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KONGSBERG

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Parabolic Reflector for Focusing of Underwater Acoustic Waves

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Master`s Thesis in Engineering Design – SHO6263 – June, 2017

Abstract

Kongsberg Maritime has produced a transponder placed on the seabed designed for receiving and transmitting sound waves from vessels and ROVs. The soundwaves contain data regarding depth and location, and can be transformed to energy thus increasing the transponder battery lifetime. The transponder can only receive a small amount of energy, since its receiving area is small. This project aims to create a parabola that increases the accumulation of soundwaves subsea, on behalf of Kongsberg Maritime.

Emphasis has been placed on achieving a functional parabola construction that is adaptable to the existing transponder, without making changes to its design. The most important factor during the project has been to create a design that can receive more soundwaves than current transponder properties. The following problem statement was the basis of this thesis:

"How to design a parabolic reflector with optimal acoustic and reflecting properties that maximize the energy accumulation from sound waves, while handling the rough subsea environment?"

This report comprises phases of a product development process, ranging from a literature study to a final design of the parabola. The report also consists of a specification table with rules and regulations applicable to the product, a material selection process, and analyses of the design.

The report concludes with a design that increases the sound wave accumulation, embodying features that enable it to function in a harsh subsea environment. Although a variety of transducers are currently available and have been developed by several different companies, none of them has the benefit of a parabola that increases the amount of sound waves received.

Acknowledgements

For their help and genuine interest in this project, a special thanks is sent to Per Johan Nicklasson and Guy Beeri Mauseth from The Arctic University of Norway, to Thor Storm Husøy and Harald Aas-Aune from Kongsberg Maritime, and to Mehdi Azadmehr from Buskerud and Vestfold University College.

Abbreviations

CB	**C**enter of **B**uoyancy
CG	**C**enter of **G**ravity
DP	**D**ynamic **P**ositioning
DNV	**D**et **N**orske **V**eritas
DNV GL	**D**et **N**orske **V**eritas **G**ermanischer **L**loyd
HPBW	**H**alf **P**ower **B**eam **W**idth
IEC	**I**nternational **E**lectrotechnical **C**omission
IMO	**I**nternational **M**atitime **O**rganisation
ISO	**I**nternational **S**tandard **O**rganization
KM	**K**ongsberg **M**aritime
NORSOK	**Nor**sk **So**kkels **K**onkurransepossisjon
OS	**O**ff**s**hore
RU	**Ru**les
ROV	**R**emotely **O**perated **V**ehicle
SF	**S**afety **F**actor
SONAR	**SO**und **NA**vigation and **R**anging
UWT	**U**nder **W**ater **T**echnology

Symbols

A	Area
a	Constant
B	Buoyancy
b	Width
c	Speed of sound
C	Constant
d	Diameter
D	Directrix
E	Elasticity modulus (Young's modulus)
ε	Strain
f	Focal point
F	Frequency
(F)	Functional requirements
F_B	Buoyant force
F_G	Gravitational force
g	Acceleration of gravity
(G)	Geometry
h	Height
L	Length
I	Moment of inertia
m	Mass
M	Material index

(M)	Material properties
P	Pressure
p	Performance
Δp	Difference in pressure
ρ	Density
q	Force/Area
R	Radius
t	Thickness
v	Speed of a sound wave in sea water
V	Volume
ϑ	Poisson's ratio
σ	Stress
σ_y	Yield strength
θ	Angle
λ	Wavelength
δ_b	Deflection

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1 Project Description

The purpose of this project is to develop a parabolic reflector that will receive acoustic waves in order to collect energy under water [6]. The parabolic reflector will be connected to one of Kongsberg Maritime's transponders called cNODE Midi, which forms the basis of the design in this project. The transponder is shown to the left in Figure 1. The red part of the transponder is known as the transducer, and the top of it represents the area where signals can be sent and received. The transponder itself consist of interchangeable parts on the top and bottom.

The Midi transponder is part of a bigger positioning system, used to position equipment and vessels. The transponder is lowered down to the seabed with a sand bag that is connected to the transponder by a rope. A float collar keeps the transponder vertically floating in the water. An example of this is shown to the right in Figure 1, where four of these are used to position a ROV (Remotely Operated Vehicle). The information is sent to a boat at the surface, where the ROV is controlled. [4]

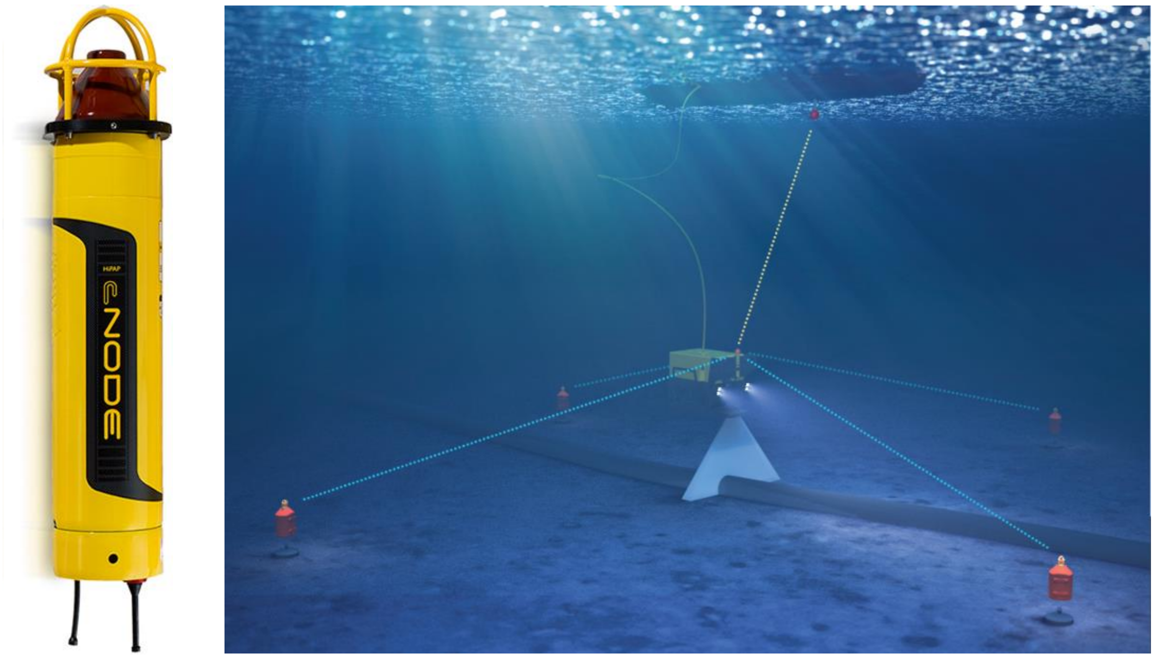


Figure 1: The cNODE Midi transponder and example of usage [3], [4].

The boat has a transducer lowered down in the ocean which can send and receive signals from most directions. An example of how this works is shown in Figure 2. The application of a parabola to the transponder system replaces the existing float collar and will enable the transponder to collect more signals from the boat at the surface, by enlarging the receiving area.

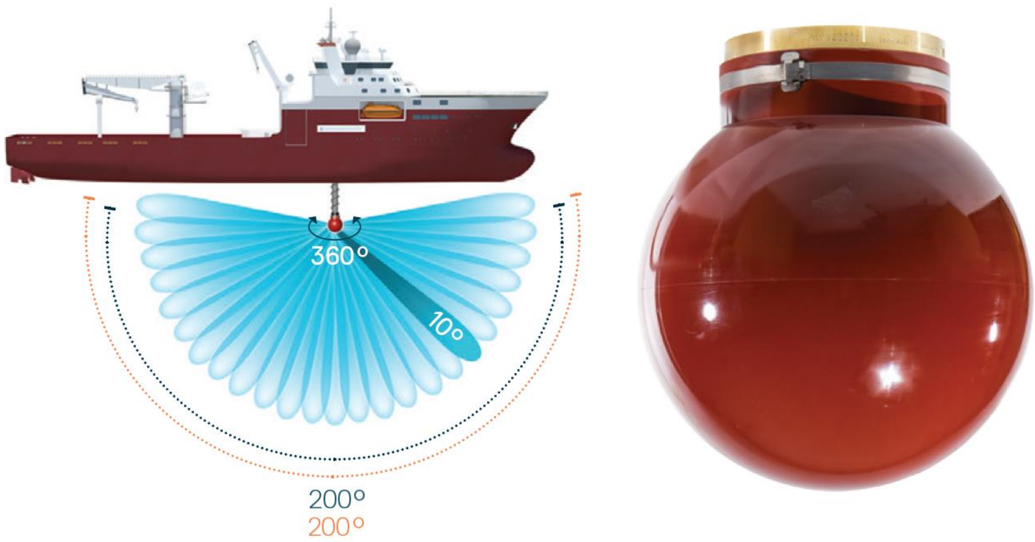


Figure 2: One of KM's transducers that are lowered down from the boat to send/receive signals [4].

Kongsberg Maritime transfers energy down to the transponder by the use of sound waves. The transducer transforms this energy into electricity, giving the transponder an extended battery life. This reduces the amount of times the transponder must be retracted to the surface - a process that is expensive. The extension of battery life is an important improvement, as this is one of the main reasons for bringing the transponders up to the surface [7]. The parabolic reflector is meant to maximize the transponders energy accumulation and focus the energy into the receiving transducer [6]. By using the parabolic reflector as a floatation device, it allows for an easy retraction of the transponder to the surface.

1.1 Project Goals

After discussing with KM as well as considering the given project description, it was clear that several important aspects must be taken into consideration during the creation of the parabolic reflector. These have been used to establish the project goals listed below. The finished product should [6], [7]:

- Handle the harsh environment anticipated by life in seawater, including resistance to corrosion and the growth of algae.
- Be constructed of a material with good reflection properties that optimizes the energy accumulation.
- Connect to the existing transponder without changing its original design.
- Maximize the reflection of acoustic sound waves.
- Handle the pressure from being under water.

- Be well tested to have an optimal design.
- Have a robust mechanical support.
- Be easy to lower to the sea floor.

The goals were used to evaluate the design of the parabolic reflector continuously in order to optimize the result of the final product. The above goals lead to a final problem statement:

"How to design a parabolic reflector with optimal acoustic and reflecting properties that maximize the energy accumulation from sound waves, while handling the rough subsea environment?"

1.2 Limitations

The design of underwater equipment can be challenging due to the increasing pressure with depth. The following limitations were set to limit the project to a manageable size:

- Kongsberg Maritime wants the final product to be used at 200 m depth. This was the basis for the calculations during the project.
- It was assumed that the sound waves would travel straight down from the surface to the parabola, hitting the seabed with an angle of 90°. These are the sound waves that has been focused on collecting.
- Concerns or design regarding electronics has not been addressed, as the group participants did not have the competence to do so. Kongsberg Maritime has stated that the electronics on the final design were highly feasible, and not a concern.

2 Literature Study

A literature study was conducted to gather relevant information that would be useful in the process of designing a parabolic reflector for underwater usage. This information is discussed in the following sections.

2.1 Underwater Acoustics

In this section, a general description of acoustic waves is presented, as well as how they behave in seawater and what the limitations are for their propagation in this medium.

2.1.1 What are Acoustic Waves?

Underwater acoustic waves are the transmission of sound waves below the sea surface. They originate from the propagation of a mechanical perturbation, traveling as a vibration consisting of alternating compression and expansion of the water (pressure waves). The sound waves transfer energy and information, and can be either man-made or biological (whales or waves) [8].

