy converter (WEC) that can aid a catastrophe-struck area. Calculations will be made to estimate the potential output of this WEC, and a testing protocol will be created.

1.2 Objectives/scope

The main objective of this project is to design a WEC to provide a short-term energy solution in an area affected by a catastrophe or a general loss of power that provides power for at least 30 days with little to no maintenance. The WEC is to be designed for a shallow coast and be able to fit into a container no larger than one cubic metre ($1m^3$), due to aerial transportation.

This main objective can be separated into three subobjectives that overall would satisfy the requirements given in this task. These subobjectives are

1: Find a fitting design that theoretically would work for the scenario described above.

2: Design a testing protocol for the design.

3: Prepare formula to calculate the potential of the design, once tested.

The first subobjective (the design phase) can then be separated into four categories to aid the design phase. These four categories are

1. Wave Interactor (absorbs/takes up force from waves)
2. Converter (converts absorbed force to usable output)
3. Casing (covers mechanical and electrical components, protection)
4. Anchoring system

1.3 Waveco

Waveco AS is a small company located on the western coast of Norway, in a little village named Selje. The company was founded by Inge Bakke in 2015 to develop his patented deep-sea wave power idea. Cooperating with several local industries and sponsors, Waveco has been able to make a model of the patented idea, and Inge hopes to realize and make a fully working device within a few years. The project given to the group reflects the company`s vision; to develop better and greener energy solutions for the next generations.

1.4 Requirements and Limitations

1.4.1 Requirements

The WEC is to be designed to:

- Fit inside one cubic meter (45x48x42 inches) due to transport restraints.
- Be installed with ease.
- Ideally operate with little to no maintenance for 30 days.
- Not weigh more than 650 kg.
- Produce at least 40 liters of purified, drinkable water every day from saltwater.
- Withstand harsh weather conditions.

1.4.2 Limitations

Despite being patented all the way back in 1799, wave energy is rather underdeveloped compared to the more established renewable energy sources. This especially applies to energy conversion on shallow coasts.

The following assumptions have been made:

- Smooth slope towards land
- Stationary sand that does not significantly affect the flow
- Seawater is assumed to be free from waste and pollution

Due to unpredicted circumstances, we are unable to:

- 3D-print and produce a working prototype
- Perform testing in a wave tank

The Wave characteristics we can expect on the coast:

- water depth of 2-5m [4]
- a wave height of 1-3m [5].
- the waves will have a wavelength of more than 7 meters.

2. Literature Review

2.1 Waves

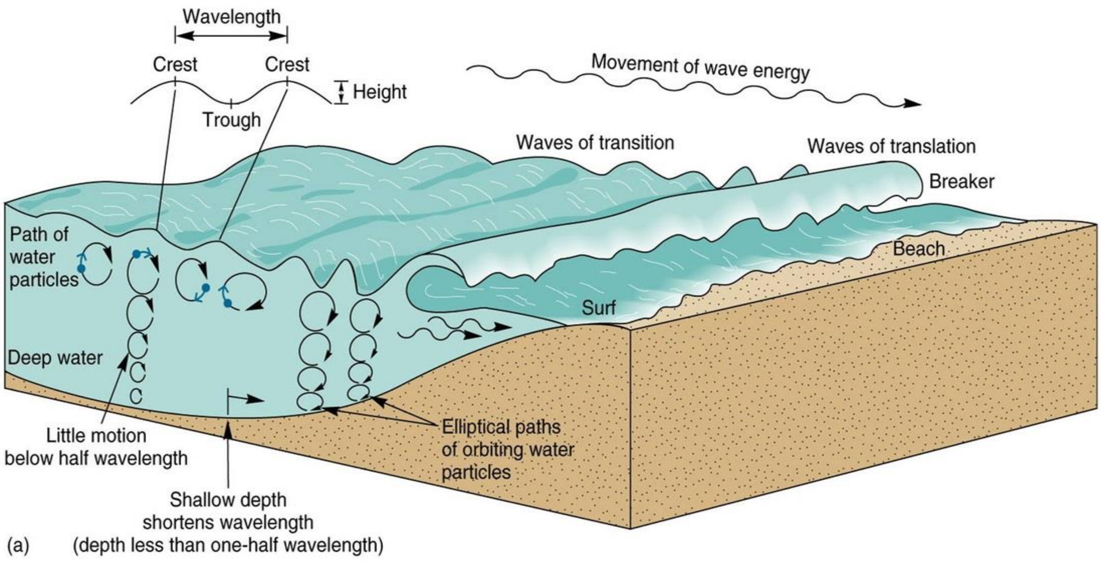


Figure 1) Coastal Waves [7]

As written by J.B. Zirker in The Science of Ocean Waves: Ripples, Tsunamis, and Stormy Seas [6], ocean waves can be explained by observing a slinky or a jump rope. Ocean waves are not the movement of water toward the coast, but rather a circular oscillation of the surface water and a transfer of energy towards the coast, as displayed in the figure above. As this energy passes through water, a crest and trough are created. A crest is the maximum point on the wave, with the maximum positive displacement from the surface. A trough is the minimum point on the wave, with the maximum negative displacement from the surface. The distance between two crests is defined as the wavelength. A period is the time taken for a wave to complete a cycle. In other words, the time delay between two crests passing the same point. The period is the inverse of the frequency of the wave: $Frequency = \frac{1}{Period}$

When deep sea waves enter an area of shallower water (typically when the depth is less than half the wavelength), the seabed slows the speed of the wave. This leads to wave shoaling, where the wavelength decreases due to the change in depth thus increasing the height of the wave while frequency remains constant leading to a higher energy density. If the water depth is 1/20th of the wavelength, this effect is so strong that the wave topples over as a breaker. This leads to a forward swash of water, followed by the backwash which creates the undertow. This phenomenon would be advantageous to harness as there is a lot of energy here. Most wave energy technology converts the up and down motion of waves into electrical or hydraulic energy; therefore, the height of the waves is typically an important factor in energy production from waves. Coastal hydrodynamics vary greatly depending on the formation of the seafloor under and the water involved. Where a wave breaks depends greatly on the wave characteristics e.g. wave height, wavelength, and direction of movement. How a wave breaks depends on not only the steepness of the slope towards land, but also whether the seafloor consists of shifting sands or solid rock and whether the slope varies with peaks and valleys [7]. The seafloor topology and incoming deep-sea waves are therefore the main contributors to wave characteristics.

When waves interact with an object, this object will typically experience one or more of the following motions (Figure 2):

- Pitch, an up and down rotation around its transverse axis
- Roll, a tilting rotation around its longitudinal axis
- Yaw, a tilting rotation around its vertical axis
- Heave, a linear up and down motion
- Sway, a linear transverse motion
- Surge, a linear longitudinal motion

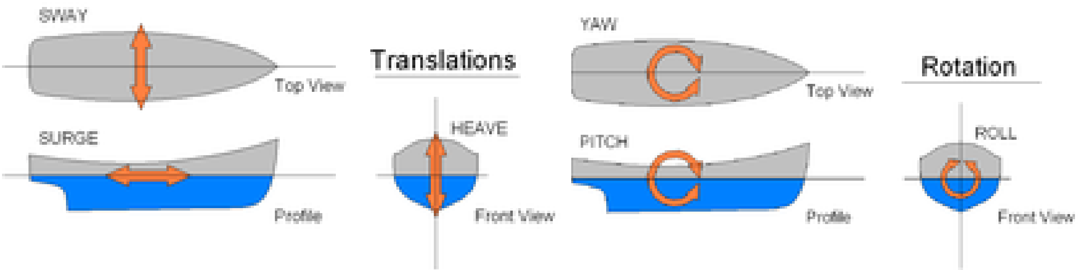


Figure 2) Boat motion [9]

2.2 Wave Energy

The U.K. could potentially get as much as 75 percent of its energy needs from the waves and tides combined and U.S. could generate as much as 25 percent of its energy needs. [8] As discussed by Manasseh et al. in [9], wave energy has the potential to not only supply the energy need of a significant part of the global population, but also as a form for coastal protection. This coastal protection is intended to mitigate flooding and coastal erosion and degradation of the coastline. There is estimated to be a total potential of around 3.5 TW available from wave energy globally [10]. In

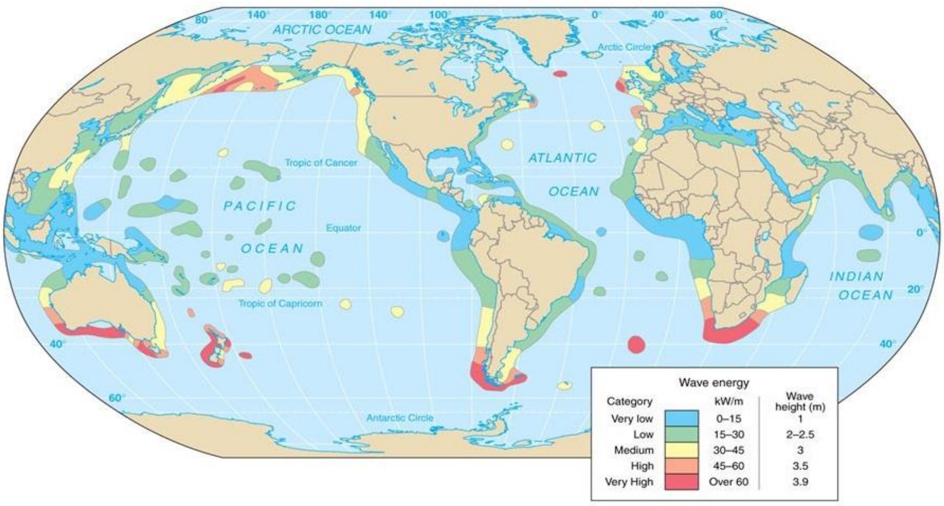


Figure 3) Global Wave energy resources [13] shows more wave energy is readily available in the southern hemisphere, typically on the western coasts.

2018 the total energy consumption, from all sources, of the world was around 157,000TWh [11]. This gives an average energy need of around 18 TW, meaning that if all the waves in the world's coastal regions could be harnessed, around 1/5th of the global energy requirement would be covered. Most of this energy is predominantly in the southern hemisphere and the western coasts of the mainland (Figure 3).

2.3 Wave Energy Flux

Wave energy flux is the measure of power available per meter of the wave front (wave crest). Blackledge et al. [12] state the formula for wave flux (F) as:

$$F \approx 0.5H^2T \quad (1)$$

Where H is defined as the height of the wave in metres and T as the period of the wave in seconds.

The wave height can be expected to vary. The following table (TABLE 1) is information gathered from the table 8.2 on page 241 in Essentials of Oceanography [13]. The wave height and period from the table have then been inserted into (1) to find the energy flux.

TABLE 1

Calculated energy flux for each given wave height and period

Average height (m)	Period (s)	Energy Flux (kW/m)
0.3	3.2	0.144
1.8	6.2	10.044
5.1	9.1	118.346
10.3	12.4	657.758

The energy flux varies greatly depending on the wave height due to this being to the power of two. Any WEC created should have a potential energy harvesting ability that is as close as possible to the Energy Flux of the incoming waves. However, turbines typically only take advantage of 30-60% of the available energy [14]. The maximum energy flux should be considered as the upper limit as it is impossible to harvest more energy than what is available.

2.4 Available Ideas and Technologies

There are typically eight main types of wave energy converter (WEC):

1. Attenuator

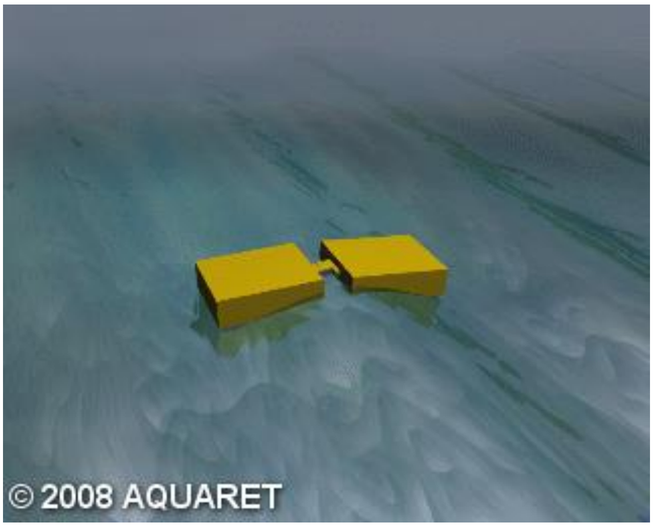


Figure 4) Attenuator

An attenuator (Figure 4) is a floating device which consists of two or more arms and a crank system between. As waves pass, these arms experience pitch, essentially folding together over the wave crest and energy is captured.

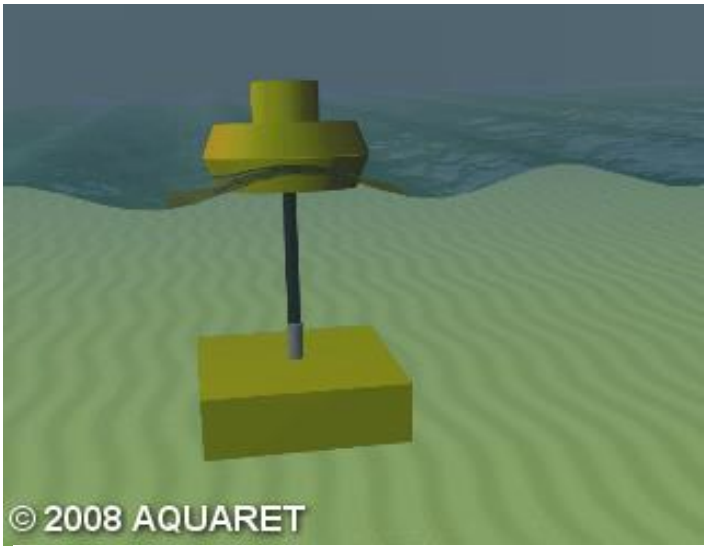


Figure 5) Point Absorber

2. Point Absorber

A point absorber (Figure 5) consists of a buoyant top, that experiences heave, and a secured pole or similar. Energy is captured by the relative movement of the floating top moving up and down the pole.

3. Oscillating wave surge converter

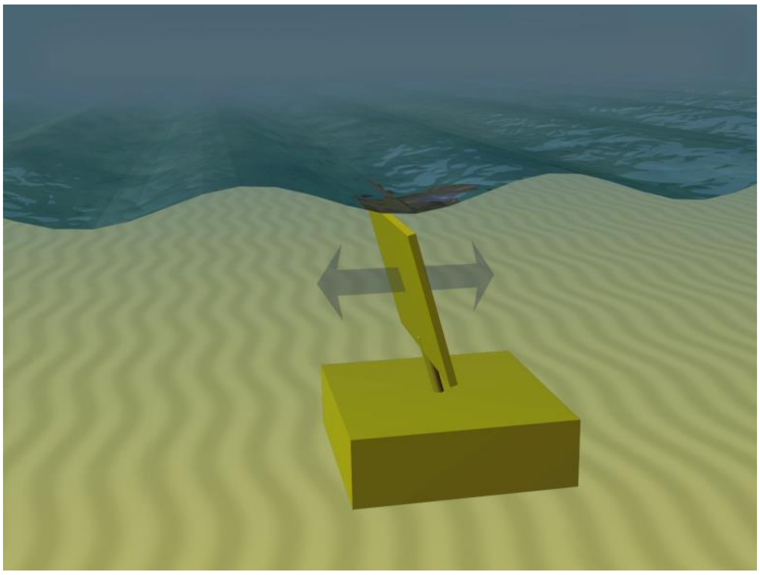


Figure 6) Oscillating wave surge converter

Oscillating wave (Figure 6) surge converters consist of an arm that oscillates as a pendulum on a pivoted joint in response to the waves.

4. Oscillation wave column

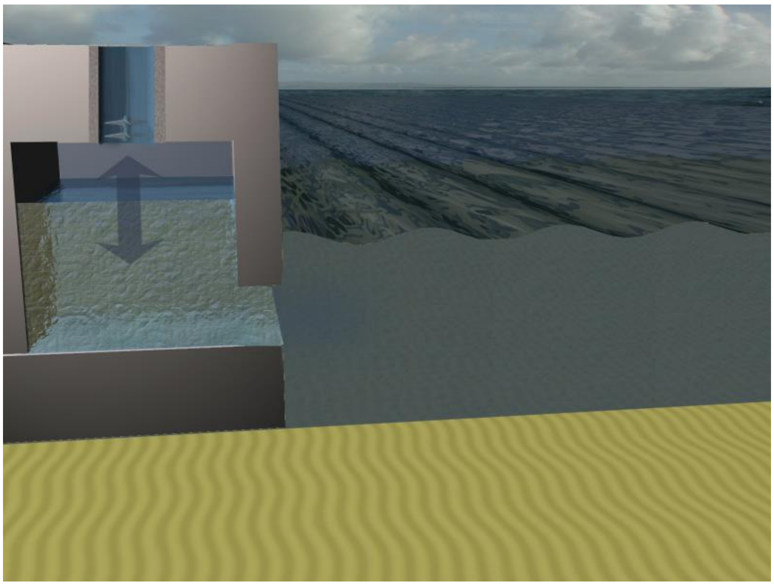


Figure 7) Oscillation Wave column

An oscillating water column (Figure 7) is a partially submerged structure installed on or near land. Water can enter the bottom and the water level rises and fall with the incoming waves, which compresses and decompresses the air within the structure. A turbine is installed with an opening on top to allow the flow of air to and from the outside atmosphere. The compressed air flows through the turbine, spinning in one direction, and as the water level falls, air flows back through causing the turbine to spin in the opposite direction. This rotation of the turbine is used to generate electricity.

5. Overtopping/terminator device

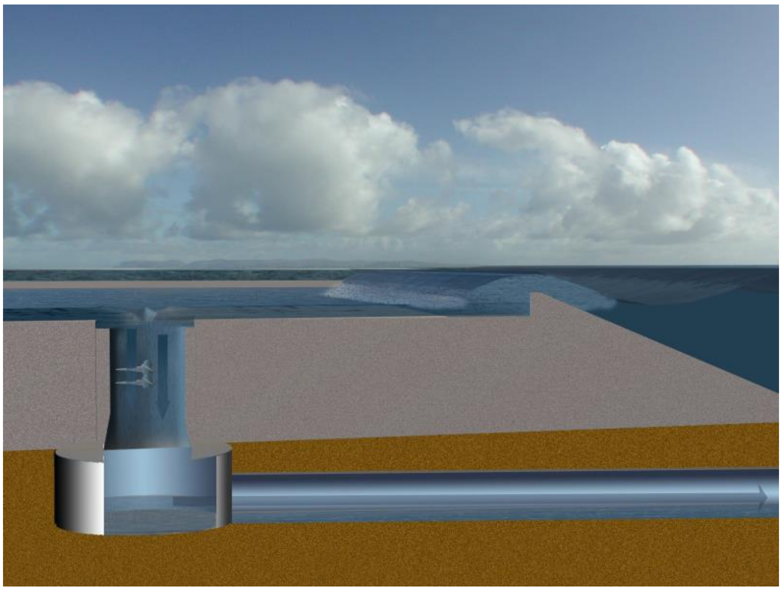


Figure 8) Overtopping Device

Overtopping devices (Figure 8) capture water as waves break into a storage reservoir. The water is then returned to the sea passing through a turbine which generates power.