2.1.2 How do Acoustic Waves Behave in Seawater?

The sound waves are limited by two interfaces, the bottom and the sea surface. As seen from Figure 3, the sound waves expand away from its source. If the wave hits an object on its path, such as the sea floor, a reflective signal will be transmitted back and inform the receiver of this information. This reflection, often unwanted, creates multiple paths of the sound waves, which show up as bursts of replicas of the sound transmitted at high frequencies, or as a spatial field of stable interferences at low frequencies. Both types of reflection signals are bad for the reception of the signals transmitted, as they interfere with the original signal and arrive with varying delay. This echo can therefore mask the actual signal meant to be received, as it is reflected back by various objects located in the seawater [8], [9].

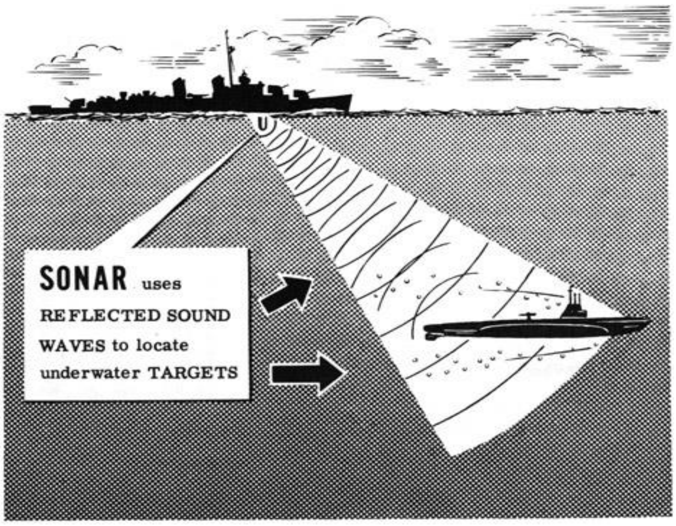


Figure 3: Sound waves reflection [10].

The transmission rate of a sound wave is named speed of sound or velocity, and is denoted c. The speed of a sound wave depends on the medium it travels in, for seawater they have a relatively low propagation speed of 1500 m/s. In applications used for detection and location, the transmitted signal is sent back by sonar to a target. The length of the wave propagated depends on the frequency of the transmitted signal. The larger the frequency, the shorter the wavelength. A shorter wavelength is favorable to obtain a more cohesive transmission of signals [8], [9].

The sound waves will be sent with a specific frequency. Kongsberg Maritime is currently using a frequency of $20 - 30$ kHz, but is working towards using an increased frequency of 1 MHz. As can be seen from the calculations done in Appendix 13.1, this influences the wavelength. The frequency that is used will not have any influence on the design, as the design of the parabola is only made to reflect the sound waves.

2.1.3 What can Limit the Propagation of Acoustic Waves?

Seawater limits the propagation of acoustic waves, as it varies in temperature (especially with depth), and salinity, which affect the water's density. This gives the sound waves a random fluctuating character, as shown in Figure 4. In addition to the reflection from objects located in seawater, the various limitations and losses experienced by an acoustic wave is:

- Absorption losses. Some of the energy from the acoustic waves is absorbed by the water (propagation medium) and turned into heat [8], [9].
- Intensity loss. The waves spread out the further away they are from the source of the propagation, moving as an expanding sphere (geometric spreading) [8], [9].

- Air bubbles. Air might be the biggest reflector underwater, and amongst some unfavorable issues, it can block the acoustic signal and create backscatter echoes. The air bubbles decrease with depth, and below $10 - 20$ m, the effects of surface-generated bubbles can be neglected [8], [9].
- Seabed relief, swell, currents, tides, antennae waves, movements of the acoustic systems and their targets, all contribute as disturbances [8], [9].
- Ambient noise that comes from movements of the sea surface, volcanic and seismic activity, shipping, living organisms, rain, etc., and the self-noise characteristic of the acoustic system and its platform. This noise tends to mask the useful part of the signal [8], [9].

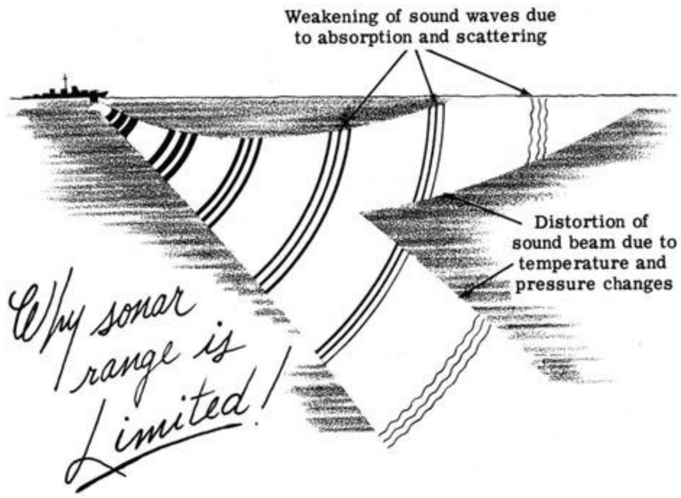


Figure 4: The spreading of sound waves [10].

2.1.4 Collecting Sound Waves by the Means of a Parabola

Since the sound waves spread out as they travel, it is important to cover a large area in order to gather as much energy as possible. This can be done by the means of a parabolic reflector. The parabola collects sound waves over a large area, and focus the waves to a focal point. How the signal is transmitted back depends on its structure, dimension, and angle. It also needs to have the right impedance and tolerate the harsh subsea environment [6].

2.2 The Subsea Environment

The subsea environment can vary significantly depending on depth [11]. The photosynthesis only occurs down to a depth of $100 - 200$ m, and the sunlight vanishes at 1000 m. Depths lower than 1000 m is often referred to as the deep sea. The ocean can get as deep as $11\ 000$ m, so big parts of the ocean is cold and dark [12].

2.2.1 UV Radiation

Some of the light from the sun that hits seawater will be reflected with an angle which is equal to the incoming angle. The remaining light that is not reflected will go into the ocean. A portion of this is also UV radiation. As mentioned above, the marine photosynthesis goes down to a depth of 200 m in the ocean, and UV radiation also penetrates down to this depth [13].

2.2.2 Temperature

The temperature difference between the surface water and the deep-sea water can be quite drastic. On a warm summer day in Norway the water temperature at the surface may be 15˚C, while it is higher in other parts of the world [14]. In the deep sea the temperature in the water is more uniform and constant, usually lying between -1˚C and +4˚C [12].

2.2.3 Pressure

Hydrostatic pressure is defined as the force a liquid exerts on an object [15]. This pressure increases as one goes deeper down in the ocean. The average atmospheric pressure on the surface of the earth is 1 atm [16]. The definition is given as [17]:

$$1 \text{ atm} = 1.013 \cdot 10^5 \text{Pa} = 1.013 \text{ Bar}$$

Pressure increases with 1 atm for each 10 m one descends deeper into the ocean [12]. A calculation has been conducted in order to understand the amount of pressure the parabola will be exposed to at a given depth. This calculation is located in Appendix 13.2, and indicates that the pressure it will be exposed to at 200 m is 2.112 MPa or 21.12 Bar.

2.2.4 Buoyancy

Buoyancy is defined by the law of Archimedes which states that the buoyancy is equal to the gravity of the displaced fluid [18]. This implies that if the immersed body has less density than seawater, it will float in the ocean [17]. This is an important factor to consider during the design process of subsea equipment.

2.2.5 Algae

In the ocean, the growth of algae is a concern. Algae growth on the parabola would affect the reflection and hence the battery life of the transponder. The growth of algae is a common problem in shallow waters, but is minimal below 100 m depth. A smooth surface will prevent the growth of algae to some degree. Materials or coatings that does not attract algae growth should be emphasized during the material selection for the parabola. Paints used on the hull of boats to prevent the growth of algae can be applied, according to Kongsberg Maritime.

2.2.6 Corrosion and Degradation

Corrosion and degradation are phenomena's where the materials are exposed to nature and chemical reactions happen causing the material to slowly degrade because of it [19]. The term corrosion is often used for metals and the term degradation is often used for polymers. Both of these processes can occur in a variety of different forms depending on the material [20]. Galvanic corrosion is a phenomenon where molecules are exchanged between two different metals. This process can occur when the metals are placed in an electrolyte, for example salt water [19]. Actions must be taken to prevent corrosion and degradation of the parabola.

2.2.7 Speed of Sound

In seawater, the speed of sound depends on three things; temperature, pressure and salinity of the water [21]. A phenomenon that alters the spreading of the spherical shaped sound waves in the ocean is inhomogeneities of these three factors. These variations differ by depth, causing the ocean to be divided into different layers. The layers of which the reflective parabola is going to operate will be the surface layer as well as the seasonal thermocline. The surface layer is very dependent on the air and surface conditions. The seasonal thermocline is below the surface layer and is more stable, but still have some seasonal variations [11] .

2.3 Reflection Theory

The law of reflection states that when a ray is reflected, the angle of the reflected ray is the same as the angle of the original ray [18]. This is the fundamental theory behind a reflecting parabola. A parabolic reflector can be used to project energy in different forms, for example light, sound, and radio waves [22].

The parabola in this project must have a shape such that the sound waves coming into the parabola are reflected to the focal point [18]. In this case the final focal point will be the receiver (transducer) of the transponder, presented earlier in this report. The focal point, as can be seen in Figure 5, is located on the symmetry axis of the parabola [23]. The bigger the parabola is, the more energy it can receive, and hence more electricity can be produced.

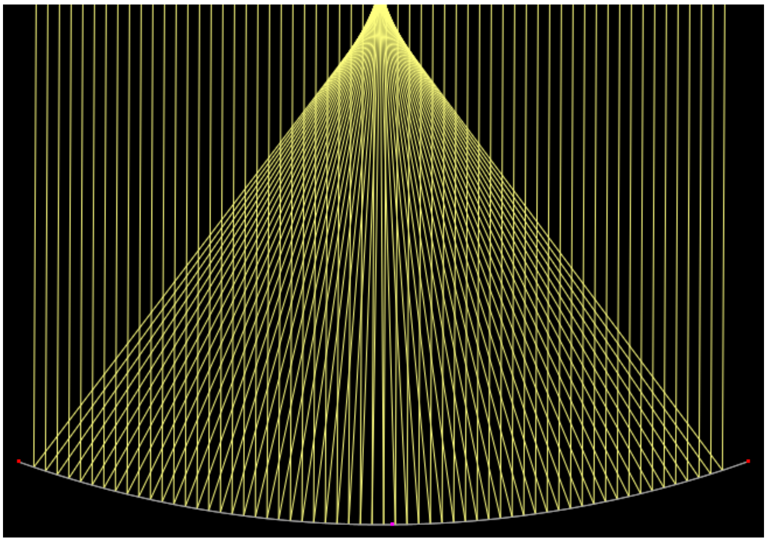


Figure 5: Parabolic reflector. Figure created in Ray optics simulation.

A given parabola can be used to find the focal point, or a given focal point can be used to find the parabola [24], [25]. This theory can be used to design a parabola with an optimal curvature. A parabola is a mathematical term and represents a curve with the form [18]:

$$y = ax^2$$

2.4 Existing Products and Competitors

A problem for Kongsberg Maritime's current transponder is that its ability to collect energy is minimal. Adding a parabola to the system will increase the collection of energy, and thereby its ability to produce more usable electricity. In order for a product to be considered as a competitor, it must be able to produce more electricity than Kongsberg Maritime's cNODE Midi 34-180 transponder currently does, while still maintaining its original features. No competitors of this caliber were found, although Kongsberg considers two companies as competitors; Sonardyne and Teledyne Benthos. It was decided to compare Kongsberg Maritime's cNODE Midi 34-180 with one of the most similar transponders from both companies, since the addition of a parabola would give each of these products the same advantage of producing increased usable electricity. The comparison can be seen in Table 1.

Sonardyne is a leading provider of underwater acoustic and sonar technology. The most similar transponder was the Wideband SUB-Mini 6 plus 8370-4172, and is compared with the other transponders below [26]. Teledyne Benthos is an American company that design and develop several marine products and systems [27]. Some of these products can be considered as competitors to Kongsberg Maritime's transponder. One of these is TR-6001, described below.

Table 1: Comparison of competing products [26] - [30].

	cNODE Midi 34-180	Wideband SUB-Mini 6 plus 8370-4172	Transponder TR-6001
Dimensions	$495\ \text{mm}\times Ø144\ \text{mm}$ (tube)	$436\times 88\ \text{mm}$	$Ø0.6\ \text{m}$
Weight in Air/Water	$16.5\ \text{kg} / 8.5\ \text{kg}$	$6.0\ \text{kg}/$	$26\ \text{kg}/$
Depth Rating	$4000\ \text{m}$	$4000\ \text{m}$	$6700\ \text{m}$
Beam Width	180°	-	-
Source Level - max	$190\ \text{dB}$	$196\ \text{dB}$	-
Operating Temperature	$-5\ °\text{C to } +55\ °\text{C}$	$-5\ °\text{C} \ to\ +40\ °\text{C}$	-
Storage Temperature	$-30\ °\text{C to} + 70\ °\text{C}$	$-20\ °\text{C} \ to\ +55\ °\text{C}$	-
Mechanical Construction	Anodized aluminum coated with polyurethane	Aluminum Alloy, Anodized	Glass sphere
Frequency Band	$21 - 31\ \text{kHz}$	-	$7 - 17\ \text{kHz}$
ACOUSTIC OUTPUT: re $1\mu Pa$ at $1m$ (acoustic power)	$180\ \text{dB (8W)}$	-	$185\ \text{dB (20W)}$
Pulse Length	$5\ \text{ms}$	-	$10\ \text{ms}$
Power Source	Lithium battery	Rechargeable NiMH Battery Pack	$16\ \text{amp} - \text{hour}$ alkaline battery pack
Release Function	Hook	Screw release	Burn wire release
Quiescent Battery Capacity	$1.25\ \text{years}$	$>\ 35\ \text{days}$	$2\ \text{years}$

The most noticeable fact in Table 1 is the difference between weight and battery capacity of Wideband SUB-Mini and the two other transponders. The weight of the product is a direct consequence of a larger battery capacity – a bigger battery can store more electricity. Adding a parabola to the transponder has never been done before, and may revolutionize this type of product if successful. Although there are no direct competitors to this addition, it has the potential of being implemented in all of these products to enhance their operating time.

3 Specification

A specification was developed to gather all the requirements that were considered during the design process of the parabolic reflector. These requirements were found through the previously gathered information as well as requirements from Kongsberg Maritime and regulations for this specific type of product. Several requirements was gathered from DNV GL, a company that specializes in developing rules and standards for the industry [31]. All the requirements were gathered in the specification shown in Table 2, where they were divided into customer, technical, design, material, and environmental requirements to give a better overview of the different aspects considered. The right part of the table shows whether the requirement needs to be fulfilled or should be fulfilled. The specification was used to design a product that fulfills the requirements given in this table.

Table 2: Specification Table for Parabola.

Specification	**Should**	**Need**
Customer Demands		
Reflect acoustic waves to a focal point		■
Maximize amount of collected energy		■
Fit the cNODE Midi $34-180$ transponder		■
Handle temperatures of -30 °C to $+70$ °C [29]		■
Elongate the battery lifetime of the transponder		■
Generate a beamwidth of approximately $10°$		■
Design the parabola as a float collar for retraction to the surface, and keeping the cNODE vertically floating in the water	■	
Parabola lifetime of 5 years	■	
Technical Requirements		
Handle a pressure of at least 21.12 Bar		■
Mechanical support system designed to prevent buckling according to DNV 30.1 [32]		■
The object's buoyancy and center of buoyancy to be defined according to DNV-OS-H102 Sec.3 C [33]		■
Handle depths of at least 200 m		■
Calculate expected loads according to DNVGL RU-UWT. Pt3Ch2 [34]		■
Design Requirements		
Not interfere with the transponders design or operation		■
Foundation Design according to ISO 19901-4 [35]		■
Easy to lower the parabola		■

Protected against accidental damage according to DNV-OS-H102 2.B [33]		
Visible on the bottom according to DNV-OS-H206 [36]		
Capture sound waves with an angle of 90° to the seabed		
Material Requirements		
Follow weight restrictions according to DNV Standard CN30.4 to prevent damage to the seabed [37]		
Corrosion resistant according to regulations set by DNVGL-RU-UWT 5.2 and 3.3 [38] [34]		
Cathodic Protection of Steel Structures in Seawater according to ISO 12473:2006 [39]		
Resist the growth of algae		
An acoustic impedance as different as possible from water, for good reflection properties*		
Low water absorption factor as stated by DNVGL-RU-UWT 5.2 [38]		
Density less than $1.025 \cdot 10^3 \ \frac{\mathrm{kg}}{\mathrm{m}^3}$ [40]		
Follow NORSOK Standard M-DP-001 with regards to Material Selection of Offshore Installations [41]		
Mechanical properties of bolts, screws, and studs according to ISO 3506 [42]		
Environmental Requirements		
Self-recovery system in the case of communication failure		
Recyclable		
Protect the marine environment by preventing contamination in accordance with all IMO regulations		
Environmental testing of the final product according to IEC 60945 to prevent emission etc. [43]		

* When a sound wave hits the boundary between one medium and the other (water and the material of the parabola), a portion of the wave undergo reflection and a portion undergo transmission across the boundary. The amount of reflection is dependent upon the dissimilarity of the two media. A dense and hard material is dissimilar to water, and thus reflects sound waves well [44]. If the surface is smooth, they are reflected as a beam [45]. The surface of the parabola needs to be coated with a material making the surface smooth and dense.

4 Idea Generation

Idea generation is the process of creating and communicating ideas [46]. In this case the process consists of two rounds of sketching, where in both rounds several ideas were created. After conducting the first round, two ideas were brought through to the second and more thorough round of sketching. The winner of the last round was then brought through to the Concept Development stage.

4.1 First Round

The purpose of the first round was to start a creative process where anything was allowed. Two moodboards were created for inspiration, and the four ideas were evaluated based on positive and negative aspects. The first round of the Idea Generation stage is located in Appendix 13.3.

Idea 2, and a combination of the "blade" designs in 1, 3, and 4 were chosen to be further developed, going into the second round of idea generation.

4.2 Second Round

Before executing the second round of idea generation, a list of design criterions was created based on the specification and the project goals listed previously in the report. These criteria's was the base for the design process, and was in the end what the ideas were evaluated upon. The design criterions are:

- Smooth water flow around the design for easier lowering to the seabed.
- Self-recovery system in case of communication failure.
- Design it as a float collar for retraction to the surface.
- Best fit the cNODE Midi 34 -180 transponder.
- Keep cNODE vertically floating in the water.
- Maximize sound wave area coverage.
- Low complexity of components.
- Low risk of operator mistakes.
- Robust mechanical support.
- No unnecessary features.
- User friendly.

4.2.1 Idea 5

This idea was based on idea 2 from the previous round of idea generation, and is shown in Figure 6. The parabolic structure is divided into two individual parts that are connected by hinges on one of the sides. On the other side, the two parts are closed together by a fastening mechanism as shown to the right on the figure. Located beneath the transponder is a magnetic shelf holding it down in an accurate position. The hole underneath the parabola goes all the way through, enabling the use of the transponder’s release mechanism. The parabolic structure is filled with air to ease retraction to the surface. The structure has a form that is a bit sharper than the previous design, improving the water flow around the parabola.

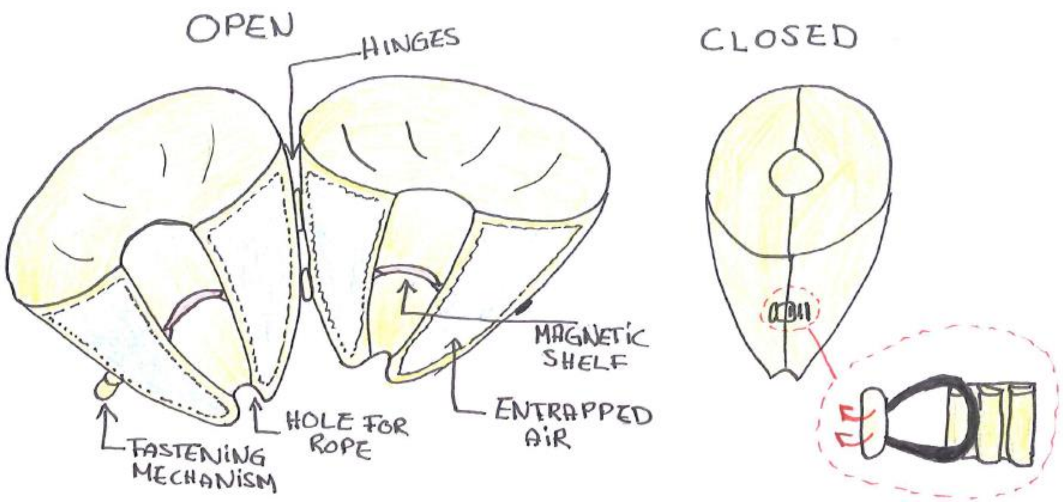


Figure 6: Idea 5 - Round 2.

4.2.2 Idea 2

The idea in Figure 7 was based on several ideas from the first round of idea generation. These ideas included the use of several smaller blades that together create a parabolic curve. The structure is divided into two parts, with the same fastening mechanism as in Idea 5. The structure has a hole going all the way through it in the middle. The individual blades overlap each other and thereby act as a support. The parabola can be opened and closed by the use of electricity or hydraulics. When closed, the structure will smoothly flow through the water.

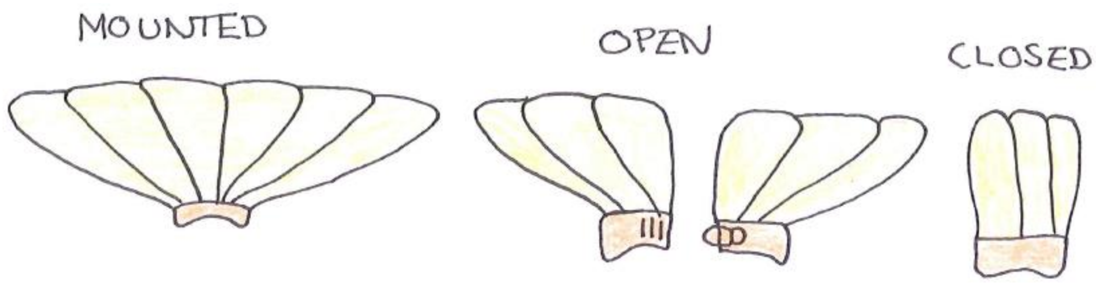


Figure 7: Idea 6 - Round 2.