6. Submerged Pressure differential

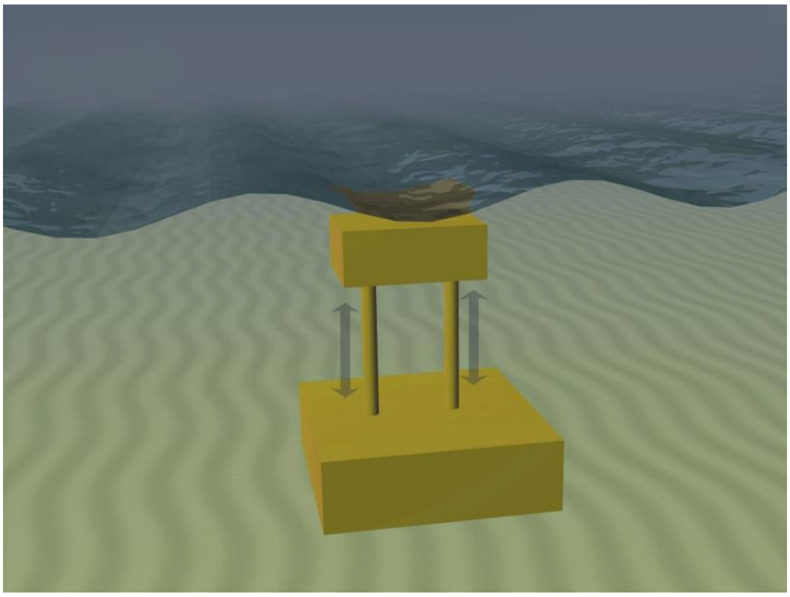


Figure 9) Submerged pressure differential

Submerged pressure differential devices (Figure 9) are typically located near shore and attached to the seabed. The pressure difference between the wave crest and trough is used to pump fluid through the device and generate electricity.

7. Bulge Wave

Bulge wave technology (Figure 10) consists of a rubber tube filled with water, moored to the seabed,

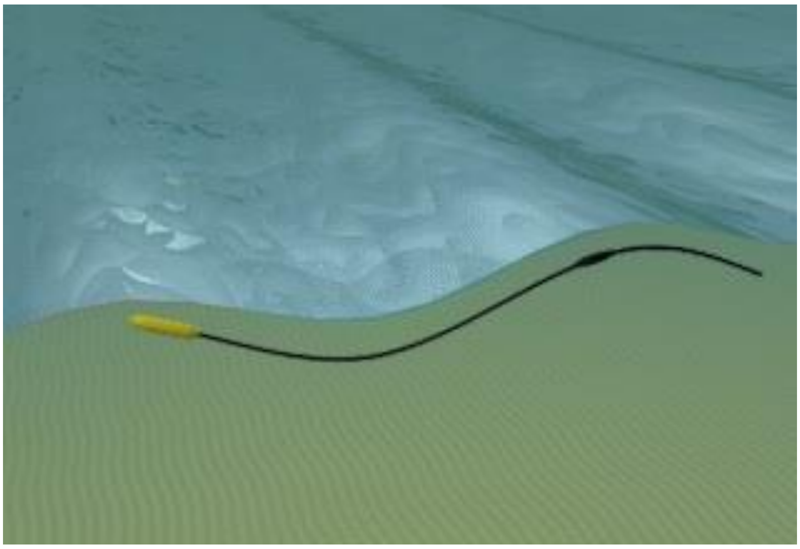


Figure 10) Bulge wave

and facing oncoming waves. Water enters the end and waves that pass the device create pressure variations along the length of the tube, creating a “bulge”. As this bulge travels along the tube it grows, and the energy is harvested via a turbine in the other end, where the water returns to the sea.

8. Rotating Mass

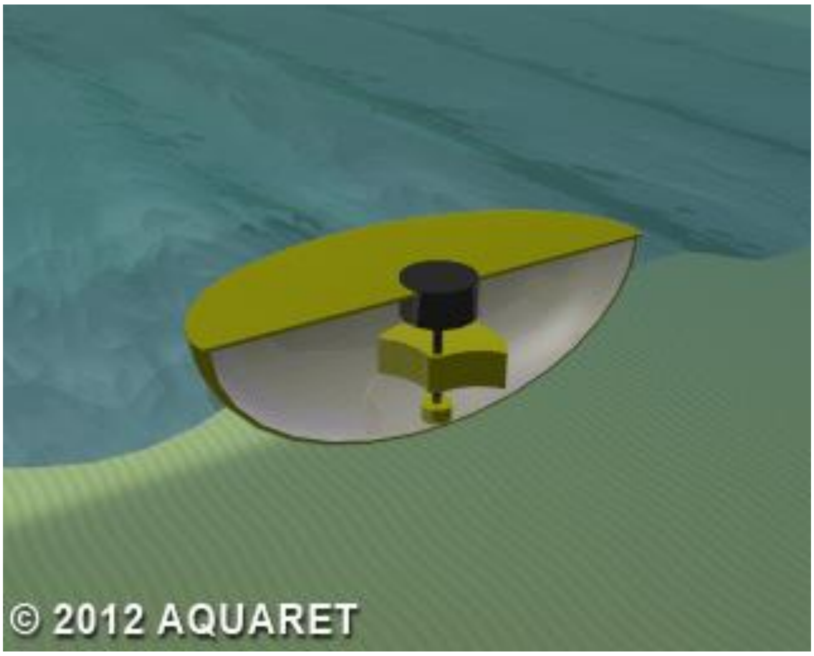


Figure 11) Rotating mass

Rotating mass devices (Figure 11) consist of a large body that sways and heaves in the motion of the waves. The relative rotation between the body and an inner axle is used to generate electricity.

These types of WEC [15] are normally for long-term offshore installations. Typically, the types of onshore installations used previously have been large constructions made of concrete or steel, intended for long-term usage. These are far too large and heavy to be considered for aerial transport, and therefore are not considered for this project.

2.5 Reverse Osmosis

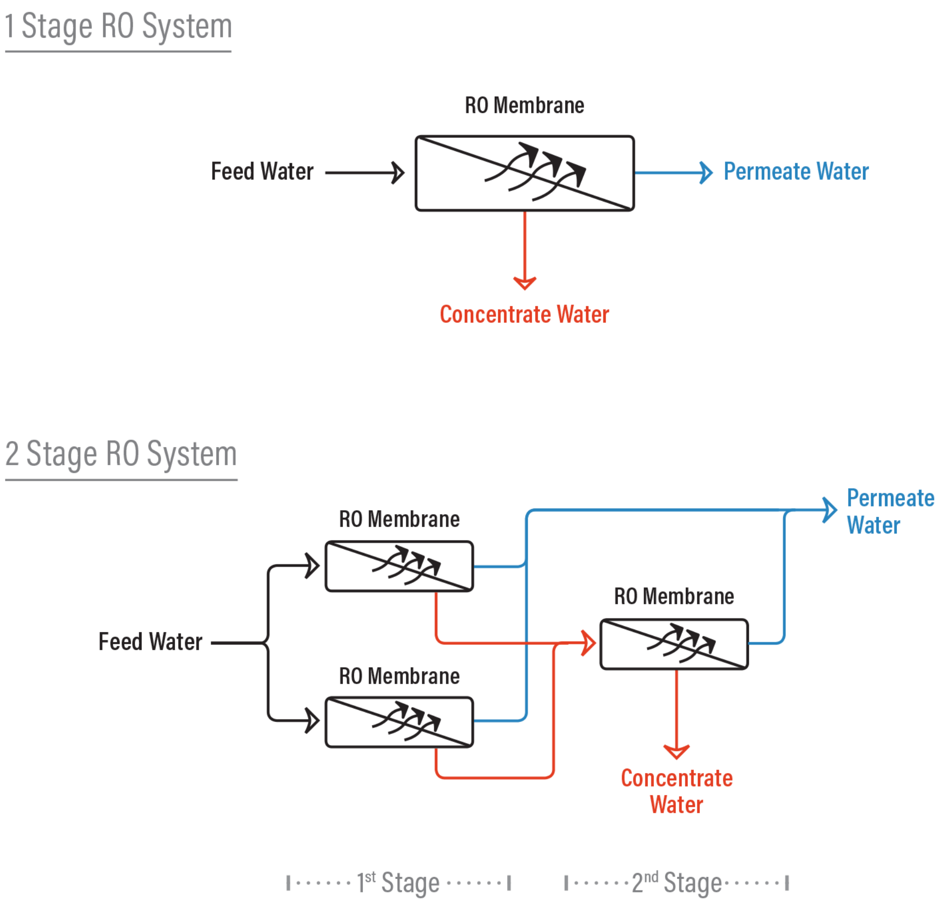


Figure 12) Reverse Osmosis (RO) [18]

To acquire drinkable fresh water from a wave energy converter, a process called reverse osmosis is to be used. It is the opposite of osmosis, a process where particles dissolved in water pass through a membrane from the side with low concentration of solute to high concentration (osmotic gradient). Reverse osmosis requires pressure to work against the osmotic gradient, i.e. from high concentration of solute to the lower concentration. A reverse osmosis membrane is provided a “feed solution”, in this case salt water from the sea. This solution proceeds through the membrane and becomes the “permeate”, in this case fresh water. The impurities in the salt water do not pass through the membrane and are instead flushed away from the membrane as more salt water enters the chamber, this impurity solution is defined as the “concentrate”. This concentrate will then be released into the sea, this requires a non-return valve to prevent flooding of the inner chamber which would stop the membrane performing its desired process. For reverse osmosis to happen, we need a pressure higher than the osmotic pressure P_0. This is typically delivered by a pump driven by electricity from either a diesel generator or power grid. Reverse osmosis is often used to produce water for sailboats, offshore platforms, and in household drinking water purification systems. This process requires large amounts of energy, salt water requires more energy due to a higher concentration of impurities.

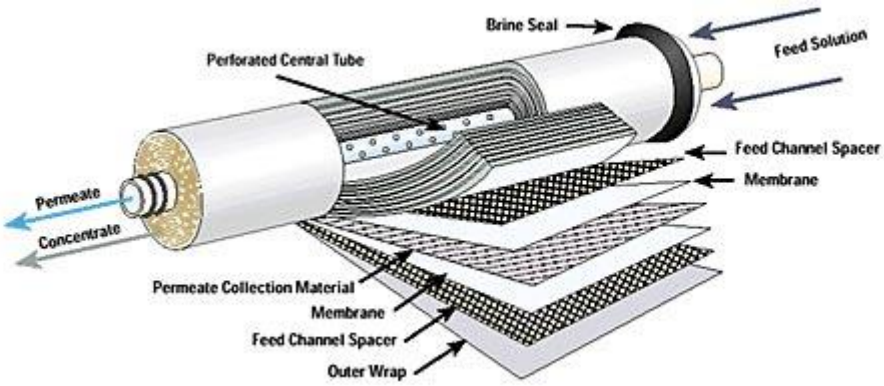


Figure 13) Reverse Osmosis membrane [19]

In our case, the required pressure will be supplied from the turbine via a crank arm that is connected to a piston.

The osmotic pressure P_o is given by the van 't Hoff equation:

$$P_o = \frac{nRT}{V'} \text{ [16]}$$

Where V' is the volume of pure solvent in which n mols of solute are dissolved. This can be converted into a constant c, mols of solute per volume of solvent. The new formula for osmotic pressure becomes:

$$P_o = cRT$$

Where R is the gas constant, R= $8.31446261815324 \times 10^3 \frac{\mathrm{L*Pa}}{\mathrm{K*mol}}$

and T is the temperature in Kelvin, this will vary depending on where the device is positioned. For simplicity we will use the average temperature of the ocean surface, which is about 17 degrees Celsius. [17]

This gives T= 290.15K.

c is the total concentration of all ions dissolved in the water. On average seawater has a salinity of approximately 3.5%, this means it contains 3.5g of salt for every 1 litre of seawater. There are a variety of different ions dissolved in the water, these are shown in the table (TABLE 2) below.

TABLE 2

The chemical properties of elements found in seawater

chemical ion	valence	concentration ppm, mg/kg	part of salinity %	molecular weight	mmol/ kg
Chloride Cl	-1	19345	55.03	35.453	546
Sodium Na	+1	10752	30.59	22.990	468
Sulfate SO4	-2	2701	7.68	96.062	28.1
Magnesium Mg	+2	1295	3.68	24.305	53.3
Calcium Ca	+2	416	1.18	40.078	10.4
Potassium K	+1	390	1.11	39.098	9.97
Bicarbonate HCO3	-1	145	0.41	61.016	2.34
Bromide Br	-1	66	0.19	79.904	0.83
Borate BO3	-3	27	0.08	58.808	0.46
Strontium Sr	+2	13	0.04	87.620	0.091
Fluoride F	-1	1	0.003	18.998	0.068
[18]					

This gives a total concentration of $1119.559\ mmol/kg$, which can be written as: $1.12\ mol/kg$

The density of seawater at 17 degrees Celsius is $1026\frac{kg}{m^3}$ [19], which can be written as $1.026\frac{kg}{L}$

This gives the value for c:

$$c = 1.149\ mol/L$$

Using these values in the van't Hoff equation gives a result of $2771kPa$, however, this value is the absolute minimum that must be achieved for reverse osmosis to take place. It does not take into consideration the pressure required to pump water into the chamber or to pump to land. The pressure should ideally be greater than this value for the process to take place within a reasonable time frame.

2.6 Electricity Generation

Electricity can be produced via a generator. A generator is a device that converts mechanical power into electrical power that can be utilized elsewhere. A commonly used generator is the electromagnetic generator. Electromagnetic generators have been developed in two configurations: linear and rotating. They are based on Faraday's law of electromagnetic induction, a law that describes how electrical circuits behave when interacting with a magnetic field. Faradays Law states that electrical current will be induced by a conductor when exposed to a changing magnetic field. The direction of this current is defined by Fleming's right-hand rule.

Linear alternators are electromagnetic generators that use motion in a straight line to produce electricity. They typically consist of a magnet passing through a coiled wire. As the magnet travels in one direction a positive current is produced, in the opposite direction a negative current, producing an alternating current (AC). This removes the need to use cranks and gears to convert linear motion to rotation.

Rotating electromagnetic generators can be either Alternating Current (AC) or Direct Current (DC), brushless or brushed. Brushed generators use carbon brushes to transfer electrical energy from the rotating centre coil out of the generator. Due to the brushes being in contact with rotating parts, friction occurs leading to energy loss and sparks developing, and the brushes are susceptible to breaking rendering the generator non-operational until the brushes are replaced. Brushless generators do not use brushes and typically have the coil stationary with magnets connected to the rotating axle. Brushless generators experience less friction, less energy loss as heat, and less interference caused by sparks. They are however more expensive.

Another type of generator is the Switched Reluctance Generator (SRG). SRGs use a switching system to activate and deactivate the load to different coil windings in the generator as the inner rotor rotates. The inner rotor is a solid salient-pole (has projecting magnetic poles) rotor. This switching system improves the usability and effectivity of the generator, but also increases the complexity of the electronics and thus the cost. Susitra et al. [20] describe SRGs as an option for electricity production in harsh environments such as wind energy conversion systems.

AC generators typically have an output voltage greater than 120V, DC generators typically have a lower output voltage. Low revolution per minute (rpm) DC generators are typically used for home wind turbines [21].

2.7 Energy Potential of a Subsea Turbine

The energy output for a wind turbine is calculated with the following formula:

$$P = \frac{\rho * A * v^3 * C_t * C_a}{2}$$

Where P is the power output of the turbine in watts, ρ is the density of the flow in $\frac{kg}{m^3}$, A is the swept area of the turbine blades in m^2, v is the velocity of the flow parallel to the axle in $\frac{m}{s}$, C_t is the extraction efficiency of the turbine (between 0 and 59.3% [22]), and C_a is the generator efficiency (typically above 80% [23]).

This formula can be applied to a subsea turbine, with the density of seawater = 1026kg/m^3. With a period of around 5s and a wavelength below 10m, the maximum velocity of water flow is $2m/s$. The maximum radius possible within 1m^3 is half a meter. Assuming a C_t of 30%, and a C_a of 80%, gives a maximum power output of around 770W. However, this is unrealistic as the water velocity is likely to be less. Calculating with a velocity of $1m/s$, gives a power output of 190W.

2.8 Design Choice using the six-hat method

During the development of the WEC the group has not been able to decide on which design is most efficient and most likely to work properly. The group has been unable to prototype and test even the smallest scale of the WEC. To accurately determine which design is better at fulfilling its purpose, a “six thinking hats” analysis [24] will be made comparing the two different ideas.

The “six thinking hats” analysis comes from the book “Six Thinking Hats” written by Edward De Bono in 1985. It describes different ways to think about a certain subject and can therefore be used on the overall design analysis. The idea is that different color hats metaphorically represents different ways of facing a problem before taking all into consideration when evaluating the final product.

White hat: Factual – The white hat is purely based on specific available data. It does not take incomplete experiments or tests into consideration.

Red hat: Emotional – The red hat is based purely on emotions and the feeling of the human beings involved in the project. This can range from getting emotionally invested in your own work to following your own gut feeling.

Black hat: Critical – The black hat helps to see everything that can go wrong with the project. It can almost entirely be referred to as *Murphy's Law*; everything that can go wrong will go wrong and needs to be taken into consideration.

Yellow hat: Positive – The yellow hat is based on the enthusiastic positivity of something that is well done. By complementing and being excited over things that might work, the yellow hat is the opposite of the black hat.

Green hat: Creativity – The green hat is used to push the already existing ideas even further. New concepts may be introduced to challenge the ones that are already existing.

Blue hat: Process – The blue and final hat concludes the thinking process, eliminating everything but the final verdict based on the prior five hats. It helps the users agree on what to do moving forward.

The two designs will be presented gradually in the following sections followed by a detailed explanation to each main part of a WEC in chapter 4. Since the idea behind each main part is similar on both designs, they can be explained together regardless of which design they are intended for. Afterwards the "six thinking hats" analysis will be used to decide which one is better in chapter 6.