4.2.3 Idea 3

The idea of the design shown in Figure 8 was to create the parabola as one entire part. This will decrease the risk of operator mistakes, and improve the user friendliness. The transponder is inserted into a slot for better support, where a magnet or some form of tightening system secures it in its position. The bottom of the parabola has an integrated air-slot. The thought is that the bottom then will have more compressed air than the rest of the design, turning it upside down when the ropes are cut and the parabola is retracted to the surface. The parabola is secured to the sand bag by four ropes on the sides, restraining it from turning sideways.

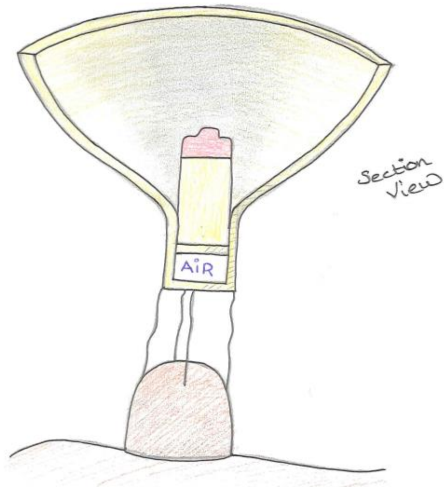


Figure 8: Idea 7 - Round 2.

4.2.4 Idea 4

The idea in Figure 9 was made up by individual, module based, blades. It is launched into the water in an open position, and as it drops down to the sea bottom, the blades will retract due to the upward pressure of the water. This creates a smoother journey downward and decreases unwanted movement, which could end up with an unknown location at the sea bed. The blades lock into position when hitting the bottom. This parabola has the same slot for the transponder and air pocket in the bottom as the previous idea. The idea is that it turns upside down when retracted, and that the water pressure has the same function when ascending as descending.

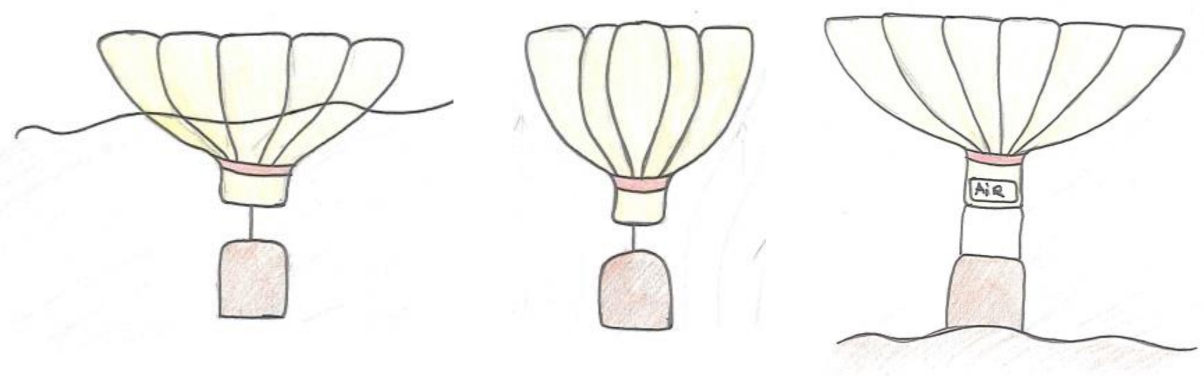


Figure 9: Idea 8 - Round 2.

4.2.5 Design Evaluation - Second Round

The evaluation of the second round of idea generation is shown in Appendix 13.4. It shows that idea 5 and 8 got the highest ranking, leading to the concept development stage.

5 Concept Development

In the concept development, new versions of the previously selected ideas were explored. These versions focus on improving the negative aspects of the previous design. The improvements are based on the requirements set during the evaluation of the second idea generation round.

5.1 Concept 1

The concept in Figure 10 has a slim shape that allows fast positioning of the parabola to the seabed. It has air pockets in the bottom to turn the parabola around when the load is released. The parabola curve starts on the bottom solid structure and is continued by the use of expandable blades. These blades are connected to the bottom structure with joints. The blades are held together by a material that dissolves in water, loosening the blades after a specific amount of time after reaching the seabed. Located on the inside of the blades are two rings connected by springs under pressure, causing the blades to open as they are released when the dissolvable material loosens. A smaller parabola is added above the transponder in the focal point of the big parabola. This is for better focusing of the sound waves.

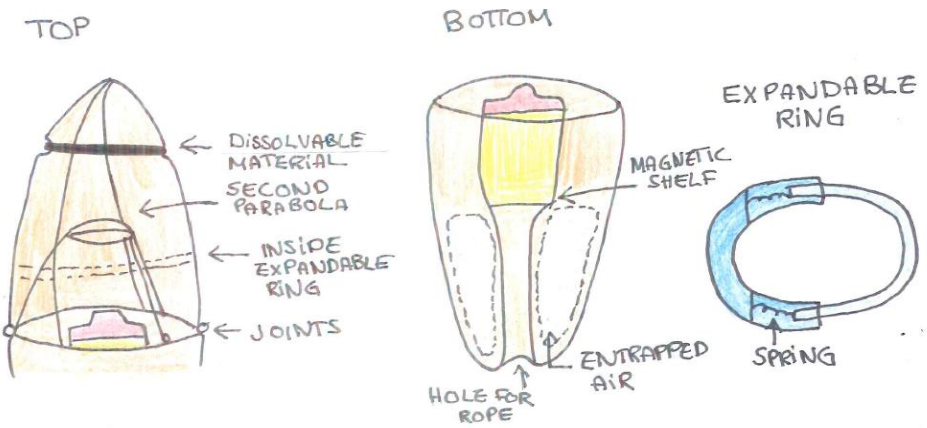


Figure 10: Concept 1.

5.2 Concept 2

The concept in Figure 11 is similar to the previous idea, and focus on covering a large amount of area. It has double blades that can be folded together, and then connected by a dissolvable material. The different segments of the parabola will be unfolded by the use of springs under tension that retracts and open the parabola when the material is dissolved in water.

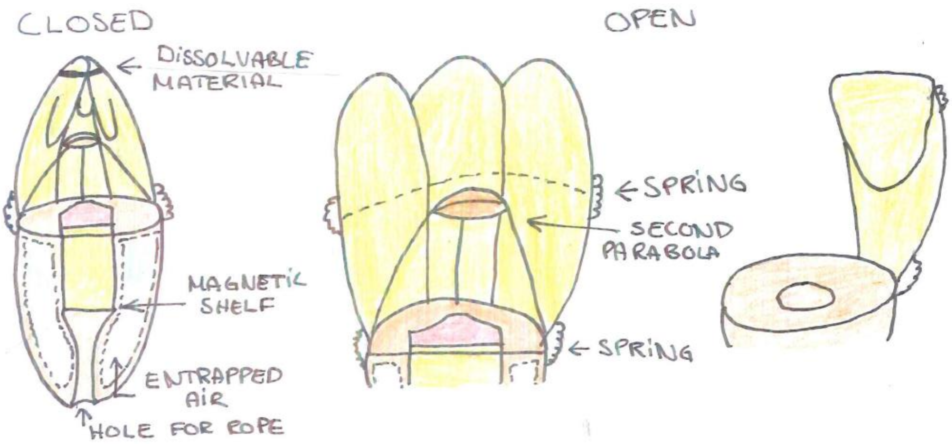


Figure 11: Concept 2.

5.3 Concept 3

In the concept in Figure 12, the hole for the rope has been made smaller to decrease flow resistance during launch and retraction. The air pockets have been moved further down to create a larger volume of air at the bottom of the design, which could turn the parabola upside down at retraction if designed correctly. The upward pressure from the water contracts the blades when the system is launched into the water. It has a spring-system on the side that spread the blades out into a parabolic shape when it hits the seabed, this to create a robust mechanical support. The blades are longer to maximize the reflective area. The system has an extra parabola for concentrating the incoming signals to the transponder.

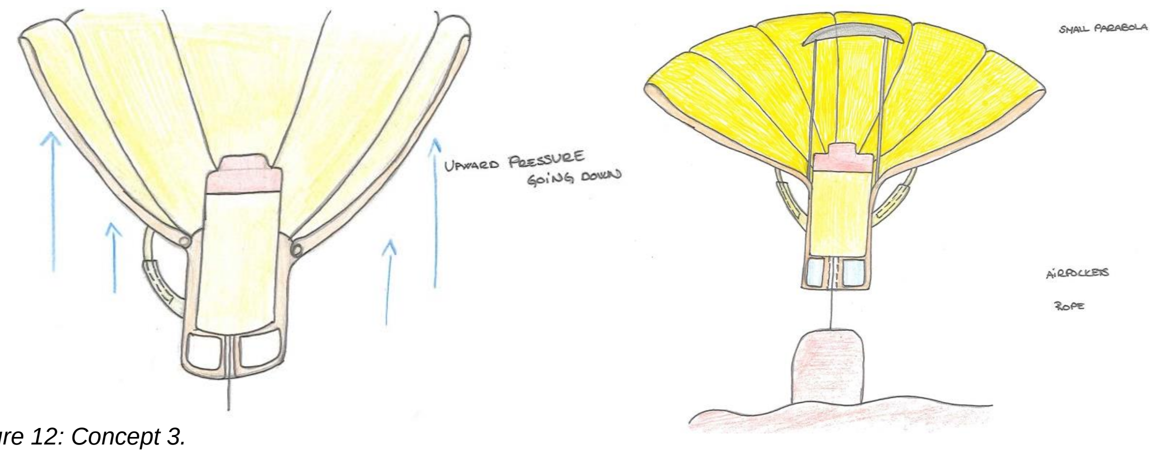


Figure 12: Concept 3.

5.4 Concept Evaluation

Customer satisfaction is extremely important when developing a product. The concepts were therefore evaluated together with three employees at Kongsberg Maritime, with the same design criteria's and scoring as the previous evaluation.

Table 3: Concept Evaluation.

Design Criteria's / Ideas	Score Weight	Idea 1		Idea 2		Idea 3	
		Point	Sum	Point	Sum	Point	Sum
Maximize sound wave area coverage	1.1	4	4.4	3	3.3	5	5.5
Best fit the cNODE Midi transponder	1	4	4	4	4	4	4
Robust mechanical support	0.9	4	3.6	3	2.7	5	4.5
Self-recovery system in case of communication failure	0.8	4	3.2	4	3.2	4	3.2
Low risk of operator mistakes	0.7	5	3.5	4	2.8	3	2.1
Smooth water flow around the design for easier lowering to the seabed	0.6	5	3	4	2.4	3	1.8
Keep the cNODE vertically floating in the water	0.5	4	2	4	2	4	2
Design it as a float collar for retraction to the surface	0.4	4	1.6	3	1.2	5	2
No unnecessary features	0.3	4	1.2	3	0.9	4	1.2
Low complexity of components	0.2	4	0.8	3	0.6	5	1
User friendly	0.1	5	0.5	4	0.4	4	0.4
Sum		**27.8**		**23.5**		**27.7**	

As can be seen from Table 3, concept 1 and 3 only differed by 0.1 points. One of the first topics discussed in the meeting was the release mechanism. The existing release function is module based, and can be screwed onto the bottom of the cNode Midi. The transponder can be fastened to the parabola with screws that already exist on the cNode Midi. As seen on the left of Figure 13, the release function sticks out through a hole in the bottom of the existing float collar. If this is implemented, it gives the opportunity of using the existing release mechanism, without making changes to its design or its adaptation to the Midi transponder. The release mechanism is shown on the right side of Figure 13.

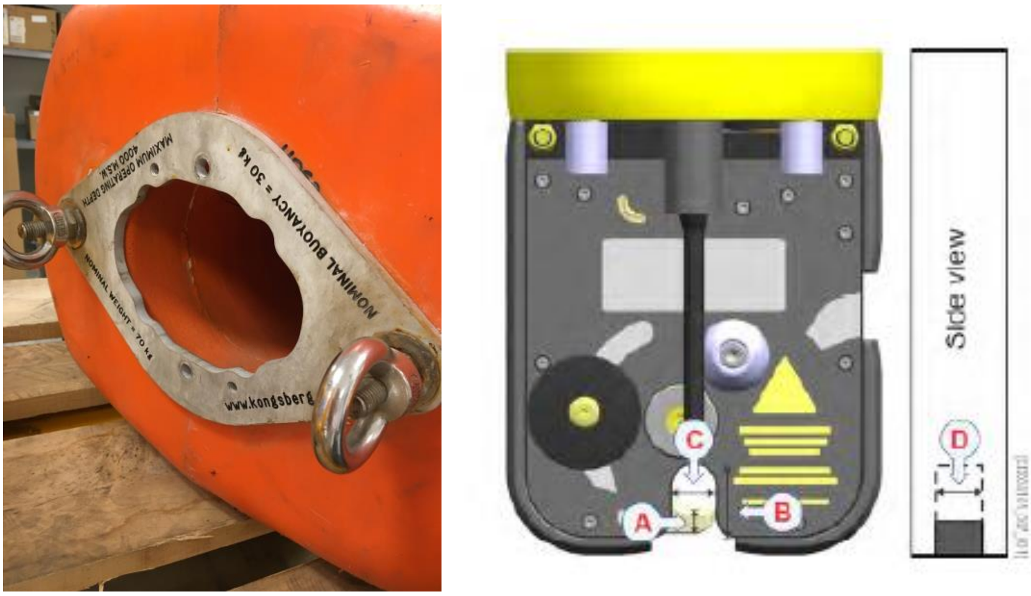


Figure 13: Bottom of a float collar on the left - release mechanism on the right [5].

Another subject that was discussed was if the air pockets are necessary or if a more massive part could replace the need for them. Calculation would have to be conducted regarding buoyancy to substantiate such a design. A massive part would save production costs because KM avoid machining the holes for the air pockets. The opening mechanism may also be replaced by simple electronics that open and close the parabola by the use of signals from the surface.

It was also discussed whether or not it is necessary with an extra parabola. It was discovered that Kongsberg Maritime has existing split transducers, making it possible to dismount the transducer which then will only be connected by a cable. This enables the sound waves to be sent directly into the transducer, which may prevent the loss of energy.

The importance of a hydrodynamic shape was also brought up as a concern. This shape is advantageous when the parabola is floating above the seabed as there is a smaller surface area that can be pushed around by the sea current. The hydrodynamic shape is not as important when descending to the seabed, as this will cause it to be lowered with too high of a speed. The parabola might be in contact with the seabed as the sand bag drops down. The fast lowering could be compensated for by having a longer rope, which in many cases is preferable according to Kongsberg Maritime. Concept 1, concept 3, and the comments from Kongsberg Maritime was used as a basis when creating the final design of the parabola.

6 Concluded Design to be Further Investigated

As can be seen from the sketch of the concluded design in Figure 14, the lower part is wide with rounded corners. This shape is more similar to the float collar KM already has developed for the Maxi transponder and causes the parabola to sink at a slower speed. The lower part is solid, and will provide the necessary buoyancy force for retraction to the surface. The design has made room for the cNODE Midi transponder and has given enough space for the release mechanism below the solid part. Fastening of the transponder is done by the use of existing screws at the bottom of the float collar, as shown in Figure 13.

The parabola itself is designed to have long blades overlapping each other, creating a large area coverage. The parabola opens and closes by the use of a signal from the surface. A small parabola above the transponder causes the sound waves to be focused into the transducer. Although this design was a conclusion of the previous evaluation, it remains to be tested, especially with concern to whether or not the second parabola is needed.

Further analysis of the design was necessary to test if the different factors would operate substantially in real life. The design was adjusted according to the findings of these analyses, ending up with a final design. In order to accomplish this, a material had to be specified.

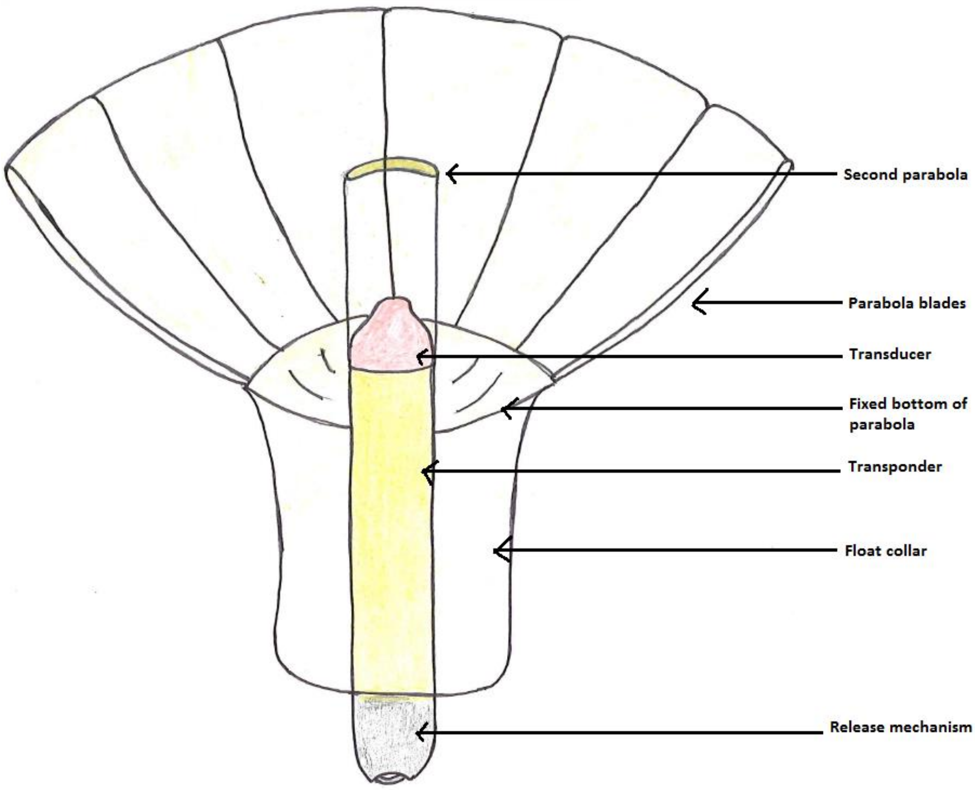


Figure 14: Section view of the final design.

7 Material Selection

A material selection process was conducted in order to find the material that had the best potential to perform well in a given environment [47].

7.1 Material Selection Methodology

A symmetric approach was necessary to be able to make a final decision, and the strategy used in this report was obtained from the book *Material selection in mechanical design* [45]. This strategy is based on requirements from the design, environment, and customer, put up against the diverse range of materials available in the CES Edupack 2016 Database.

Kongsberg Maritime use a material called Divinycell HCP in their float collar for the current transponder. They are interested in investigating if any other suitable materials exist that perform on the same scale, or even better than Divinycell HCP. To give other materials a fair chance, the first part of the material selection process was conducted without regards to Divinycell - only focusing on the constraints that the environment and design holds to a suitable material.

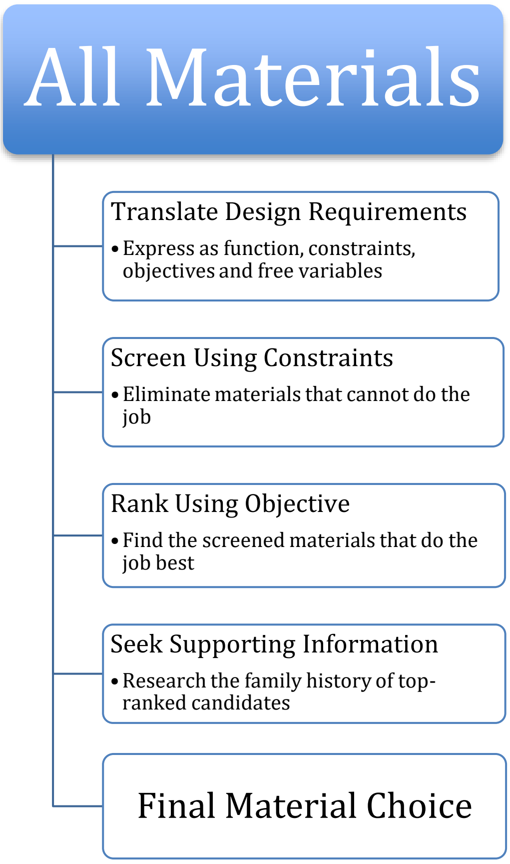


Figure 15: The four steps of material selection [45].

A number of factors needed to be evaluated before making a final decision. According to the book, there are four main steps conducted before choosing a suitable material; translation, screening, ranking, and supporting information. These steps in its context can be seen in Figure 15, and are presented individually below.

7.2 Translation of Design Requirements

The first of four steps is *Translation of Design Requirements*. This step is divided into four individual parts; *Function, Constraint, Objective* and *Free Variables*. The function of the design must be achieved subject to the constraints, because certain dimensions are fixed. The objective can be optimized or minimized, and free variables can be changed in order to choose the best material [45]. Function, constraints, objective and free variables define the boundary conditions for the selection of a material. They are first presented individually, then together as a summary in a table similar to Table 4.

Table 4: Function, constraints, objective and free variables [45].

Function	What does the component do?
Constraints	What non-negotiable conditions must be met? What negotiable but desirable conditions should be met?
Objective	What is to be maximized or minimized?
Free variables	What parameters of the problem is the designer free to change?

7.2.1 Function

The function of the design is an important aspect of the material selection. The chosen material needed to provide specific characteristics in order for the product to conduct its intended purpose. The function of the parabola is to reflect incoming acoustic waves, to function as float collar for the transponder, and to contain its load.

7.2.2 Constraints

A material has several attributes that distinguishes it from another; its density, strength, level of water absorption, amongst some. In order to find a material that is suitable for the environment surrounding the parabola, as well as taking into consideration the different elements of the design, a list of constraints retracted from the list of requirements conducted earlier in the report was gathered. Table 5 shows the constraints that had an effect on the choice of material, differentiated between being a hard or a soft constraint. A hard constraint is a non-negotiable condition that must be met, while a soft constraint is a negotiable but desirable condition.

Table 5: Constraints for material selection.

Constraints	**Soft**	**Hard**
Handle temperatures of $-30\ ^\circ\mathrm{C}$ to $+70\ ^\circ\mathrm{C}$		x
Handle depths of at least $200\ \mathrm{m}$		x
Visible on the bottom		x
Corrosion resistant		x
Resist the growth of algae		x
Density dissimilar to water for good reflection properties		x
Low water absorption factor		x
Density less than $1.025 \cdot 10^3\ [\frac{\mathrm{kg}}{\mathrm{m}^3}]$		x
Recyclable	x	
Protect the marine environment by preventing contamination		x

7.2.3 Objective

An objective is defined as a specific result that is desirable to achieve by the utilization of the resources that are available [48]. After applying the constraints, only a few screened materials remain. The objective is then applied to rank the candidates that remain by using a calculated material index to measure how well the individual materials perform. The property that maximize performance for the given design is called the material index [45].