3. Development of Ideas

3.1 Idea Phase

The first step in developing an idea was to roughly draw any ideas we had by hand, this allowed the group to visualise the ideas without wasting too much time modelling and/or printing the design. The first design the group came up with was based on abandoned watermills found all over Norway. It is a classic design of a concept that works well for its intention (Figure 14). The next figure (Figure 15) shows an idea based on using the raw force of a wave to harness its energy. The idea here was to use a spring-loaded plate that would convert the mechanical energy of the impact of the wave to electrical energy. The following picture (Figure 16) shows a floating buoy that would use the undertow and eventual riptide to create electrical energy. The idea was based on a grandfather clock where the turbine would always stay in the most optimal location based on the current undertow. The last picture (Figure 17) shows a stationary turbine located on the seabed that would harness energy from the waves, tides, and the undertow.

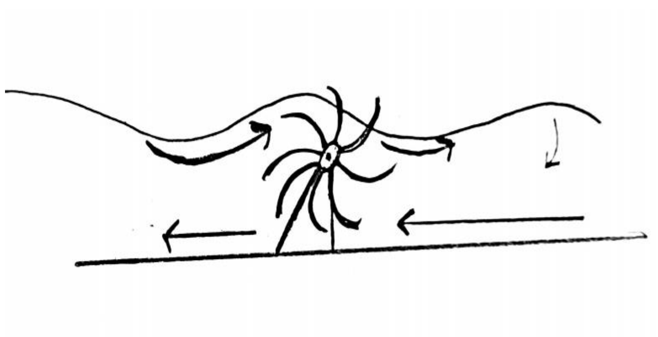


Figure 14) Inspiration taken from a classic water mill.

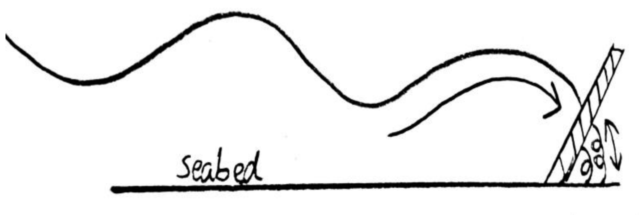


Figure 15) A plate that receives energy from the waves hitting it using spring coils

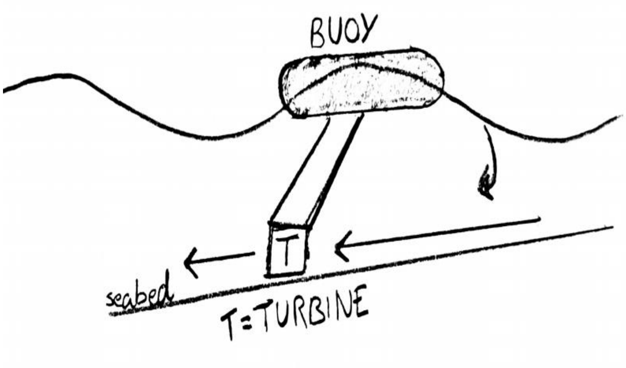


Figure 16) turbine mounted on an arm connected to a floating platform.

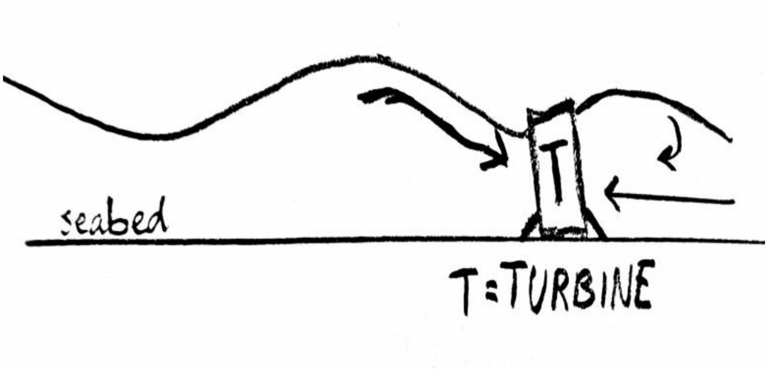


Figure 17) A turbine placed in the right area to take advantage of undertow, tides, and waves as they break

Taking a step back, the group tried to figure out why wave energy in general is so underdeveloped. The answer is simply that we humans have not found an efficient way to use waves to spin turbines. Almost all electrical energy humans create comes from heating up water and use steam to spin a turbine. So knowing that turbines is used to transform the mechanical energy of a substance into eletrical energy, the group needed to figure out why nobody has managed to use turbines to harvest the energy of the waves. The answer might lie in the fact that waves are only oscillating motions. To harness the energy of waves the group either had to think “outside the turbine”, or use a little bit in engineering ingenuity to make a turbine able to use the oscillating motions efficiently.

3.2 Modelling Phase

After exploring the brief concepts of water turbines, the group started briefly modelling different turbines based on the sketch designs. Using these sketches, the group were able to determine which of the sketches had potential. The watermill design is such a classic design meant for generating electricity where the environment is under controlled circumstances. Putting a windmill in the ocean would very likely destroy it, so after making a brief 3D sketch of it (Figure 20) the idea was not followed up further. The plate (Figure 15) was a fun idea, but it was not based on any theory or prior knowledge. Trying to come up with something completely new based on fiction is not worth while working on a lengthy assignment, so this idea was also disbanded. Since the group was convinced that turbines are the way to go, the group decided to work further on the ideas in figure 16 and figure 17.

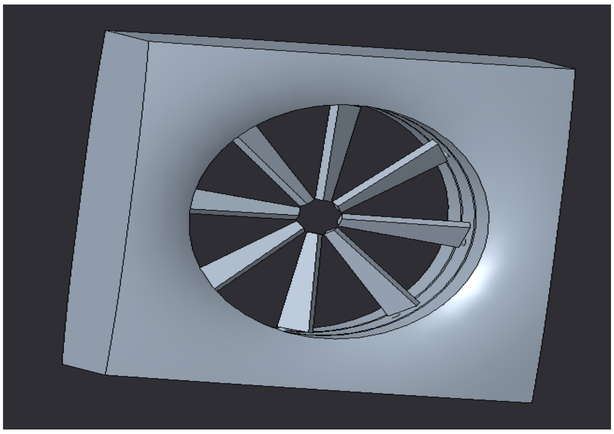


Figure 18) Turbine with the blades attached to the outside

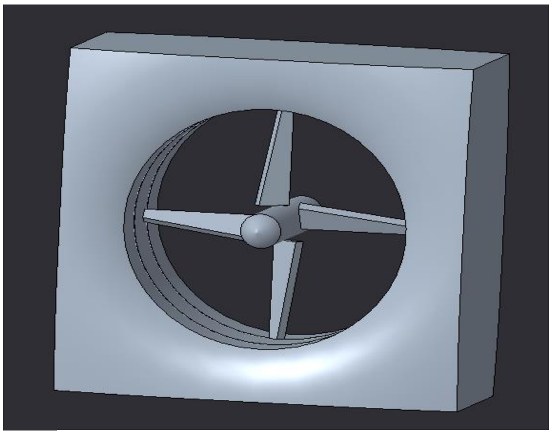


Figure 19) Turbine with blades attached to an axle in the middle

Figure 20) Rendering of the water mill idea

While sharing ideas and drawings with Waveco, the company helped the group by mentioning an important theory regarding turbines in general; Betz`s law. Betz`s law says that all Newtonian fluids including wind and water cannot be completely still after going through a turbine. In this case, if all the water stopped completely after going through the WEC no “new” water would be able to go through. Betz`s limit is set to 59,3% due to the geometrical limits of any given turbine. Even the most optimized turbine can achieve an energy output of 80% of Betz`s limit at best in theory, but realistically this number is much lower. Regarding the WEC, Betz`s law implies that more turbine blades equals more energy output, up to a certain limit. Waveco suggested no more than six blades per shaft to make it as efficient as possible regarding Betz`s law. This led to the group discarding ideas with more than 6 blades (Figure 22). The design with the central axle was improved and support arms were added to hold the axle in place while rotating and to add rigidity to the structure (Figure 21).

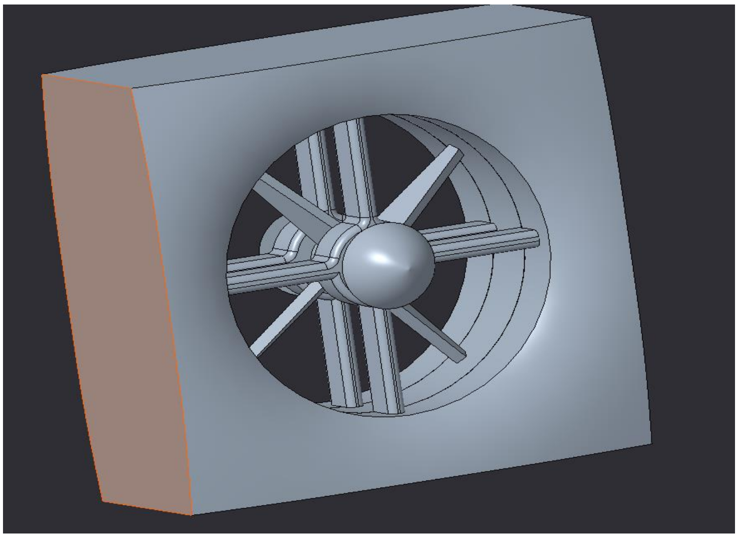


Figure 21) Turbine with a centre axle and support arms

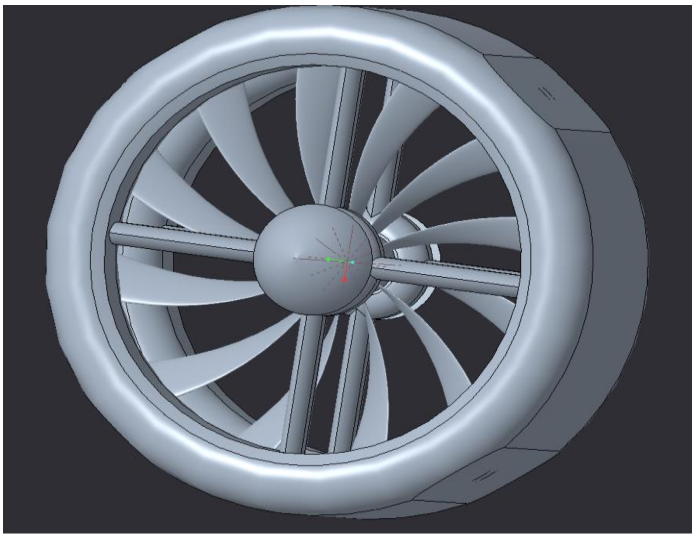


Figure 22). This iteration was drawn before the group had investigated Betz`s law

A six-propeller design (Figure 23-26) was also discussed. Due to the increased force interaction, this propeller design would require more stability. This stability is given in the form of an outer ring that the propeller blades are attached to. This ring then uses a form of pulley wheel with bearings to ensure smooth rotation, while preventing friction.

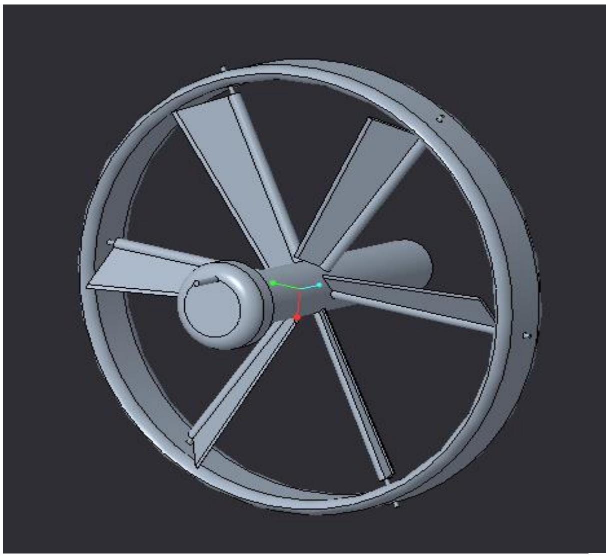


Figure 23) Close-up of the six-blade design with the outer ring

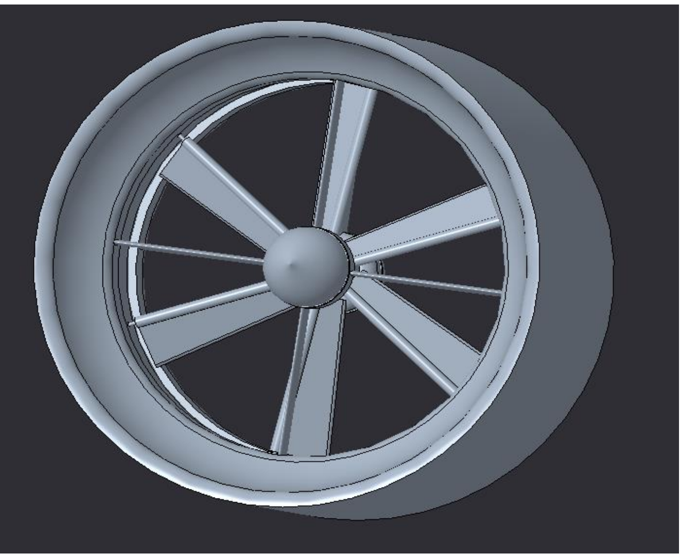


Figure 24) A six bladed design

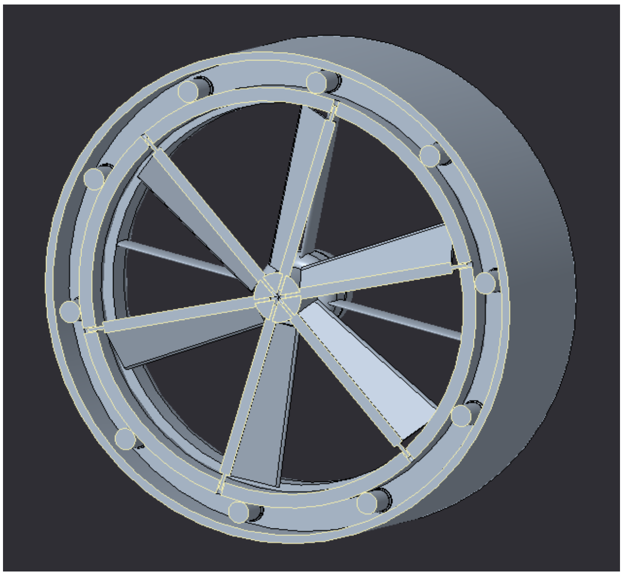


Figure 25) Sliced View of the six-blade design showing the pulley wheels

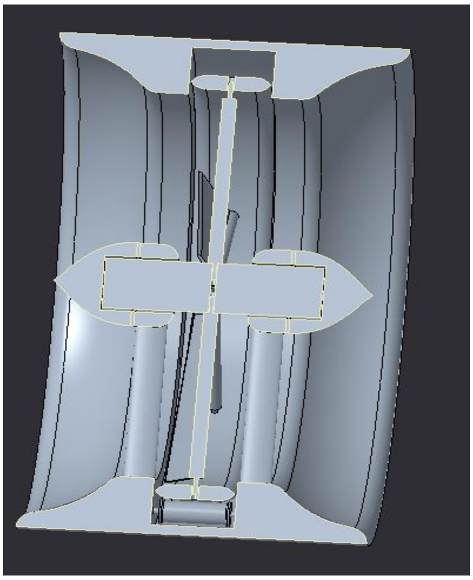


Figure 26) Sliced Side view of the six-blade design

At this point in time, Waveco announced that the design they were working on is using a special kind of turbine blade that is flexible around its axis. This design choice (Figure 28) will be explained further in section 4.2. The group then improved the design of the outer casing to improve the internal flow while reducing the material used (Figure 27). This was then applied to the six-bladed design (Figure 29) and the four-bladed design (Figure 30). The six-bladed design was discarded due to the complexity this design.

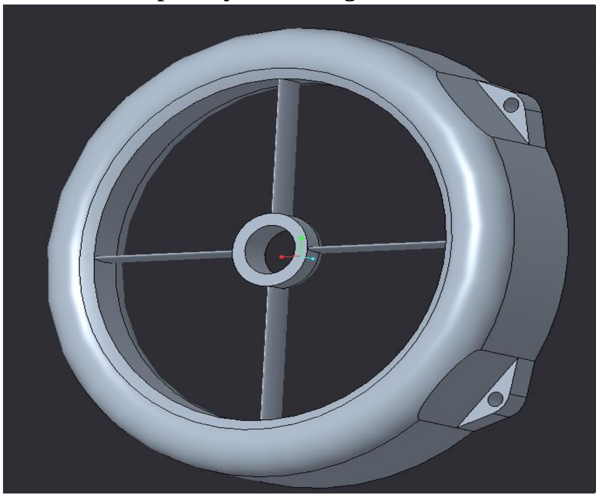


Figure 27) Outer Casing

Figure 28) Turbine blade design after discussion with Waveco

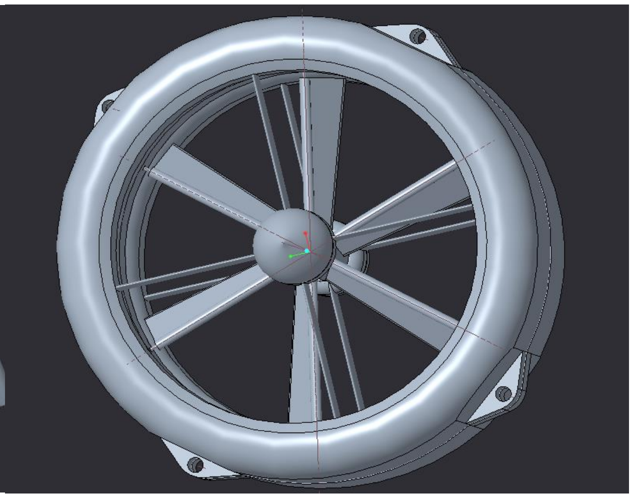


Figure 29) Six-propeller design with the outer casing

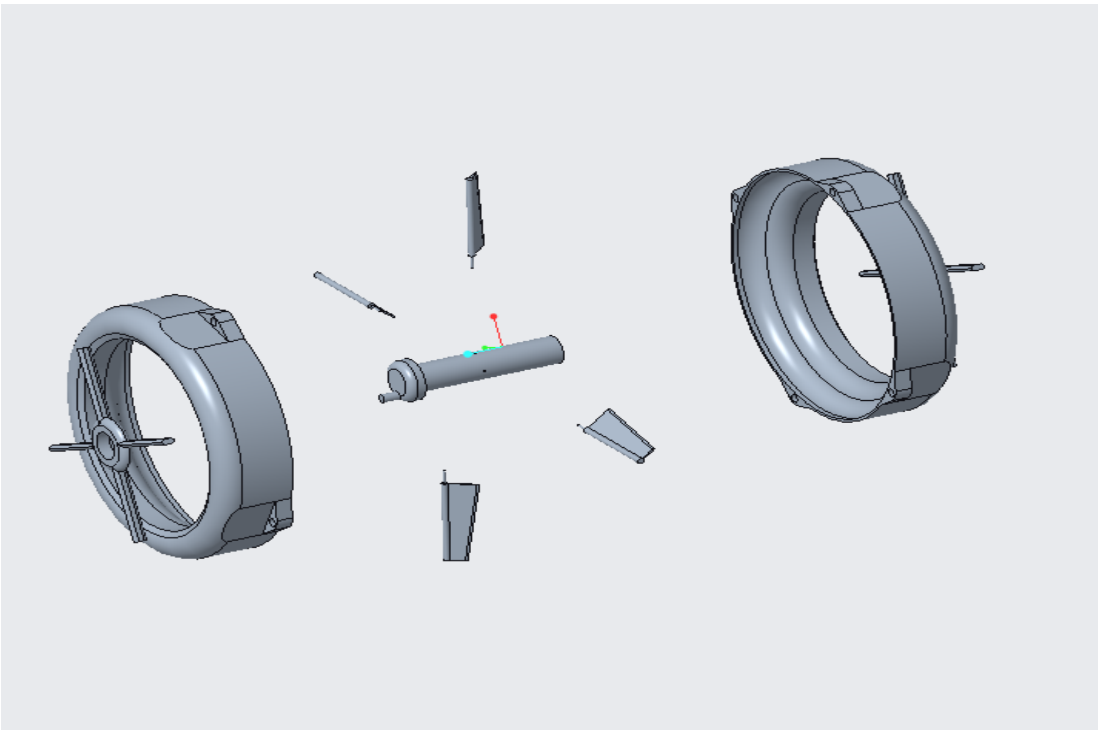


Figure 30) Exploded view of the four-blade design with the outer casing

3.3 Reverse Osmosis

It was at this point the group was inspired to try to make a version of this design that would produce water rather than electricity. This was due to the specified requirements for the American challenge and not the requirements given to the group by Waveco. Nevertheless, Waveco supported this approach and the group drew the reverse osmosis WEC (Figure 31 and 32).

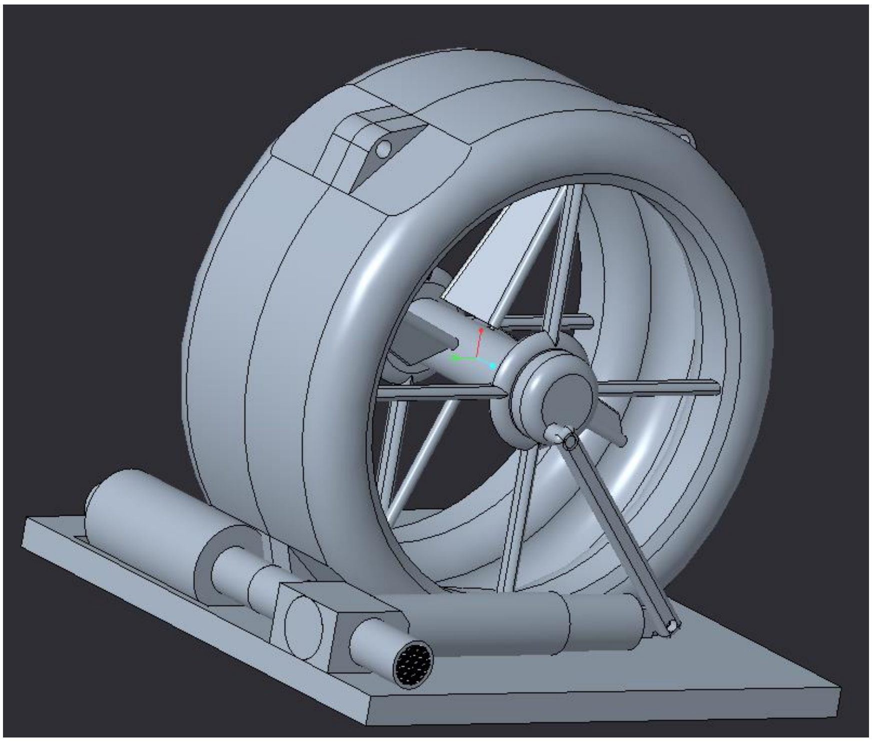


Figure 31) The finished WEC with four turbine blades that turn a piston which in turn creates the pressure needed for the reverse osmosis process.

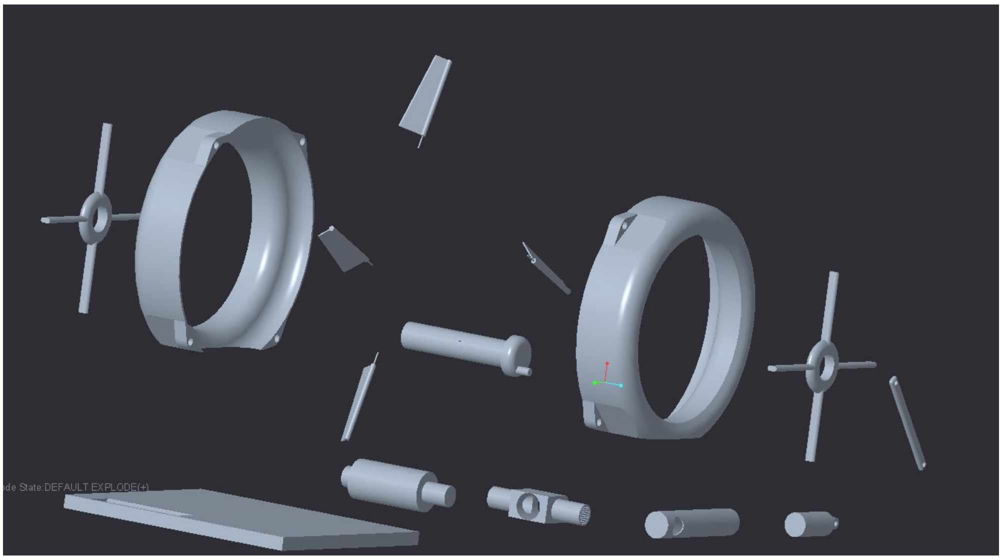


Figure 32) The exploded view of the reverse osmosis WEC. This picture was originally intended for the group to see how to 3D print and assemble the WEC as best as possible.

3.4 Finalising the Ideas

The reverse osmosis idea (Figures 33 and 34) was then prepared for 3D printing and prototyping, but due to the circumstances outside the groups control, none of this could be done. Meanwhile, due to the competition [3], Waveco was interested in an alternate idea for their contribution (Figure 35). This idea involved the previously patented idea from Waveco, but with the axle horizontally installed on a frame (Figure 36). Because the group were unable to test the RO design, Waveco shared the idea of the horizontal Subwave design and asked if the group could create a 3D model of it for them. This design was then to be compared to the reverse osmosis idea.

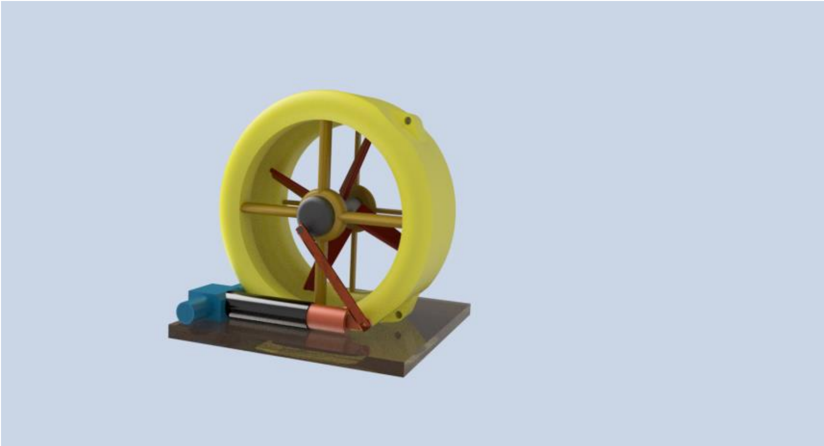


Figure 34)Rendered View of the Reverse Osmosis Turbine

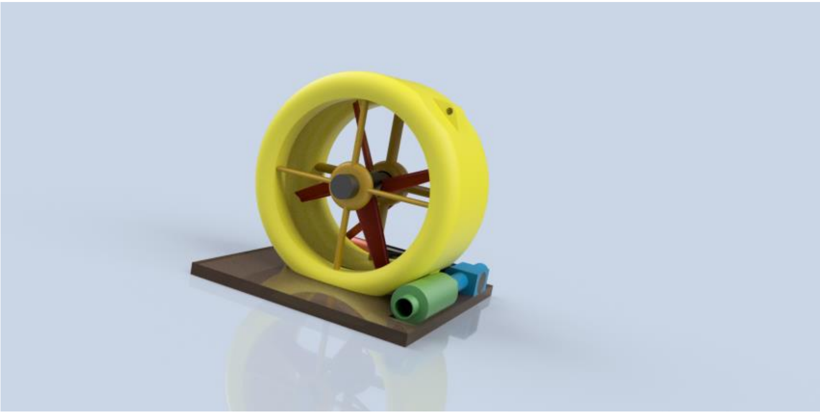


Figure 33) Rear Rendered View of the Reverse Osmosis Turbine

The Subwave turbine (Figure 35) sits vertically in the ocean, hanging from a buoy, and harnesses energy from the heaving motion of waves. This design is intended to be installed in deep water oceans. It produces electricity using rotating alternators installed in the yellow hub. The red rings and propellers rotate as the turbine moves up and down in the water, giving mechanical energy to the alternators.

The horizontal contra-rotating turbine (Figure 36) uses a similar idea, but in a smaller format and with a base and frame to allow for installation on the seabed in coastal areas.

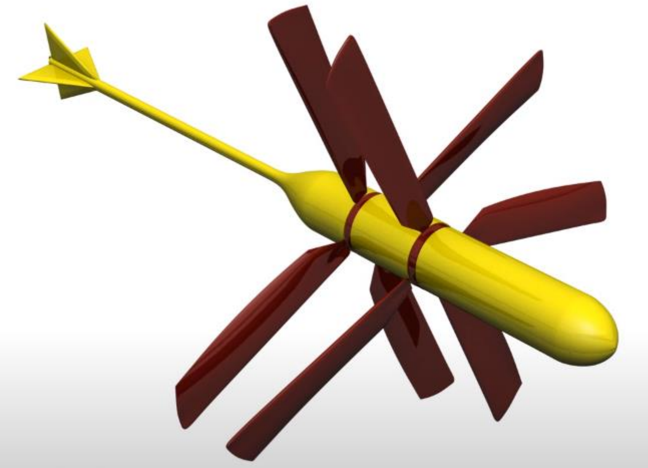


Figure 35) The Subwave turbine made by Waveco.

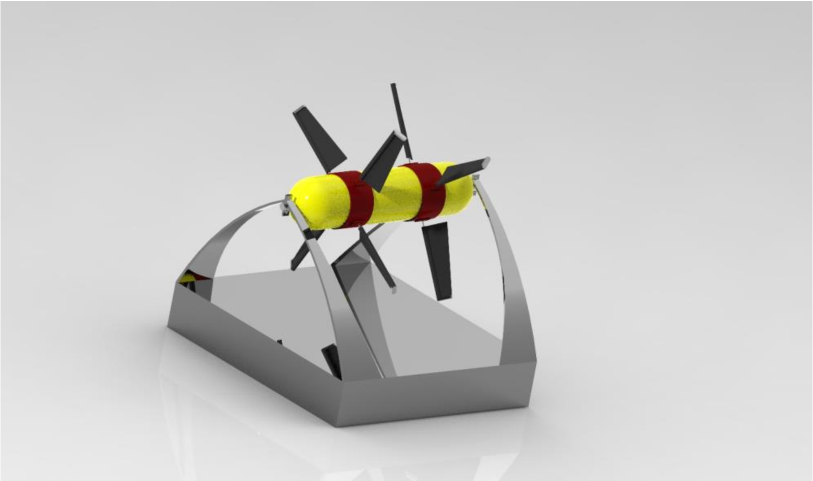


Figure 36) Contra-rotating Turbine.

4. Engineering a Product

4.1 Reverse osmosis WEC vs electric WEC

The table below shows the main differences and similarities between the electrical WEC (Figure 35) and the reverse osmosis WEC (Figure 33). The following section will describe the general turbine, material choice and anchoring system for the WEC.

TABLE 3

Characteristic comparison of the Contra-rotating and the reverse osmosis WECs

	Eletrical WEC	**Reverse osmosis WEC**
Objective	Produces electricity	Crank-arm connected to pump
Maintenance	Maintenance for electric components	Complex assembly makes maintenance difficult. Filter and membrane need cleaning, moving parts need lubrication.
Effectivity	Contra-rotation increases energy output. Electricity can be stored in a battery or capacitor, allows for rotation to be non-constant	Potentially increases pressure of the flow, reduces turbulent flow effecting the blades. Pump means constant rotation is desirable.
Anchoring	Two ropes connected to base; base filled with sand/water	Ropes connected to four points around the ring.
Cost-effective	2nd set of turbine blades increases the power output with relatively little extra cost	Expensive to manufacture, the ring must be 3d-printed, or a mold needs to be produced.
Assembly	Simple assembly	Slightly more complex assembly
Transport	Simpler assembly allows for “flat-pack” under transport. Base is relatively large, otherwise can be packed compactly	Diameter relatively large, limits packaging.
Material	Primarily HDPE	Primarily HDPE
Turbine	Hobie Mirage Drive ST turbo fin	Hobie Mirage Drive ST turbo fin

4.2 Turbine

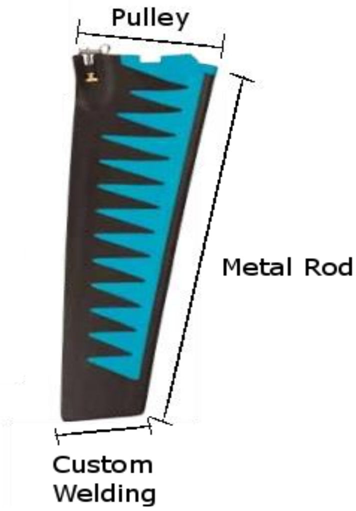


Figure 37) Hobie Mirage Drive ST turbo fin

The propeller (Figure 37) used in the design concept is based on the Hobie Mirage Drive ST Turbo [25]; a kayak fin used to travel more efficiently through the water. This blade can be used as a propeller, by welding the tip to create a hard edge. By using these propellers to make a turbine, you get some desirable features. The blades are passively pitched according to the water pressure, which means that they are not fixed at a certain angle of attack, yet they cannot be controlled manually. This means that the turbine blades are flexible and will shape themselves to form a propeller when water flows through them. This theory has been tested by earlier students of HVL, and Waveco has patented this idea combined with a double contrarotating turbine.

A common problem is found when a structure must be fixed to the ocean floor in shallow waters; it usually breaks. Therefore, it is desirable to have flexible turbine blades that can rotate at a constant speed like a controlled pitch propeller. A marine engine with a controlled pitch setup like this does not need a gear mechanism because the thrust it produces to speed up the marine vessel is mostly limited by the angle of attack of the turbine blades; the steeper the angle, the more thrust. Similarly, if the water flow is reversed the angle of the blades must be altered in the opposite direction. The engine always runs in the same direction at the same speed because of this. In short, the propellers on the turbine are very similar to a controlled pitched propeller used on boats and other marine vessels with the main difference being that the turbine harness energy while marine vessels consumes energy.

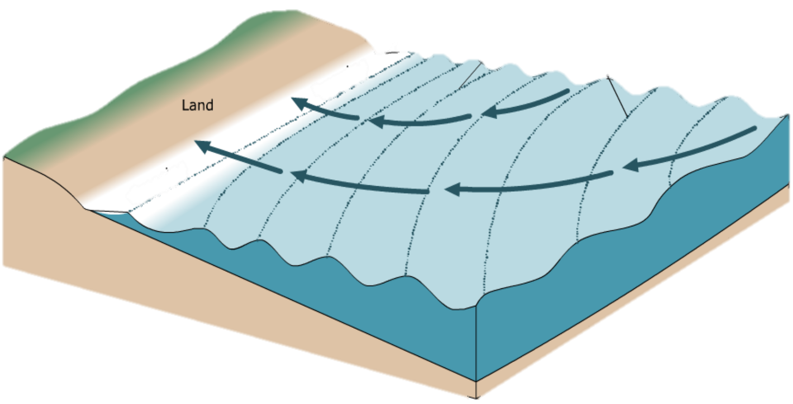


Figure 38) Wave refraction, drawing based on [13].

As previously mentioned, waves approaching shallow coasts are slowed by the seabed. These waves rarely approach the coast straight on, but the slowing effect causes refraction. In the case of a gentle sandy slope towards the coast, this refraction leads to the waves bending so they become near-parallel to the coast (Figure 38). Therefore, the sum of the force of the incoming waves points towards the shore, and the sum of the force of the undertow points away from the shore. The force of the undertow is considerably less than the force of the wave. Because of the features mentioned in the previous section, the angle of the blades is dependent on which direction the sum of the overall force is at any given moment. The turbine should therefore rotate in the same direction at any given time and the speed is dependent on the size of the force. Theoretically, it should never stop spinning completely but this would need to be tested to confirm the theory.

4.3 Material Choice

There are a wide variety of materials available including, but not limited to, concrete, steel with varying carbon content and many different polymers (plastics). Typically, concrete and/or a form of steel is used for WECs, however due to our design needing to be aerially transported and require little to no maintenance, plastic polymers are a viable choice. A polymer is a chemical compound with molecules bonded together in long, repeating chains. Because of this structure, polymers can have a wide variety of properties. One polymer, polyethylene is made from the natural gas ethane. When ethane is heated to 815 ºC, the molecules break forming ethylene which is then used to create polyethylene through a chemical reaction requiring pressurization and a catalyst. Polyethylene can be made into different types of plastic, Low density, or high-density polyethylene (LDPE or HDPE), and polyethylene terephthalate (PET) [26].

High-density polyethylene (HDPE) is commonly used for pipe, food packaging, and bottles for beverages and shampoo. HDPE has many benefits,

- it is lightweight yet strong,
- it is impact resistant,
- it is long-lasting and weather resistant,
- it does not experience galvanic corrosion from saltwater,
- it is malleable allowing it to be 3D-printed or molded into almost any shape with ease,
- it is cheap and can be easily recycled.

The strength of HDPE can be increased greatly by adding fibers to the polymer-mix. For example, HDPE with 40% glass-fiber filling with a density of $\frac{1g}{cm3}$ and a tensile strength of $80MPA$ [27]. Whereas HDPE without added fibers can be expected to have a similar density but a tensile strength of $24MPa$ [27].