The final material needs to contain a substantial amount of buoyancy so that the parabola floats to the surface at retraction, as well as to keep it vertically floating above the seabed. Performance is therefore limited by the property (ρ) because the most adequate materials for good buoyancy properties are those with low density [45]. Minimizing this single property maximizes the parabolas performance. The less dense a material is, the lighter it is. The objective was therefore to:

- Minimize mass.

7.2.4 Free Variables

Free variables are dimensions in the design that have not been constrained by the requirements set for the material. These parameters can be chosen freely by the designer in a way that benefits the design [45]. The free variables during the material selection for the parabola was:

- Choice of material.
- Shape of the design.
- Thickness of the structure.

7.2.5 Summary

A summary of the translation of design requirements are given in Table 6. The parameters were considered as the boundary conditions during the material selection process. The most suitable material complies with as many of these as possible.

Table 6: Summary of the Translation of Design Requirements.

Features	Parameters
Function	• Reflect. • Float. • Contain a load.
Constraints	• Handle temperatures of -30 °C to $+70$ °C. • Handle depths of at least 200 m. • Visible on the bottom. • Corrosion resistant. • Resist the growth of algae. • Good reflection properties. • Low water absorption factor. • Density less than $1.025 \cdot 10^3$ $[\frac{kg}{m^3}]$. • Recyclable. • Protect the marine environment by preventing contamination. • Be considered/function as a core material.
Objective	• Minimize mass.
Free variables	• Choice of material. • Shape of design. • Thickness of the structure (t).

7.3 Screen Using Constraints

The constraints that was developed in Table 6 was then used in CES Edupack to eliminate the materials that cannot do the job at all, because one or more of their attributes lie outside the limits set by the constraints. Each limit entered in the program is described in the following section.

7.3.1 Mechanical Properties

The material will be experiencing a pressure from the surrounding water. Since the pressure that the water exerts on the parabola at 200 m is 2.112 MPa, it was set as a minimum under compressive strength.

7.3.2 Physical Properties

The most important physical property was the materials density. For the parabola to be able to float, its density must be less than the density of seawater.

Kongsberg Maritime's existing floating collar is only designed for the Maxi transponder, where the material Divinycell floats well enough to retract the transponder to the surface. This floating collar is smaller than the final design of the parabola, and the Midi transponder used for the parabola is smaller than the Maxi. It is not unlikely that the parabola therefore will have a greater buoyancy than the existing float collar. A greater density in the new material may therefore be permitted for the parabola design. As the density of Divinycell is $250\ \mathrm{kg/m^3}$, the density constraint in CES Edupack was therefore set to be maximum $500\ \mathrm{kg/m^3}$ to eliminate unwanted materials.

7.3.3 Durability

The material will experience long term exposure to seawater. Its resistance to degradation in material performance as a result of this medium was therefore set to excellent, as the parabola will spend most of its time in the ocean.

7.3.4 Surface Treatment and Production

When a sound wave hits the boundary between one medium and the other (water and the material of the parabola), a portion of the wave undergo reflection and a portion undergo transmission across the boundary. The amount of reflection is dependent upon the dissimilarity of the two media. A dense and hard material is dissimilar to water, and thus reflects sound waves well [44]. If the surface is smooth, they are reflected as a beam [45]. The surface of the parabola needs to be coated with a material making the surface smooth and dense.

The material should be protected against various hazards in the ocean as the growth of algae, corrosion and water absorption. These features may need to be covered by the use of a coating material. The material also needs to be able to be manufactured in a variety of shapes.

7.3.5 Temperature

The material is required to handle temperatures that at least ranges from $-30\ ^\circ\mathrm{C}$ to $+70\ ^\circ\mathrm{C}$. These are the temperatures that Kongsberg Maritime's transponder can handle, which means that the parabola must handle the same temperature range. This constraint was applied to the maximum-, and minimum operating temperature range in CES Edupack.

7.3.6 Optical Properties

One of the constraints states that the parabola must be visible at the bottom. A limitation for the material to be opaque was therefore set in CES Edupack, meaning that the material is completely non-transparent, and that no light passes through it [49].

7.3.7 Price

Since the material Divinycell HCP already is used in the float collar for the parabola, Kongsberg Maritime have reliable production and manufacturing facilities available. To implement a new material will require new producers with decent availability, new production facilities and new manufacturers. The maximum price point of a new material was therefore set to $150\ \mathrm{NOK/kg}$, just above the price of Divinycell HCP in Edupack. A possible switch to a different material will still be more expensive, but not as excessive as if the material was double the price per kg. The price given in CES Edupack is an approximate price for a high volume purchase [49].

7.3.8 Anisotropy Ratio

The anisotropy ratio describes the ratio of which foams and honeycomb structures are anisotropic. If the anisotropy ratio is equal to 1, then the material is isotropic [49]. An isotropic material has the same properties in all directions [50]. The parabola will be exposed to the same amount of pressure in all directions, so the possibility of having an isotropic material makes the construction less complex. The anisotropy ratio was therefore set to 1.

7.3.9 Environmental Concerns

After implementing the above constraints, there were no materials left when recyclable was inserted as a constraint in CES Edupack. As the above constraints were more important for the function of the parabola, being recyclable was neglected from the material properties. The material Kongsberg Maritime uses is not recyclable according to CES Edupack.

7.3.10 Summary

Only a few materials were remaining after applying all the constraints (14 out of 301):

- Mullite Foam (NCL)(0.46).
- Polyethylene Terephthalate Foam (closed cell, .. (x3).
- Polyurethane Foam (rigid, closed cell, .. (x2).
- PVC Cross-Linked Foam (rigid, closed cell, .. (x9).
- PVC Foam (semi-rigid, closed cell, 0.500).

Three materials, Polyethylene Terephthalate Foam, Polyurethane Foam, and PVC Cross-Linked Foam, came in 3, 2, and 9 different varieties respectively, where each has a slight difference in properties. PVC Cross-Linked Foam in the type of composition has the tradename Divinycell. Divinycell comes in different variations, and the material Kongsberg Maritime utilize (Divinycell HCP50) has almost identical characteristics to PVC Cross-Linked Foam (rigid, closed cell, KR 0.260), where 0.260 is the specific gravity [49]. A comparison of these similarities is shown in Appendix 13.5.

One can assume that this is the same material, with slightly different properties. It was therefore decided to only bring this composition of PVC Cross-Linked Foam onward, to be able to compare it to the other materials remaining. The materials going into the “Ranking using Objectives”-stage was:

- Mullite Foam (NCL) (0.46).
- Polyethylene Terephthalate Foam (closed cell, 0.15).
- Polyethylene Terephthalate Foam (closed cell, 0.26).
- Polyethylene Terephthalate Foam (closed cell, 0.32).
- Polyurethane Foam (rigid, closed cell, 0.24).
- Polyurethane Foam (rigid, closed cell, 0.3).
- PVC Cross-Linked Foam (rigid, closed cell, KR 0.260).
- PVC Foam (semi-rigid, closed cell, 0.500).

These materials can be seen in the figure in Appendix 13.6 in red.

7.4 Ranking Using Objectives

Ranking by the use of objectives is a way to measure how well the different materials perform in the given environment by using a material index [51]. In this case, the objective was to minimize the mass. The reason for this is to obtain a light and buoyant, but strong parabola. This is done by minimizing the density of the material - which in turn maximize the buoyancy - putting it up against Young’s Modulus in a chart. Maximizing performance in this case means minimizing the mass while still tolerating the amount of stress the structure will be exposed to, caused by pressure from the surrounding water.

7.4.1 Material Index

The equation for mass is called the objective function. The mass of a disk was used to simplify the calculation as the shape of it is similar to that of a parabola, with the exception of the parabola's downward curve. The objective function is given as [45]:

$$m = At\rho = \pi r^2 t\rho$$

This equation was used to calculate the slope of a guideline that is inserted into the Young's Modulus - Density chart. The calculation can be found in Appendix 13.7, and indicated that the slope was 2, and that the material index was

$$M = \frac{E^{\frac{1}{2}}}{\rho}$$

which is the guideline for minimum weight design.

7.4.2 The Young's Modulus – Density Chart

Young's modulus (E) is a measurement that shows the ability of a material to withstand changes in shape due to external forces [52]. This property is important, as the parabola will be exposed to pressure from the surrounding water. Density (ρ) is a measurement of how compact a substance is composed, and influences the buoyancy of the respective material [53].

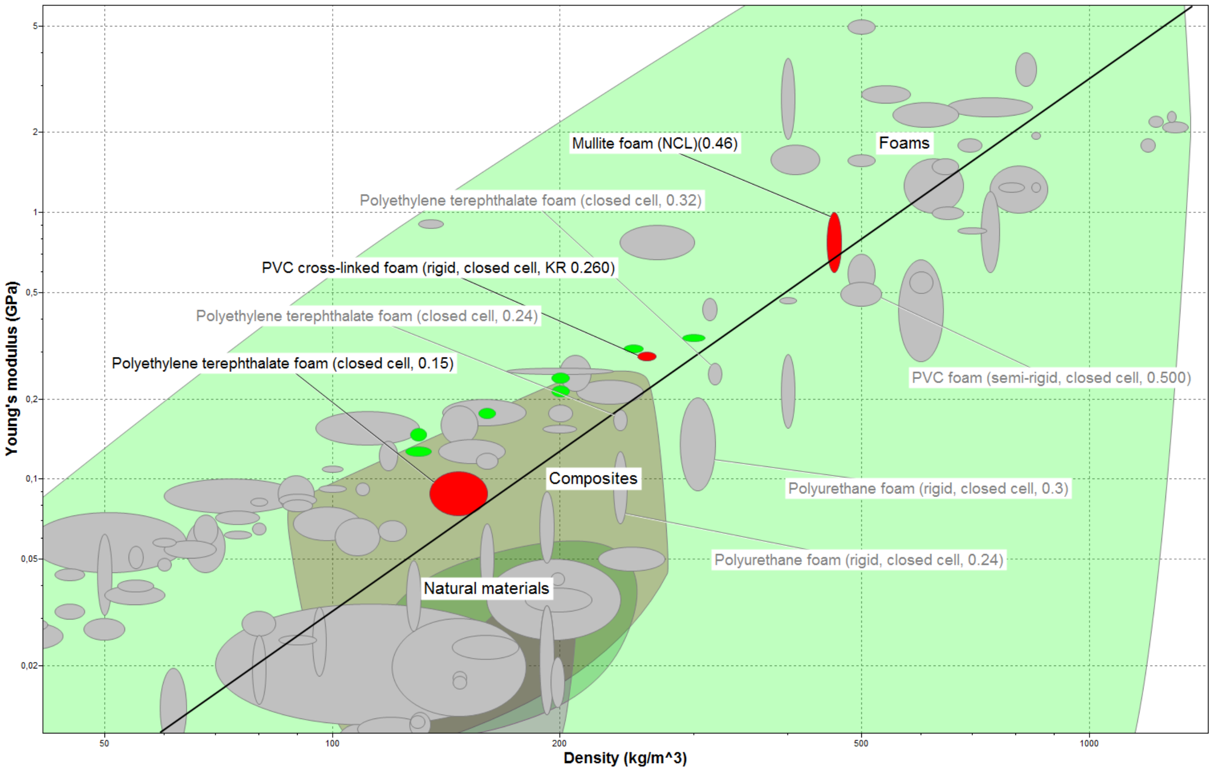


Figure 16: Young's modulus – Density chart with material index. Figure created in CES Edupack.