4.4 Anchoring Mechanism

The turbine should not be attached permanently to the seabed due to this being intended as a temporary emergency alternative to a diesel generator. It should also not be completely loose; it must be able to be adjusted easily to compensate for high and low tide. The challenging, destructive properties of waves in the coastal area require this anchoring system to firmly hold the WEC in place while also having the ability to be adjusted to compensate for the conditions. A solution to this is to attach wheels to the base of the turbine and fill the base with sand or gravel, giving ballast weight to the structure. By doing so the turbine should be able to be pulled across the seabed without getting tipped over because of the extra weight of the sand/gravel. This should allow the turbine to be pulled in and out, adjusting to the best position for energy harvesting, dependant on the conditions.

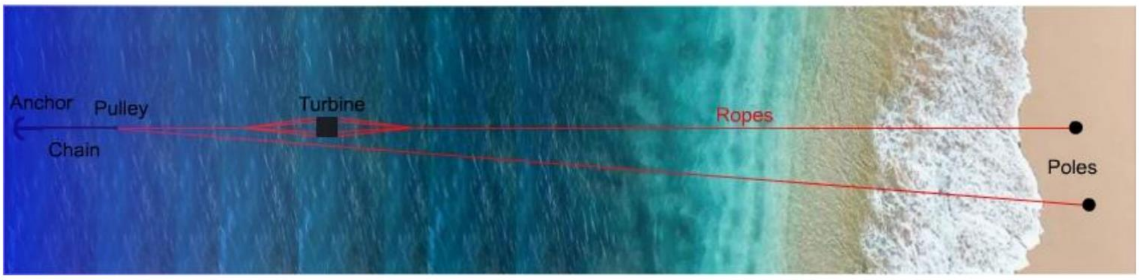


Figure 41)Aerial view of the Anchoring

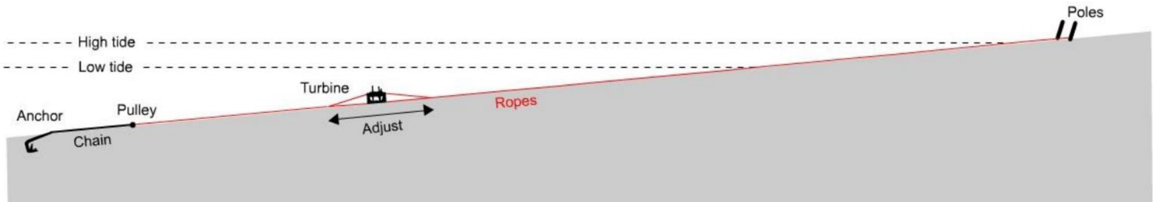


Figure 40) Side view of the anchoring

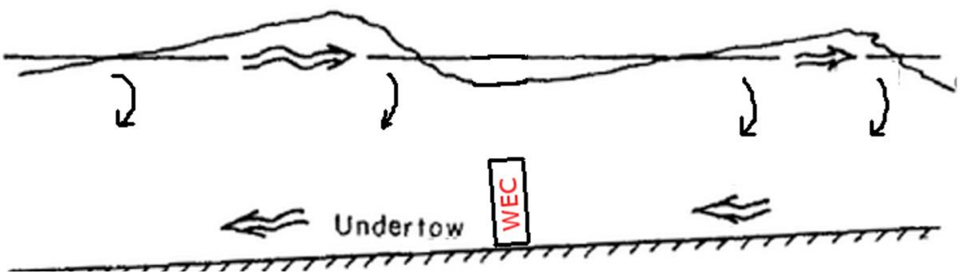


Figure 39) Placement of the WEC

The assembly processes

1. A boat is required to place an anchor with a chain ending in a pulley (Figure 39). The distance of the anchor to the shore depends on the layout of the beach and should be positioned so that the WEC can be adjusted to all conditions. Figure 38 shows how the WEC is likely to be positioned when it is assembled.

2. A rope (Figures 39 and 40) runs from the poles on the shore to the pulley and back. The rope is attached in a way that makes the turbine stuck to the rope. This system is somewhat like a ski lift where the user must pull the rope manually to place the WEC.
3. The wheels attached to the electrical WEC will make it able to drive across the seabed. Some additional weight in the form of sand or gravel located in a container inside the base might be needed to make sure it stays on the seabed. This container would be filled during installation to ensure a low weight during transportation, while still fulfilling the purpose.
4. Since the turbine has wheels it is possible drag it out into the surf by pulling the end of the long rope. The rotors should be pulled out far enough, so the rotors are completely submerged even in the trough. Because of the pulley system, the position of the turbine can easily be adjusted to match the different tides from the shore if necessary.

5. Testing of a Turbine

Ideally, we would test all our designs to find the best one, but it is not realistic due to events beyond our control. The initial plan was to create a small-scale prototype to be tested in a wave tank under specific conditions. The proposed test below is somewhat inspired by a test carried out by Clarke et al. [28] on a contra-rotating turbine. Due to the circumstances, this prototype creation and testing had to be cancelled. Below is the test procedure that was planned and should be carried out in the event of further work on these ideas.

5.1 Instrumentation

One of the propellers should be marked with a different color, so the rotation can be easily seen and recorded.

Figure 42 shows the proposed testing setup and the positioning of the instrumentation. A disc brake caliper (shown in orange) with a strain gauge load cell (shown in dark blue) should be installed on the arm holding the caliper to indicate the braking force applied, and hence the frictional torque. This arm should be firmly installed to either the ceiling or a frame with adequate support to prevent movement. The disk brake (shown in red) acts on a rotating axle from a belt-driven pulley system (shown in green and purple). This pulley system transfers the rotational energy from the turbine (shown in pink) to the disk brake and allows the brake to operate without being submerged in the tank. A frame of some form is also required to hold the pulleys and all rotational axles in place.

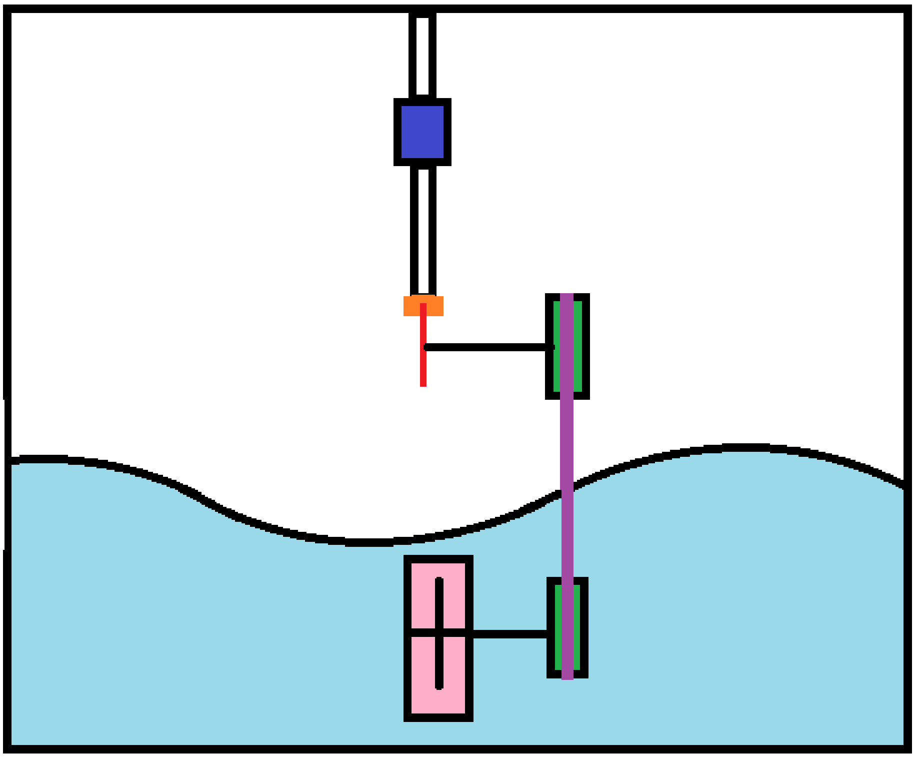


Figure 42) Proposed testing setup

5.2 Procedure

The turbine should be secured in a position so that the column of water above is maintained between 1m and 2m throughout the test. The wave conditions should also be maintained constant throughout the test. Ideally, the wave height should be between 0.5m and 1m with a frequency of 0.2Hz.

We would first count the rotations per minute (rpm) without any braking applied, then gradually increase the braking force until the axle is barely able to rotate. The braking force and rpm should both be logged at regular intervals for use in the formula for Power output of a generator:

$$Power = Torque * rotational\ speed\left(in\frac{rad}{s}\right)$$

For converting rpm to rad/s: $1\ rpm = 0.10466667\frac{rad}{s}$

$$Torque\ (Nm) = Braking\ force\ (N) * Distance\ from\ centre\ of\ rotation\ to\ strain\ gauge\ bridge\ (m)$$

5.3 Sources of error

- Loss of torque due to friction.
- Losses due to transferring the rotation via a belt pulley system.
- Losses due to eccentric rotation.
- Failure to anchor the turbine or the arm holding the load cell sufficiently can lead to errors in measurement.
- Inconsistent wave conditions.
- Depth of the water column above the turbine varying.

6. Results and Discussion

6.1 Six thinking hats analysis

The electrical WEC, the reverse osmosis WEC and ideas behind them have now been presented. The times has come to decide which one is better. Each hat will get their own section with a small verdict in the end. The blue that includes the final verdict.

6.1.1 White hat

Reverse osmosis – This design is new and has not been tested by any former students or Waveco. Due to the testing restrictions there is no available data to support this design.

Electrical – This design is somewhat like the sub-wave turbine designed by Waveco. It has an analysis sheet of potential energy output relative to its size. However, this document suggests that the data is not backed up by any tests. Since it also is made for a horizontal wave turbine meant to harvest energy from deep-water, this data is void. Clarke et al. [28] ran a test on a contra-rotating turbine and found that this style of design leads to near-zero reactive torque on the structure, meaning the structure will be less prone to instability.

Conclusion – Both designs are relatively new, but the electrical WEC has had its concept tested and documented. This makes the electrical WEC favorable over the reverse osmosis WEC.

6.1.2 Red hat

Reverse osmosis – The group believes that this design has less turbulent flow through it, which makes it less exposed to damage. Since it is safer it should also have less energy output potential, but this does not matter much because the group wants something that works.

Electrical – The emotional connection to this design is low. This design was made by Waveco and got introduced to the group after the ring was designed to inspire the group and raise a discussion.

Conclusion – The reverse osmosis WEC has a higher emotional connection to the group. The group also thinks that with more testing and development, the reverse osmosis WEC would come out on top.

6.1.3 Black Hat

Reverse osmosis – Due to a huge area on impact and only one set of turbines, the group believes that the anchoring mechanism might mess up the reverse osmosis WEC by twisting and turning it in the water rather than staying in place. The reverse osmosis pump system might also be clogged or fails constantly if the maintenance is slacking, rendering the machine useless. Due to the lack of testing this WEC might not work at all.

Electrical – The anchoring system is considerably less prone to fail on this design due to a smaller area for the water twist it and the contra-rotating action giving near-zero torque on the structure, but the possibility is still there. This design lacks protection, and the turbine blades might take some damage because of it. The electrical components can get damaged since the machine is located underwater.

Conclusion – The electrical WEC is more developed and is less likely to fail due to a simpler design and overall has less components that can fail. The reverse osmosis WEC should be further developed before it can compete with the safer bet that is the electrical WEC.

6.1.4 Yellow Hat

Reverse osmosis – The protection granted by the large ring around the turbine makes is stronger so it can tolerate harsh conditions. Assuming the reverse osmosis pump works perfectly; all the produced energy goes to making fresh water without any batteries or other energy storage being necessary. This design can fit easily with the cubic meter requirement.

Electrical – Since the electrical WEC has two propellers rather than one, it is believed to be more stable and be able to grant a higher energy output. It is also very easy to assemble and deal with any potential maintenance due to easy access to all the components. This design has also been developed and somewhat tested earlier, which makes more reliable than its contester. This design can easily fit within the cubic meter, but this requires assembly and disassembly.

Conclusion – Both designs has a lot going for them, the electrical WEC has overall more positives and a higher potential energy output than the reverse osmosis WEC.

6.1.5 Green Hat

The agonizing fact of not testing a prototype is not being able to know if it works or not. By not seeing the potential of both designs, it is hard to decide whether to implement components from the reverse osmosis WEC to the electrical WEC or vice versa. The groups hypothesis is that the design of the electrical WEC superior, nevertheless. However, if the reverse osmosis WEC has a lot of potential going for it. Further testing and design improvements in the future would most likely result in a hybrid between the two that would utilize the better features of each one.

6.1.6 Blue Hat

Overall, the electrical WEC seems better suited for further development based on the sections above. It is not perfect, but the group agrees that this design is more likely to succeed based on the available data. The reverse osmosis WEC can of course be further developed, but at this moment in time it would be wiser to not do that. The main advantage the electrical WEC has over the reverse osmosis WEC is that it produces electricity that can be used for whatever the user desires rather than only producing drinkable water. The electric WEC can also be used to supply a topside reverse osmosis system with power, meaning easier access for maintenance to the membrane and pump. The group is happy that the electrical

WEC came out on top, but they are also curious to see what the eventual development of the reverse osmosis WEC can lead to.

6.2 Results and Discussion

Due to limited testing on the different designs, an alternate method was used to determine the best design. This provided a structured method of analyzing and evaluating the work done. This led to the group deciding that the electrical WEC has the better overall design and most likely to succeed. Theoretically it can:

- Fit inside one cubic meter
- Be installed with ease
- Operate with little to no maintenance for 30 days
- Fulfill the 650kg weight limit with ease
- Withstand harsh weather conditions
- Produce usable energy as a substitute for a diesel generator

Since the group decide to go for the electrical WEC (Figure 43) instead of the reverse osmosis WEC, the requirement to produce at least 40 liters of drinkable water every day is negotiable. This is because this requirement was originally intended for the reverse osmosis WEC. The electrical WEC can in theory power a device that creates fresh water if necessary [29]. The design theoretically covers all the requirements for this project and further testing would be desirable to confirm this in practice.

Due to unpredictable circumstances the group has been unable to commit to the test mentioned in chapter 5. The group has also not been able to 3D print the electrical WEC to test desirable features that could improve or impair the overall vision of this project. Regardless, the group is still happy with the results because we feel that the electrical WEC can fulfill the desired requirements given to us by Waveco. We have designed a WEC capable of supporting a group of people in the unfortunate event of a natural catastrophe. The electrical WEC can generate clean green energy without producing any hazardous gases for human beings. If this technology can be developed further, the need for oil and gas may be greatly reduced in the future.

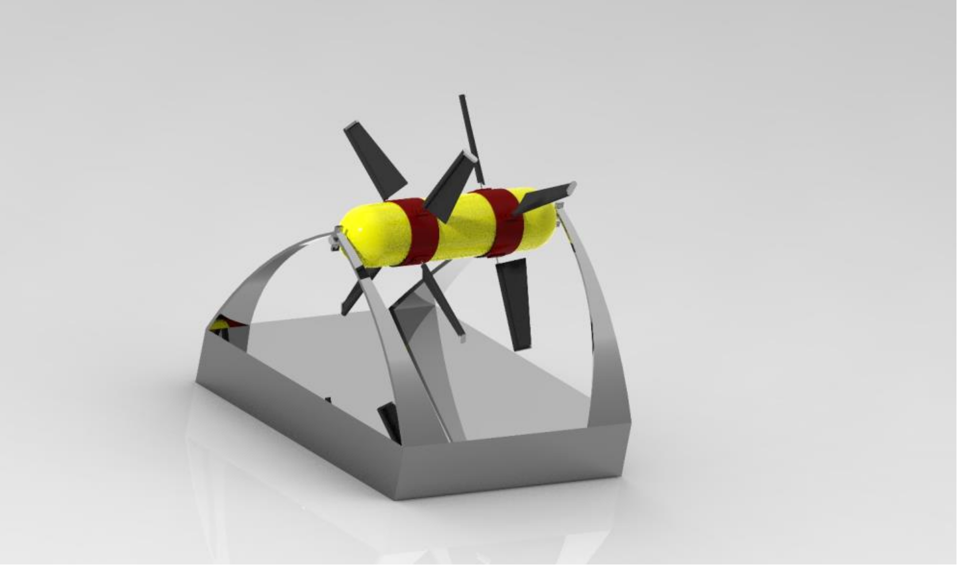


Figure 43) The electrical WEC

7. Conclusion

The aim of the project was to explore the different possibilities of utilizing wave energy under special conditions. Possible concepts were to be explored and developed, and ultimately a wave energy converter was to be designed, within the given requirements. The theoretical analysis performed in this project, formed the basis for determining which of the concepts had most potential to be developed further.

The first idea for this project, was a wave energy converter that utilized reverse osmosis (RO) to make drinkable water. The energy of the waves makes a turbine rotate, activating a pump, pushing saltwater through a RO membrane, creating fresh water.

The second idea was to use an electrical energy converter. Energy from the waves would make a turbine rotate, which in turn makes an alternator rotate, creating electricity.

Using an electrical energy converter is a more established idea than the converter using RO and has been more extensively researched. We ultimately decided that our project would benefit more from further developing the electrical energy converter, than using reverse osmosis. Therefore, we rejected the RO concept, to fully focus on the electrical wave energy converter. This idea was also more in line with the scope of our project, which aims to replace diesel generator as an emergency energy source.

The wave energy converter was going to be 3D printed, and then the concept would be tested in a wave tank. However, due to unpredictable global events, this was not possible. This project now aimed at selecting the best possible concept and give a good theoretical basis for someone else to perform the testing.

The project has shown that using an electrical wave energy converter on shallow coasts is possible but requires further developing of ideas and testing. The potential of waves to be utilized for their energy, is large. Coastal wave energy alone could cover 20% of the world's electricity needs.

In addition, we have also shown that there can be other ways of utilizing wave energy, than purely electrical energy, but these ideas are underdeveloped, and require much more extensive theoretical research before they can be ready for testing.

The work performed in this project lays a foundation for future work to further develop green alternatives so that future generations can enjoy energy produced from waves.

8. References

[1] "Oxfam," [Online]. Available: https://www.oxfam.org.uk/donate/oxfam-pioneers/example-projects. [Accessed 21 April 2020].

[2] "SINN Power," [Online]. Available: https://www.sinnpower.com/waveenergy. [Accessed 21 April 2020].

[3] «American Made Challenges,» [Internett]. Available: https://americanmadechallenges.org/wavestowater/index.html. [Funnet 21 April 2020].

[4] "Norgeskart," Kartverket, [Online]. Available: norgeskart.no. [Accessed 7 April 2020].