The guideline of value 2 was drawn in the modulus - density chart in Figure 16, and was used to eliminate undesirable materials. The slope of the material index can be moved up and down in the chart in CES Edupack to exclude or include more materials as desired. All materials lying above the line has more fitting properties than the ones below. As can be seen from the figure, it was possible to exclude five materials by dragging the guideline to the left. The materials remaining are now shown in red above the guideline.

7.4.3 Summary

The calculation of the value of the material index for each individual material is shown in Appendix 13.8. The material with the smallest mass is the one with the greatest value of M. This calculation support the guideline in the figure above, as it reveals that the same three materials has the highest material indices as in the modulus - density chart.

On the basis of the information drawn from the Young's modulus - Density chart, as well as the calculation of material indices, it was natural to eliminate five materials; Polyethylene Terephthalate Foam (closed cell, 0.24), Polyethylene Terephthalate Foam (closed cell, 0.32), Polyurethane Foam (rigid, closed cell, 0.24), Polyurethane Foam (rigid, closed cell, 0.3), and PVC Foam (semi-rigid, closed cell, 0.500). To ensure that the most suitable material is chosen, information was gathered regarding the three remaining materials.

7.5 Seeking Information Regarding the Remaining Materials

The last part of the material selection process was gathering information about the three remaining materials, investigating how well their properties fit the intended purpose, as well as what type of products they are currently applied to. Since there was no longer any use for CES Edupack, the material PVC Cross-Linked Foam was exchanged with Divinycell HCP50; Kongsberg Maritime's original floating collar material. This gave a proper comparison with the remaining materials; Polyethylene terephthalate foam (closed cell, 0.15) and Mullite foam (NCL)(0.46), which can be seen in Table 7.

As can be seen from Table 7, the remaining materials fulfills the previously set constraints and are proven to have a high material index, according to Appendix 13.8. These materials still have variations in their properties that had to be considered, as it influences their individual behavior.

Table 7: Comparison of remaining materials [49], [54].

Properties	**Divinycell HCP50 (PVC Cross-Linked Foam (rigid, closed cell, KR 0.260)**	**Polyethylene terephthalate foam (closed cell, 0.15)**	**Mullite foam (NCL)(0.46)**
Compressive strength [MPa]	6.1 - 7.2	2 - 2.68	0.8 - 2.3
Elasticity modulus [MPa]	350 - 400	73.2 - 107	600 - 1000
Tensile strength [MPa]	8.0 - 9.2	3.31 - 4.75	0.6 - 1.3
Shear strength [MPa]	3.9 - 4.5	1 - 1.36	-
Yield strength [MPa]	6 – 7.1*	0.734 – 1.03	0.6 – 1.3
Shear modulus [MPa]	81 - 97	30 - 38.1	250 - 400
Density $[\frac{kg}{m^3}]$	250	134 - 160	450 - 470
Buoyancy $[\frac{kg}{m^3}]$	775	-	-
Buoyancy force for 1kg material [N] (Appendix 13.9)	40.221	62.95	21.39
Operational depth [m]	300	Unknown	Unknown
Crush depth [m]	500	Unknown	Unknown
Price [NOK/kg]	136 – 149*	90.8 - 99.7	91.9 - 110
UV radiation (sunlight)	Good	Good	Excellent
Recycle	No	No	No
Water absorption @24 h [%]	0.949 - 0.991*	0.14 - 0.18	0.5 - 1
Reflective Properties	Good	Unknown	Unknown

*PVC Cross-Linked Foam

Divinycell HCP50 has the highest values of the properties; compressive-, tensile-, and shear strength. Compared to the other materials in Table 7, it has a medium value in elasticity- and shear modulus, density, and calculated buoyancy force. The advantage of Divinycell HCP50 is that it has a known operational- and crush depth which is deeper than the position depth of 200 m. In addition it has the reflective properties that Kongsberg Maritime desires. A drawback is that it has the highest price of the three materials. Polyethylene terephthalate foam (closed cell, 0.15) has the highest calculated buoyancy force and has a low or medium range on all other listed properties. Mullite foam (NCL) (0.46) has the highest elasticity- and shear modulus. The drawbacks of this material is that it has a low buoyancy force, and compressive- and tensile strength. It also has the highest density, causing it to be the heaviest of the three materials.

7.6 Coating

Polyurethane (PU) spray-coatings are applied to products to improve their appearance and lifespan. It is used on car exteriors because of its improved scratch and corrosion resistance. In construction application, the coating is used for easy maintenance due to its smooth surface, while preventing the construction from rusting and pitting [55]. It is applied in a wide range of products, from concrete constructions like bridges and motorway structures, to wooden furniture [56].

The polyurethane spray-coating will be applied with a thin coat of $3 - 5$ mm on the outside of the Divinycell parabola structure. This application gives a slight improvement in strength, but a high impact resistance according to Kongsberg Maritime. The coating is an excellent application to PVC foam according to CES Edupack. Kongsberg Maritime applies it to their existing float collar today.

Although algae growth is a minimal concern at 200 m depth, the smooth surface of the polyurethane coating will contribute to resist the attachment of the small amount of algae present. The improved scratch resistance of the coating will prevent small damages to the smooth surface, which prevents deformation of incoming signals. As for the reflection properties, a dried layer of coating is highly dissimilar to the density of seawater, causing good reflection properties. It also contributes to less water absorption.

7.7 Aluminum Alloy 6082-T6

The transponder is constructed with the aluminum alloy 6082-T6, which is a medium strength alloy, strongest within the 6000 series. It is typically used in highly stressed applications, trusses, bridges, and cranes. The alloy has very good weldability, and when welded to itself, alloy 4043 is recommended [57]. Table 8 display the material properties of 6082-T6.

Table 8: Properties of 6082-T2 [57], [58].

Property	Value
Density	$2700\ \mathrm{kg/m^3}$
Melting Point	$555\ °\mathrm{C}$
Thermal Expansion	$24 \cdot 10^{-6}\ /\mathrm{K}$
Thermal Conductivity	$180\ \mathrm{W/m.K}$
Poissons Ratio	0.33
Young`s Modulus	$71000\ \mathrm{MPa}$
Yield Strength	$270\ \mathrm{MPa}$
Shear Strength	$220\ \mathrm{MPa}$
Tensile Strength (Ultimate UTS)	$330\ \mathrm{MPa}$

It is important to take into account that by using a different material than 6082-T6 for other applications of the parabola construction, galvanic corrosion can occur. The alloy will therefore be used for most applications, and the weldability factor is important as it most likely will be welded to itself.

7.8 Conclusion

Divinycell HCP50 is a lightweight buoyant material with excellent characteristics in high-performance environments. It is widely used in flotation units, diving bells, and impact protection structures, and has very low buoyancy loss because of its excellent hydraulic compressive properties during long term loading conditions [55]. HCP stands for Hydraulic Crush Point, where the number 50 defines the maximum hydraulic pressure the material can withstand in Bar [56], [54]. Divinycell has low water absorption under long-term loading conditions, and it can be shaped into almost any design. [57]

Based on the information received during the material selection process, it is safe to conclude that Divinycell HCP50 is the most suitable material as it contains the most desirable properties of the listed materials. Although the price is a little higher than the other materials, the adequate properties of Divinycell HCP50 makes it reliable. The slightly higher price can also be justified by the fact that Kongsberg already has production facilities for the material up and running, and therefore avoids the cost of finding new manufacturers.

8 Analyzing the Design

Before starting the construction of the parabola in SolidWorks, it is important to consider various aspects and hazards of the design. The preliminary design was analyzed with respect to the path the sound waves will take, different curvatures for the parabolic shape, calculating stability subsea, and testing the constructions Von Mises strength to find an optimal design has been conducted.

8.1 Path of Sound Waves

The path of the sound waves must be tested in order to understand if the sound waves will travel in the desired direction. The concluded design was tested with respect to incoming and outgoing signals as well as concave and convex shapes of the smaller parabola [59]. Ray Optics Simulation is an online software used for these tests, as it illustrates reflection to a decent degree.

8.1.1 Incoming Signals

The first simulation is shown in Figure 17 and shows the path the incoming sound waves will take on the original design when they hit the smaller parabola with a concave shape. The green line represents the source of the signals which are sent toward the big parabola. As seen from the figure, the sound waves do not end up in a focal point that would represent the top of the transponder. Instead they leave an untouched area where the signals originally were intended to travel to. The reflected sound waves have a small angle compared to the original angle of the path they came from. The conclusion was that a small parabola with a concave shape is not suitable, as first intended.

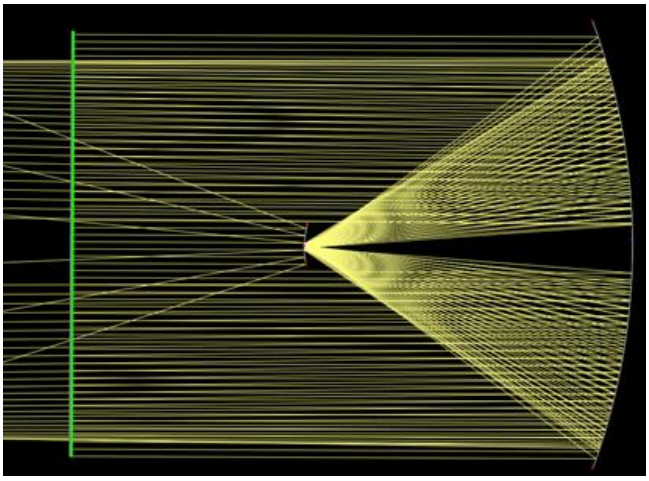


Figure 17: Incoming rays hitting the smaller parabola on a concave shape. Figure created in Ray optics simulation.

In Figure 18, a similar simulation was done with the only change being the shape of the smaller parabola. As the figure shows, this is a better option than the previous design, as the small parabola will reflect sound waves into the position of the transponder. Some sound waves will

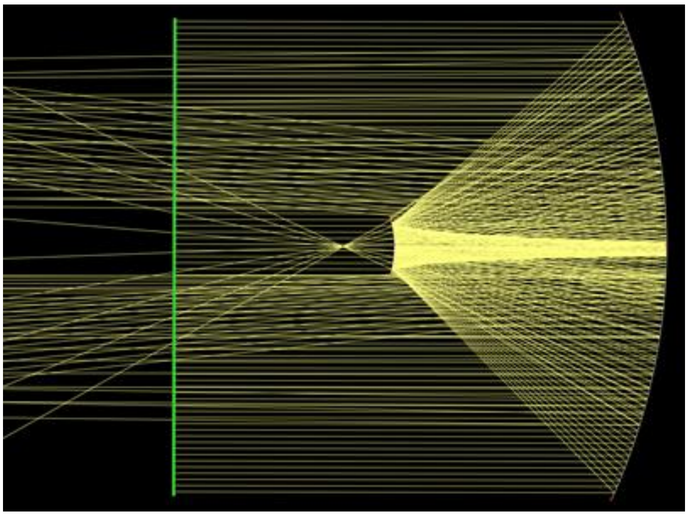


Figure 18: Incoming rays hitting the smaller parabola on a convex shape. Figure generated in Ray optics simulation.

not hit the transponder, but return to the surface with an angle similar to the incoming path. This angle is larger than the one in the previous simulation. The simulation of the outgoing signals is shown in Appendix 13.10. The relationship between a parabolas focal point and incoming signals is shown in Appendix 13.11.

8.1.2 Conclusion

The testing of the path which the sound waves take was useful in order to understand where the sound waves would be reflected. It was concluded that the original design of the smaller parabola with a concave curve cannot be used. An option of using a convex shape is possible, as these tests shows a much better result.