[5] "Bølgevarsel," [Online]. Available: https://www.barentswatch.no/bolgevarsel/. [Accessed 7 April 2020].

[6] J. B. Zirker, in *The Science of Ocean Waves : Ripples, Tsunamis, and Stormy Seas*, Johns Hopkina University Press, 2013.

[7] "Exploring our Fluid Earth," [Online]. Available: https://manoa.hawaii.edu/exploringourfluidearth/physical/coastal-interactions/wave-coast-interactions. [Accessed 07 April 2020].

[8] D. Levitan, "Yale Environment360," 28 April 2014. [Online]. Available: https://e360.yale.edu/features/why_wave_power_has_lagged_far_behind_as_energy_source. [Accessed 20 January 2020].

[9] R. Manasseh, S. A. Sannasiraj, K. L. McInnes, V. Sundar and P. Jalihal, "Integration of wave energy and other marine renewable energy sources with the needs of coastal societies," *The International Journal of Ocean and Climate Systems,* vol. 8, no. 1, pp. 19-36, 2017.

[10] A. Pecher and J. P. Kofoed, in *Handbook Of Ocean Wave Energy*, Springer, 2017.

[11] "Our World In Data," [Online]. Available: https://ourworldindata.org/energy. [Accessed 15 April 2020].

[12] J. Blackledge, E. Coyle, D. Kearney, R. McGuirk og B. Norton, «Estimation of Wave Energy from WInd Velocity,» *IAENG Engineering Letters,* nr. 4, pp. 158-170, 2013.

[13] A. P. Trujillo and H. V. Thurman, Essentials of Oceanography Tenth Edition, Pearson, 2011, pp. 230-258.

[14] «Turbin on Wikipedia,» [Internett]. Available: https://no.wikipedia.org/wiki/Turbin. [Funnet 19 April 2020].

[15] "The European Marine Energy Centre LTD," [Online]. Available: http://www.emec.org.uk/marine-energy/wave-devices/. [Accessed January 2020].

[16] G. N. Lewis, «The Osmotic Pressure Of Concentrated Solutions, And The Laws Of The Perfect Solution,» *Journal of the American Chemical Society,* 1908.

[17] «Windows To The Universe,» [Internett]. Available: https://www.windows2universe.org/earth/Water/temp.html. [Funnet 22 March 2020].

[18] J. F. Anthoni, «Seafriends,» [Internett]. Available: http://seafriends.co.nz/oceano/seawater.htm. [Funnet 22 March 2020].

[19] «Engineering Toolbox,» [Internett]. Available: https://www.engineeringtoolbox.com/sea-water-properties-d_840.html. [Funnet 22 March 2020].

[20] D. Susitra, E. A. E. Jebaseeli and S. Paramasivam, "Switched Reluctance Generator-Modelling, Design, Simulation, Analysis and Control A Comprehensive Review," *International Journal of Computer Applications*, vol. 1, no. 2, pp. 0975-8887, 2010.

[21] "Earthava," [Online]. Available: https://www.earthava.com/top10-10-best-home-wind-turbines/. [Accessed 28 April 2020].

[22] "Betz's Law," Wikipedia, [Online]. Available: https://en.wikipedia.org/wiki/Betz%27s_law. [Accessed 6 May 2020].

[23] R. Wies, «Research Gate,» [Internett]. Available: https://www.researchgate.net/publication/221928648_Energy-Efficient_Standalone_Fossil-Fuel_Based_Hybrid_Power_Systems_Employing_Renewable_Energy_Sources/figures?lo=1. [Funnet 23 April 2020].

[24] «Six Thinking Hats on Wikipedia,» [Internett]. Available: https://en.wikipedia.org/wiki/Six_Thinking_Hats. [Funnet 19 April 2020].

[25] «Sailsport Marine,» [Internett]. Available: https://sailsportmarine.com/products/hobie-mirage-st-turbo-fin-kit-v2. [Funnet 20 May 2020].

[26] W. D. Callister og D. G. Rethwisch, i *Materials Science and Engineering, Ninth Edition, SI Version*, Wiley, pp. 9-10,118-122.

[27] «Make it from,» [Internett]. Available: https://www.makeitfrom.com/material-properties/40-Percent-Glass-Fiber-40-GF-HDPE. [Funnet 14 April 2020].

[28] J. A. Clarke, C. M. Johnstone, G. Connor og A. D. Grant, «Design and testing of a contra-rotating tidal current turbine,» *Proceedings of the Institution of Mechanical Engineers Part A Journal of Power and Energy*, 2007.

[29] «Spectra Watermakers,» [Internett]. Available: https://www.spectrawatermakers.com/us/us/11141-aquifer-200-expedition. [Funnet 22 May 2020].

[30] H. Ding, Z. Mao og W. TIan, «Design, test and numerical simulation of a low-speed horizontal axis,» *International Journal of Naval Architecture and Ocean Engineering*, pp. 782-793, 28 December 2017.

[31] "American Membrane Technology Association," 2016. [Online]. Available: https://www.amtaorg.com/Reverse_Osmosis_Membrane_Separation.html. [Accessed February 2020].

[32] "Avidity Science," 11 October 2018. [Online]. Available: https://www.avidityscience.com/en_gb/news/what-is-reverse-osmosis/. [Accessed February 2020].

[33] "CoastAdapt," [Online]. Available: https://coastadapt.com.au/. [Accessed 22 March 2020].

[34] "The Geographer Online," [Online]. Available: https://www.thegeographeronline.net/coasts.html. [Accessed January 2020].

[35] "APEC Water," [Online]. Available: https://www.freedrinkingwater.com/whole-house/water-filter-knowledge-base/how-does-ultraviolet-water-purification-work.htm. [Accessed 30 March 2020].

[36] «PureTec,» [Internett]. Available: https://puretecwater.com/reverse-osmosis/what-is-reverse-osmosis. [Funnet 31 Mars 2020].

[37] S. Beneghali, M. Benbouzid and J. F. Charpentier, "Marine Tidal Current Electric Power Generation Technology: State of the Art and Current Status," *IEEE IEMDC'07,* pp. 1407-1412, May 2007.

[38] "Ship motions on Wikipedia," [Online]. Available: https://en.wikipedia.org/wiki/Ship_motions. [Accessed 14 April 2020].

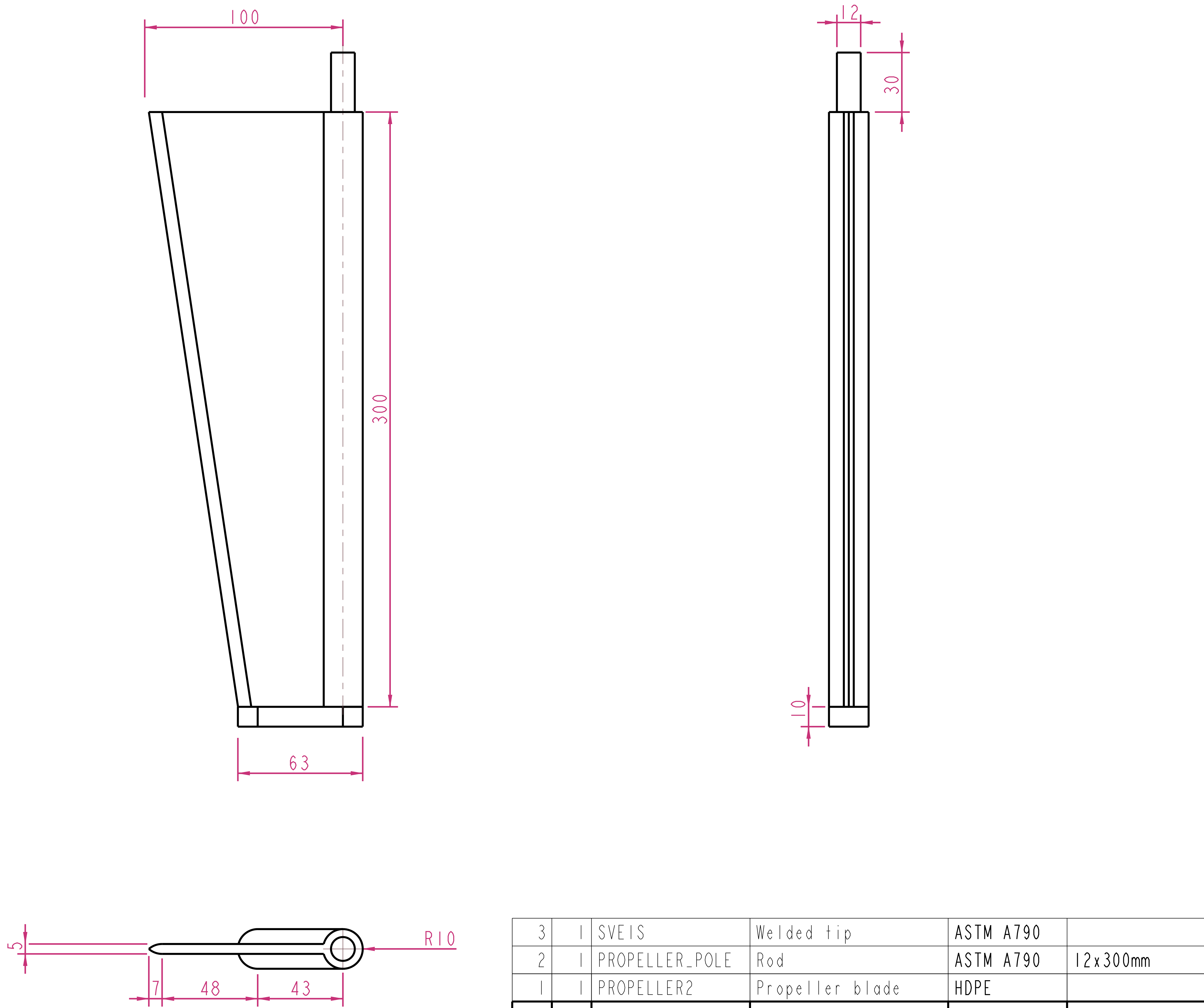
[39] «Crest and trough from Wikipedia,» [Internett]. Available: https://en.wikipedia.org/wiki/Crest_and_trough.

[40] R. Govindan, R. Kumar, S. Basu og A. Sarkar, «Altimeter-Derived Ocean Wave Period Using Genetic Algorithm,» *IEEE Geoscience And Remote Sensing Letters,* vol. 8, nr. 2, pp. 354-358, 2011.

[41] "Tables from meteo.no," [Online]. Available: http://www.systemsoft.no/Sobekklia/tables.htm. [Accessed 20 April 2020].

[42] I. Bakke, Interviewee, [Intervju]. 22 04 2020.

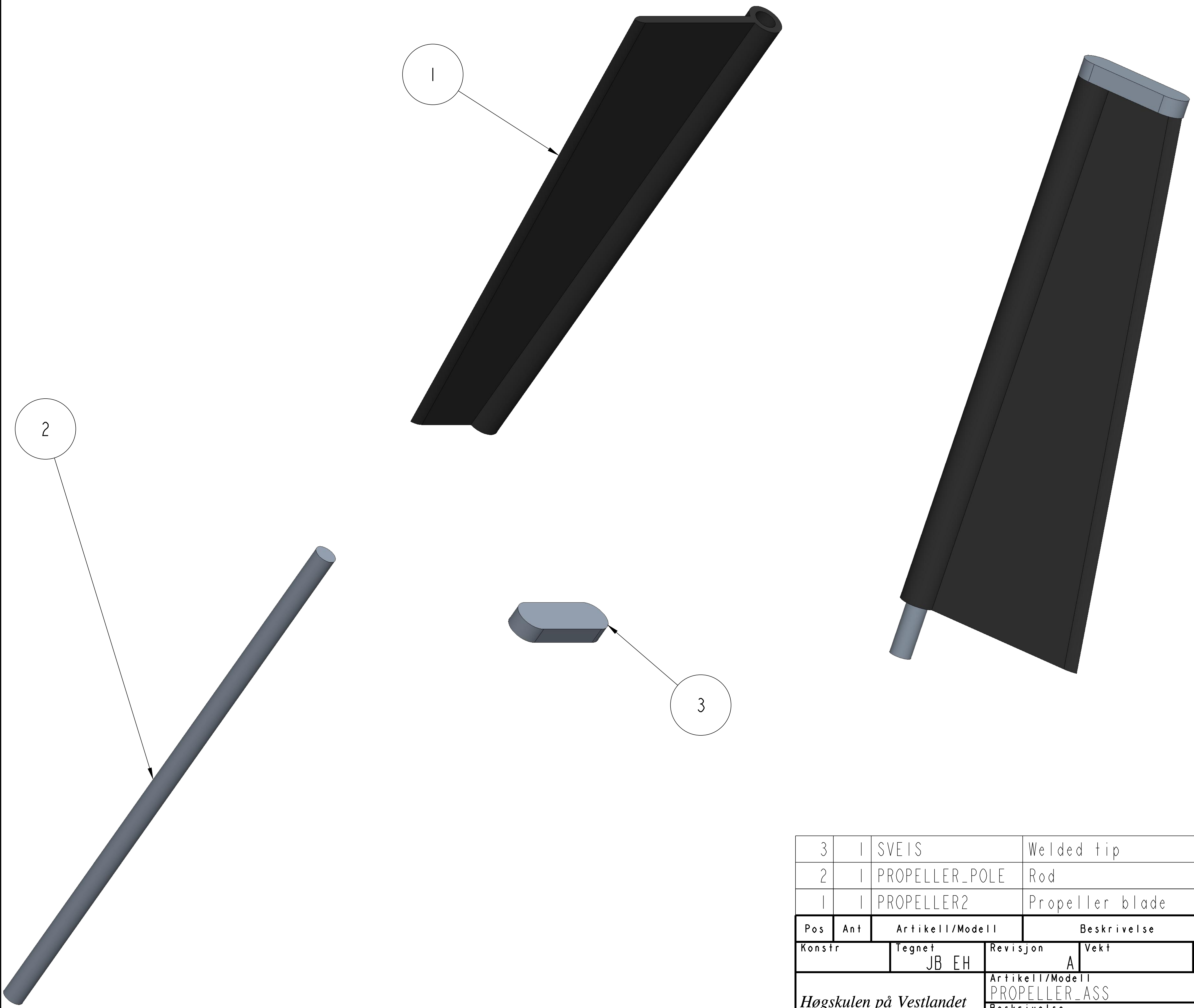
[43] «Oscillation on WIkipedia,» [Internett]. Available: https://en.wikipedia.org/wiki/Oscillation. [Funnet 19 April 2020].



Pos	Ant	Artikell/Modell	Beskrivelse	Materiale	Dimensjon
3	1	SVEIS	Welded tip	ASTM A790	
2	1	PROPELLER_POLE	Rod	ASTM A790	12x300mm
1	1	PROPELLER2	Propeller blade	HDPE	

Konstr	Tegnet	Revisjon	Vekt	Skala	Format	Blad.nr
	JB EH	A		1:2	A3	1(8)

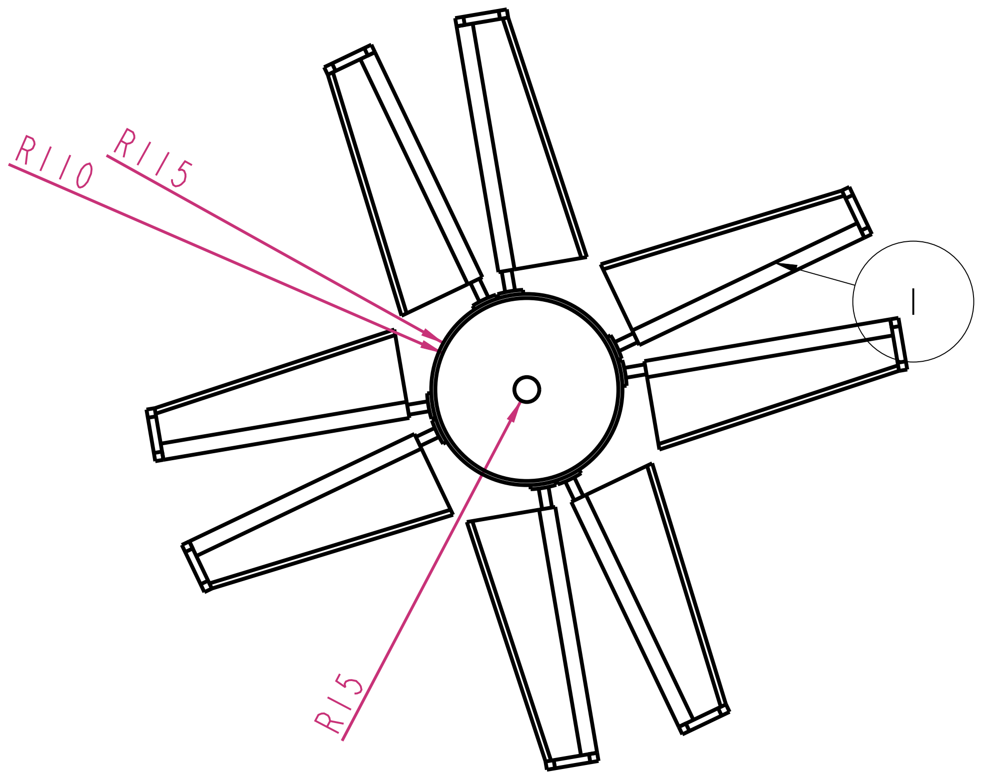
Høgskulen på Vestlandet IMM	Artikell/Modell: PROPELLER_ASS	Dato: 21-May-20
	Beskrivelse: Propeller	Tegning: TURBINE

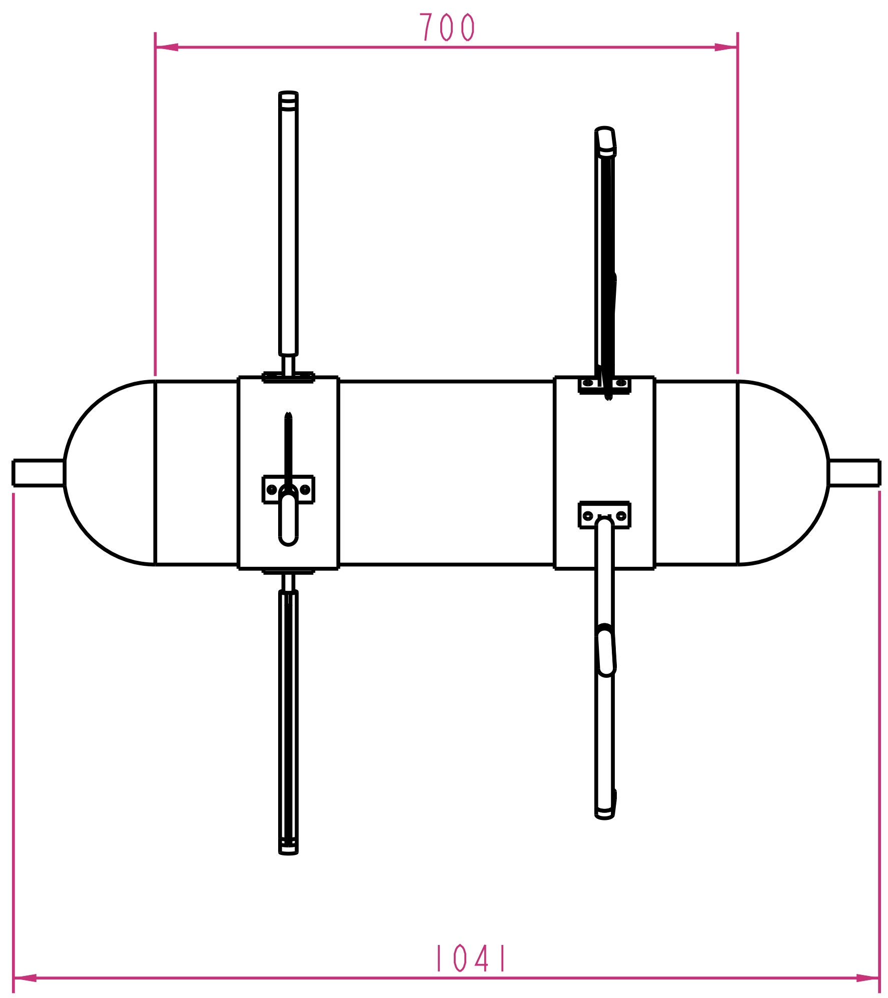


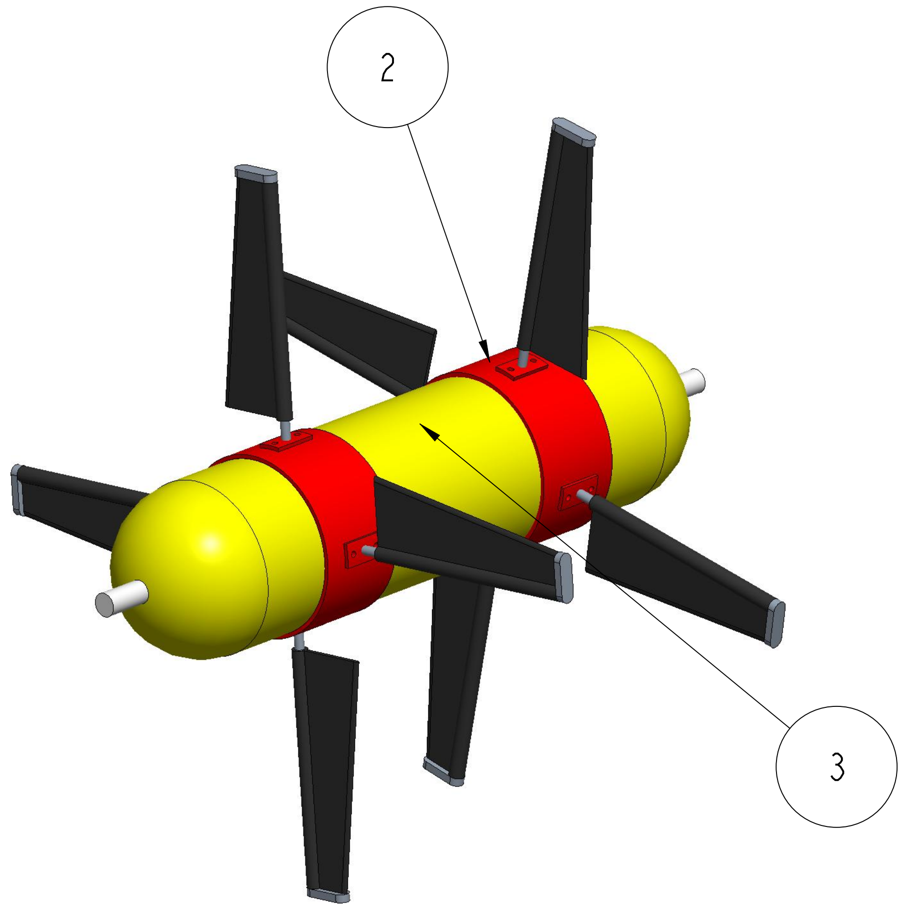
Pos	Ant	Artikell/Modell	Beskrivelse	Materiale	Dimensjon
3	1	SVEIS	Welded tip	ASTM A790	
2	1	PROPELLER_POLE	Rod	ASTM A790	12x300mm
1	1	PROPELLER2	Propeller blade	HDPE	

Konstr	Tegnet	Revisjon	Vekt	Skala	Format	Blad.nr
	JB EH	A		1:2	A3	2(8)

Høgskulen på Vestlandet IMM	Artikell/Modell: PROPELLER_ASS	Dato: 21-May-20
	Beskrivelse: Propeller	Tegning: TURBINE



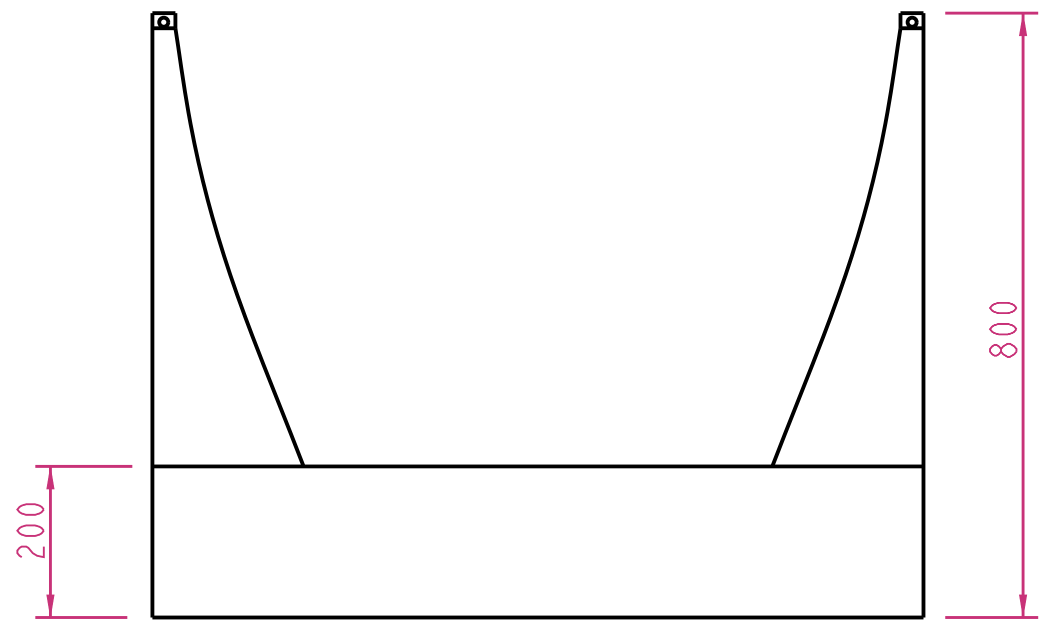


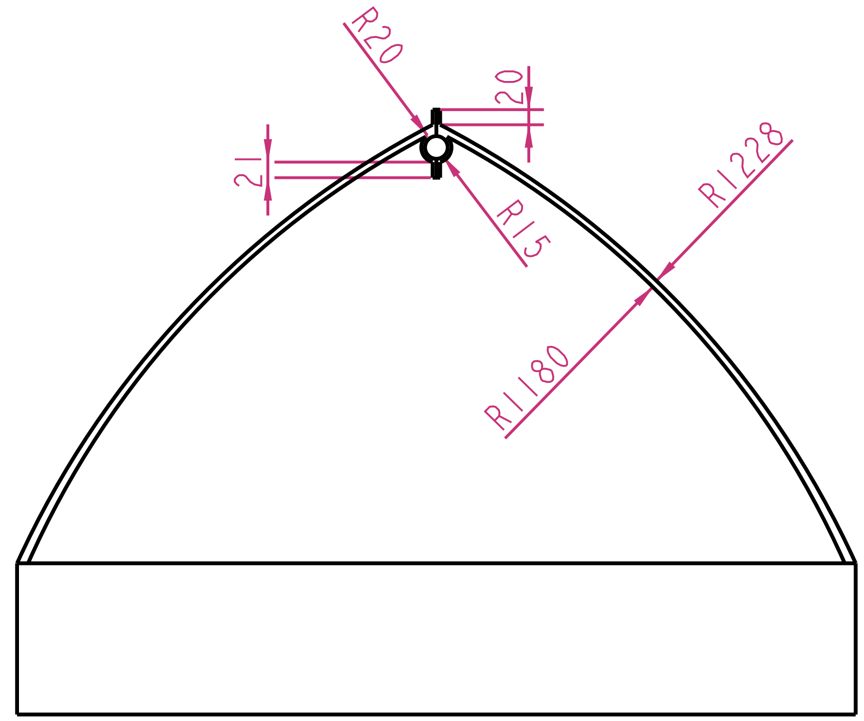


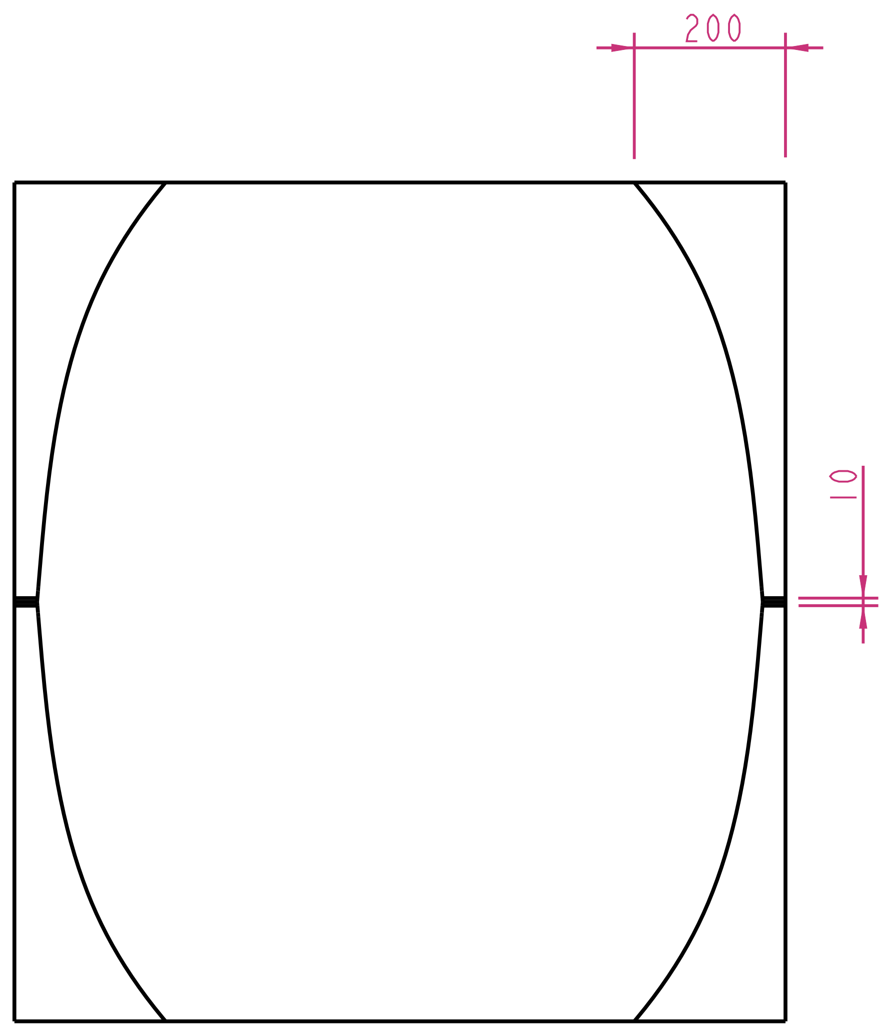
Pos	Ant	Artikell/Modell	Beskrivelse	Materiale	Dimensjon
3	1	TURBINE_BODY	Protective Casing	HDPE	
2	2	PROPELLER_RING	Propeller Ring	HDPE	
1	8	PROPELLER_ASS	Propeller	HDPE, A790	

Konstr	Tegnet	Revisjon	Vekt	Skala	Format	Blad.nr
	JB EH	A		1:100	A3	3(8)

Høgskulen på Vestlandet *IMM*	Artikell/Modell: TURBINE_ASS	Dato: 21-May-20
	Beskrivelse: Turbine	Tegning: TURBINE



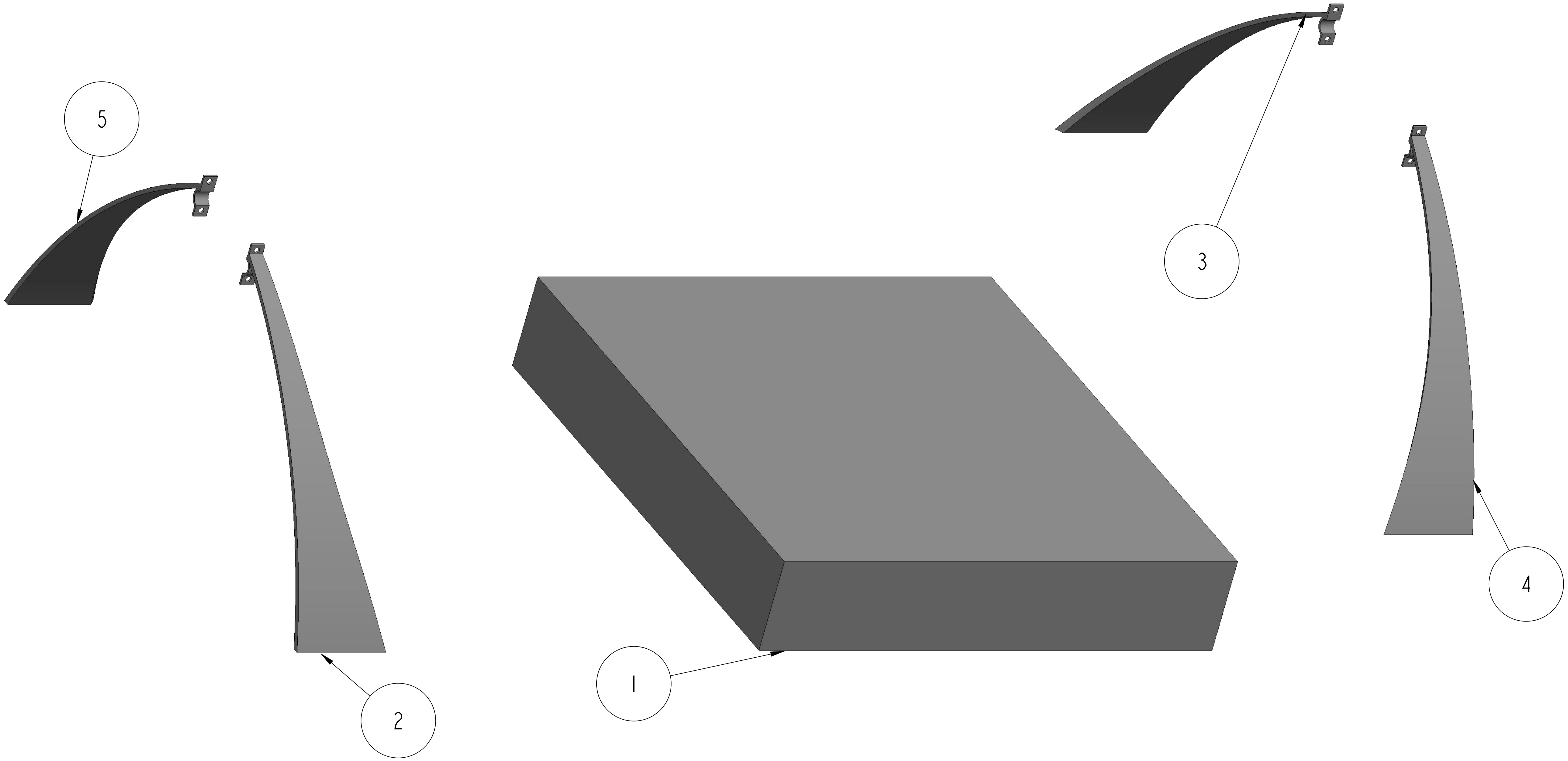


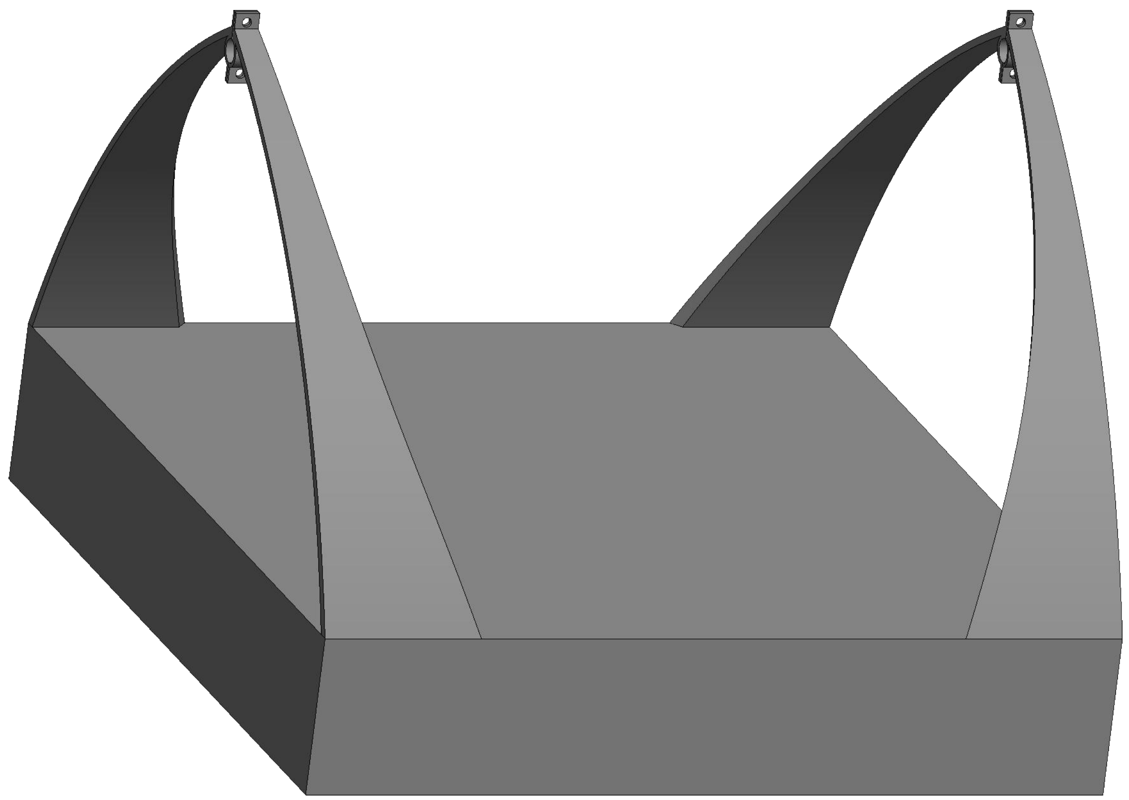


Pos	Ant	Artikell/Modell	Beskrivelse	Materiale	Dimensjon
5	1	STØTTESTAGENE	Support arm	ASTM A790	
4	1	PRT0014	Support arm	ASTM A790	
3	1	PRT0013	Support arm	ASTM A790	
2	1	PRT0003	Support arm	ASTM A790	
1	1	BASE	Ballast weight base	HDPE	1110x1020x200mm

Konstr	Tegnet	Revisjon	Vekt	Skala	Format	Blad.nr
	JB EH	A		1:10	A3	4(8)

Høgskulen på Vestlandet IMM	Artikell/Modell: RAMME_ASSEMBLY	Dato: 20-May-20
	Beskrivelse: Support Frame	Tegning: TURBINE

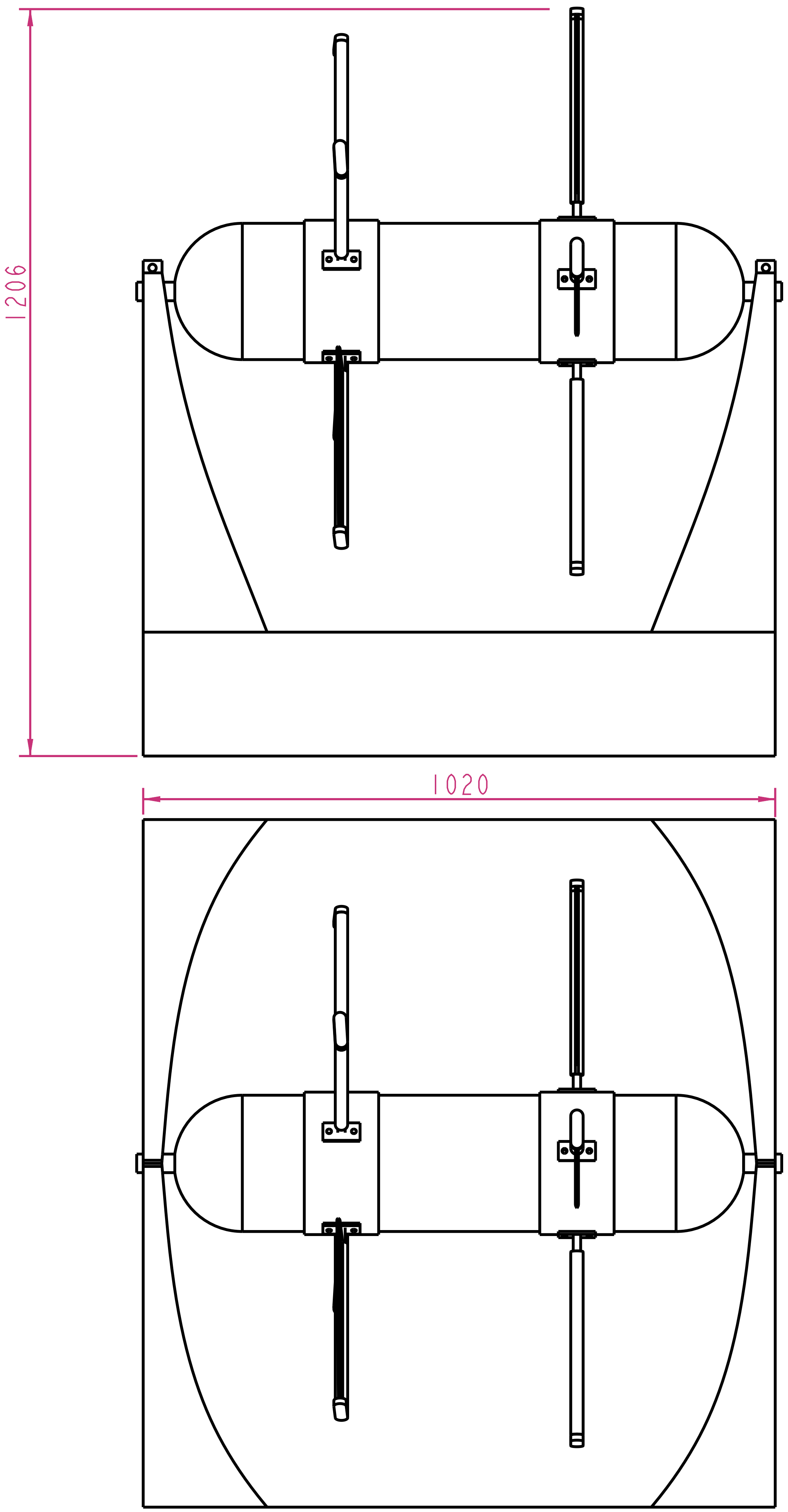


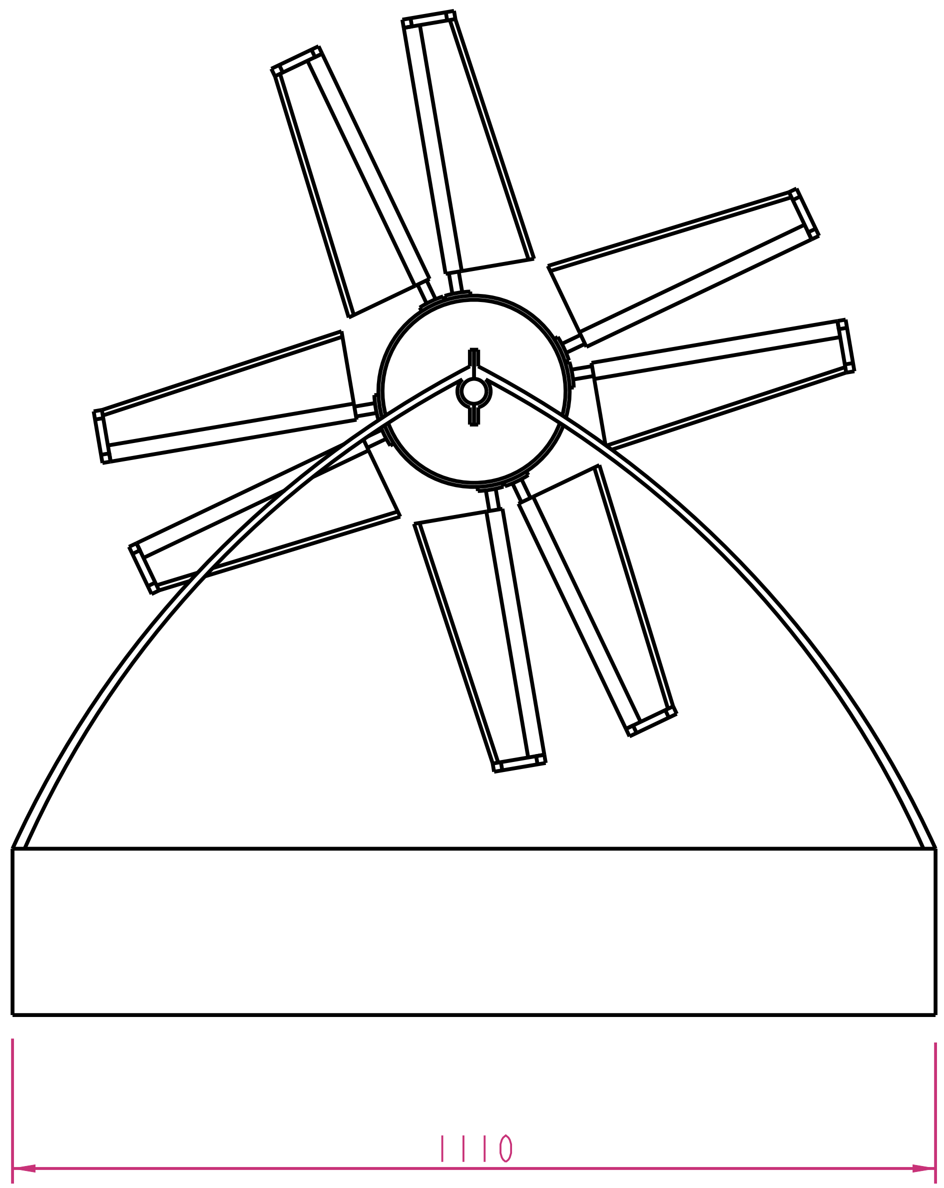


Pos	Ant	Artikell/Modell	Beskrivelse	Materiale	Dimensjon
5	1	STØTTESTAGENE	Support arm	ASTM A790	
4	1	PRT0014	Support arm	ASTM A790	
3	1	PRT0013	Support arm	ASTM A790	
2	1	PRT0003	Support arm	ASTM A790	
1	1	BASE	Ballast weight base	HDPE	1110x1020x200mm

Konstr	Tegnet	Revisjon	Vekt	Skala	Format	Blad.nr
	JB EH	A		1:100	A3	5(8)

Høgskulen på Vestlandet IMM	Artikell/Modell: RAMME_ASSEMBLY	Dato: 21-May-20
	Beskrivelse: Support Frame	Tegning: TURBINE

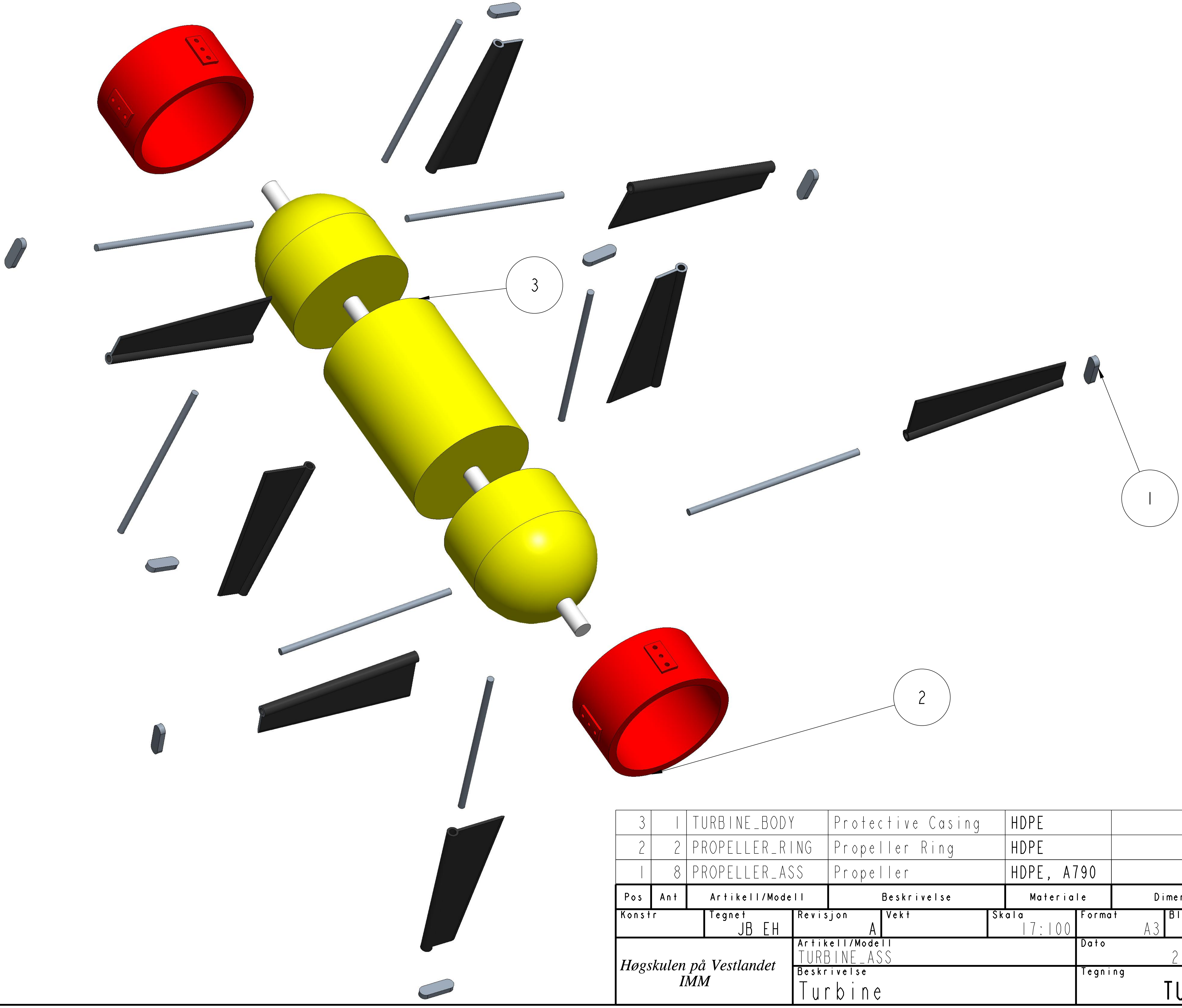




Pos	Ant	Artikell/Modell	Beskrivelse	Materiale	Dimensjon
2	1	TURBINE_ASS	Turbine	HDPE,A790	
1	1	RAMME_ASSEMBLY	Support Frame	HDPE,A790	

Konstr	Tegnet	Revisjon	Vekt	Skala	Format	Blad.nr
	JB EH	A		1:100	A3	6(8)

Høgskulen på Vestlandet IMM	Artikell/Modell: TURBINE_COMPLETE	Dato: 21-May-20
	Beskrivelse: Complete turbine	Tegning: TURBINE



Pos	Ant	Artikell/Modell	Beskrivelse	Materiale	Dimensjon
3	1	TURBINE_BODY	Protective Casing	HDPE	
2	2	PROPELLER_RING	Propeller Ring	HDPE	
1	8	PROPELLER_ASS	Propeller	HDPE, A790	

Konstr	Tegnet	Revisjon	Vekt	Skala	Format	Blad.nr
	JB EH	A		17:100	A3	7(8)

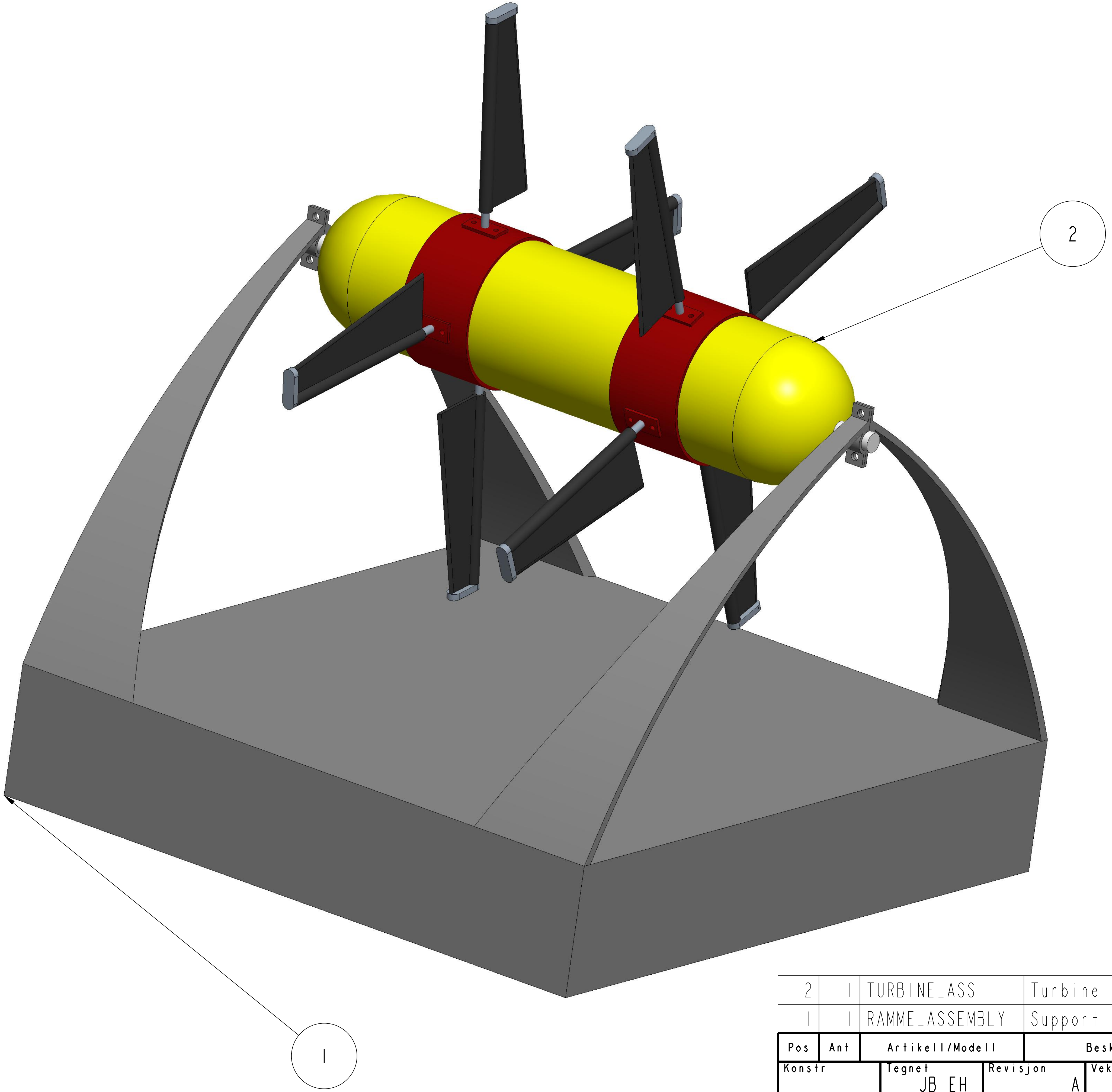
Høgskulen på Vestlandet
IMM

Artikell/Modell: TURBINE_ASS

Beskrivelse: Turbine

Dato: 21-May-20

Tegning: TURBINE



Pos	Ant	Artikell/Modell	Beskrivelse	Materiale	Dimensjon
2	1	TURBINE_ASS	Turbine	HDPE,A790	
1	1	RAMME_ASSEMBLY	Support Frame	HDPE,A790	

Konstr	Tegnet	Revisjon	Vekt	Skala	Format	Blad.nr
	JB EH	A		17:100	A3	8(8)

Høgskulen på Vestlandet
IMM

Artikell/Modell: TURBINE_COMPLETE

Beskrivelse: Complete turbine

Dato: 21-May-20

Tegning: TURBINE