After discussing with Kongsberg Maritime, it was brought to the attention that it is possible to separate the transducer from the transponder. They have a split transducer which can be connected to the rest of the transponder by a cable. This new information allows an elimination of the smaller parabola, and replacing it with the split transducer. By positioning the transducer in the location of the smaller parabola, the sound waves are sent directly to the transducer after being reflected from the parabola. This lowers the chance of energy loss and hence causes the design to be more efficient.

8.2 Parabolic Theory – Beam Width

The specification developed earlier in the report states that the parabolic disk needs to produce a beam width of approximately 10°. To be able to construct a parabola that generates the specified beam width, one would need to understand what it entails.

8.2.1 Radiation Pattern

The beam width is related to the radiation pattern of an antenna [2], where the antenna in this case is the transducer head. The radiation pattern is the directional dependence of the strength of the waves generated from the antenna [60], [59]. The power radiated from the parabolic antenna, shown in Figure 19, is mostly concentrated in a main lobe along the antenna's axis. The main lobe contains the maximum power, and exhibits the greatest field strength. The residual power is radiated in side lobes, in directions dissimilar to that of the main lobe. They are usually undesired, but can never be completely eliminated. The back lobe is in the opposite direction of the main lobe, and is generated due to the spillover radiation from the transducer that misses the parabola [61].

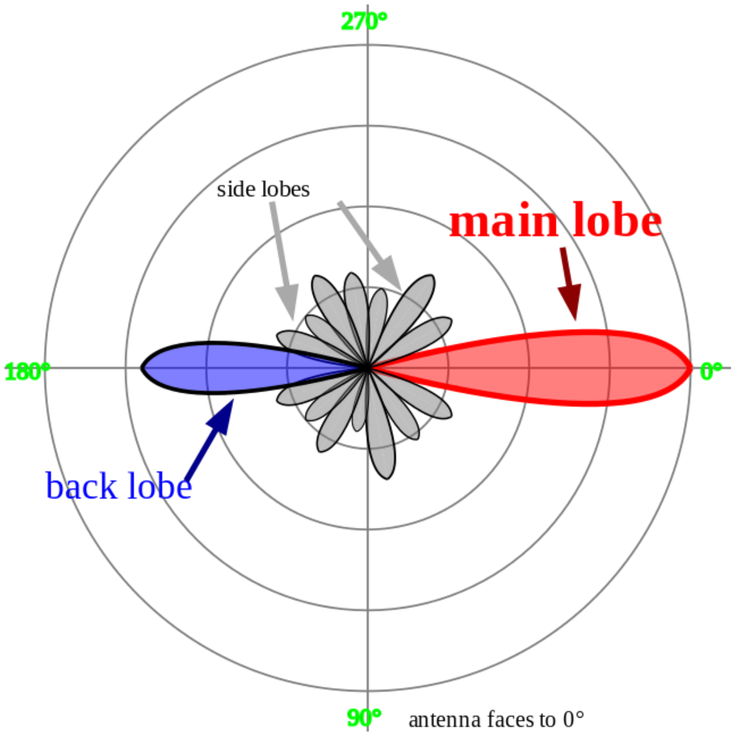


Figure 19: Radiation Pattern [1].

The main- and side lobes are often used to describe the radiation pattern of acoustic transducers. The radiation pattern of antennas are, amongst some, characterized by its beam width [62].

8.2.2 Beam Width

The beam width is an angle which can be measured from the radiation pattern. It represents the angle between two directions on the main lobe [63]. In Figure 20 these directions are represented by straight lines located on each side of the axis. The axis is called the beam axis and is located in the center of the main lobe, showing the maximum value of the radiation [64].

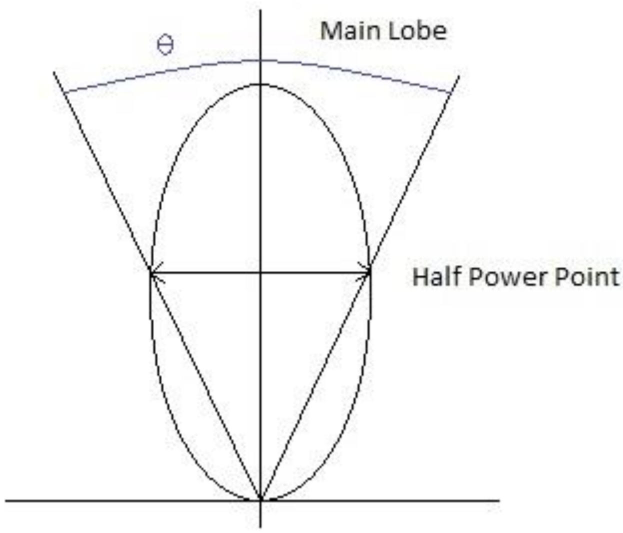


Figure 20: The half power beam width of the main lobe.

The two half power points where the straight lines intersect with the main lobe is where the intensity of the frequency is $1/2$ of the maximum value [63]. The angle between the two lines represents the beam width, θ. It is also known as the Half Power Beam width (HPBW) [62]. The beam width, which is given to be $10°$, is used to calculate the required diameter of the parabola by the formula [2];

$$d = \frac{k \cdot \lambda}{\theta}$$

where d is the diameter, λ is the wavelength, θ is the beam width, and k is a factor which is approximately 70 [65] for a typical parabolic antenna. The wavelength has already been found in Appendix 13.1, and is $\lambda = 0.06$ m. Inserting this, and the beam width of 10 ° into the above formula gives a diameter of;

$$d = \frac{70 \cdot 6}{10} = 42 \text{ cm}$$

These calculations are approximate, as k vary slightly from parabola to parabola. It has been advised by KM to round up the diameter to 50 cm, instead of the 42 cm derived from the equation above. This diameter gives a beam width of 8.4 °. The specification noting a beam width of approximately $10°$ is therefore fulfilled.

8.3 Investigating Curves

Calculations were conducted to find the best possible curve of the parabola. These calculations gave multiple curves to investigate, which in the end resulted in an optimal shape for the final parabola design.

8.3.1 Constraints

An optimal curve must have the desired diameter of 50 cm, while still contributing to a stable construction for the transponder underwater. There are additional constraints to consider for the particular design, which are:

1. The sound waves must be reflected from the parabola in such a way that they hit underneath the transducer. Sound waves hitting the outside or on top of the transducer will not be received by the transponder. This means that the focal point cannot be too low.
2. It is desirable to use the blades of the parabola to protect the transducer when the system is closed. The blades must therefore be long enough to cover this area, which means

that the parabola cannot have a high focal point. It must be taken into account that some of the parabola will be fixed at the bottom and cannot be moved.

3. Steep curves need more material than wide curves as they have a larger surface area than less steep curves, but with the same diameter. To save money on material, steep curves with large surface areas should therefore be avoided.
4. The parabola must be of a size that can easily be handled by personnel.

8.3.1.1 The f/d Ratio

The f/d ratio is a comparison between the length of the focal point and the diameter. This ratio is often used in the description of curves. Based on f/d ratios that are commonly used for parabolas, it was decided to investigate the f/d ratios ranging from 0.1-1 [24], [66].

8.3.2 Calculation of Curves

Certain terminologies are used when a parabola is constructed. In addition to the focal point of a parabola, all parabolas also have a directrix and a vertex. In a coordinate system, the directrix is located below the parabola if it is u-shaped, or above if it has the opposite shape. The directrix is located such that a random point on the parabolic curve will have the same distance to the directrix as it will have to the focal point. The vertex is the point of the parabola which is closest to the directrix, and is located on the same symmetry axis as the focal point [67], i.e. the bottom of the parabola.

The calculation of curves and the illustrations of them made in GeoGebra are shown in Appendix 13.12. It can be seen from the GeoGebra illustration in the same appendix that the yellow curve represents the most ideal curve for fulfilling the above constraints. The yellow curve represents an f/d ratio of 0.3 and has a focal point of 0.15 m.

The removal of curves located above the yellow curves are according to the first and third given constraint, and the calculation validating this removal is found in Appendix 13.13. The second and fourth constraint allows for the removal of the curves below the yellow line. These constraints ensure that the blades can be used to cover the transducer and keeps the parabola at a manageable size. Appendix 13.14 contains a discussion regarding second constraint and the folding of blades

Based on the above information, it was decided to use the yellow curve in Appendix 13.12, which has an f/d ratio of 0.3, a focal point of 15 cm, and a diameter of 50 cm. The curve is shown in Figure 21. The blades do not prevent sideway communication when they are unfolded, as the end of the parabola curve is lower than the focus point. This is not a given requirement from KM, but it might be desirable for communication with other subsea equipment, and is therefore worth noticing.

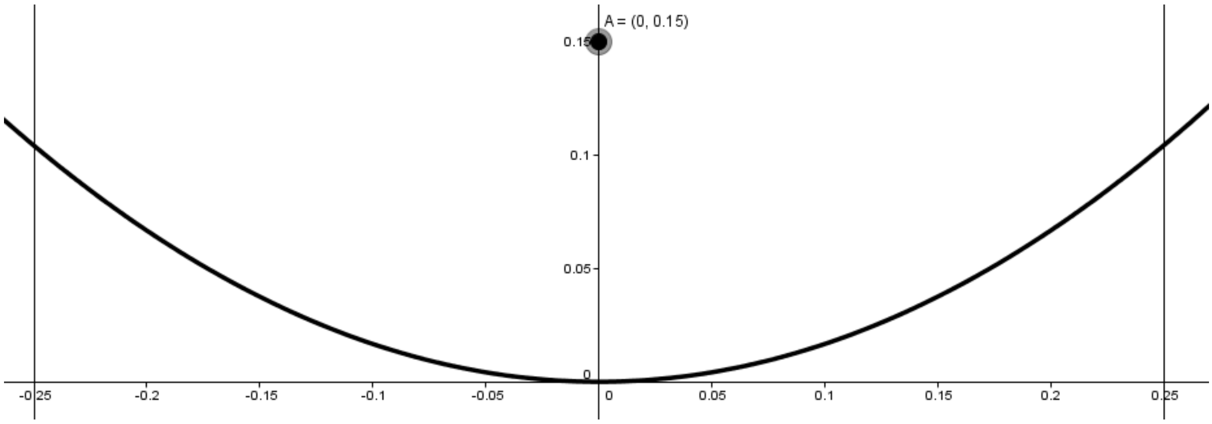


Figure 21: Final curve and focal point. Unit on the axes are given in meter. Figure created in GeoGebra.

8.4 The Spreading of Sound Waves

Sound waves spread out as they travel away from its source, as stated early in the report. This means that the sound waves will cover a larger area when they reach the surface than they do when they leave the parabola. This is desirable, as the boats receiving the signals transmitted from the parabola has a bigger location to pinpoint in order to receive the signals. Calculation of the area coverage that the sound waves will have when they reach the surface is shown in Appendix 13.15. These calculations show that the sound waves will cover a circular area with a diameter of 35 m.

8.5 Edited Design

The design that was presented earlier had some changes due to the analyses that had been conducted. It was chosen to split the transponder up, and to use a remote transducer. The aluminum transponder will consist of the parts in Figure 22 in addition to a connecting cable.

Figure 22: Transponder components from left: Transducer, split transponder, tube, and release mechanism [4].

A section view of the edited design with names of the different parts is shown in Figure 23. The remote transducer is connected to the parabola by three supporting rods, making the end of the transducer the focal point. The transducer is fastened by a two-piece housing, connected with screws. The rods will be made out of the same aluminum alloy as the transponder to avoid galvanic corrosion. The transducer is connected to the transponder by a cable which is threaded through a hole into one of the supporting rods.

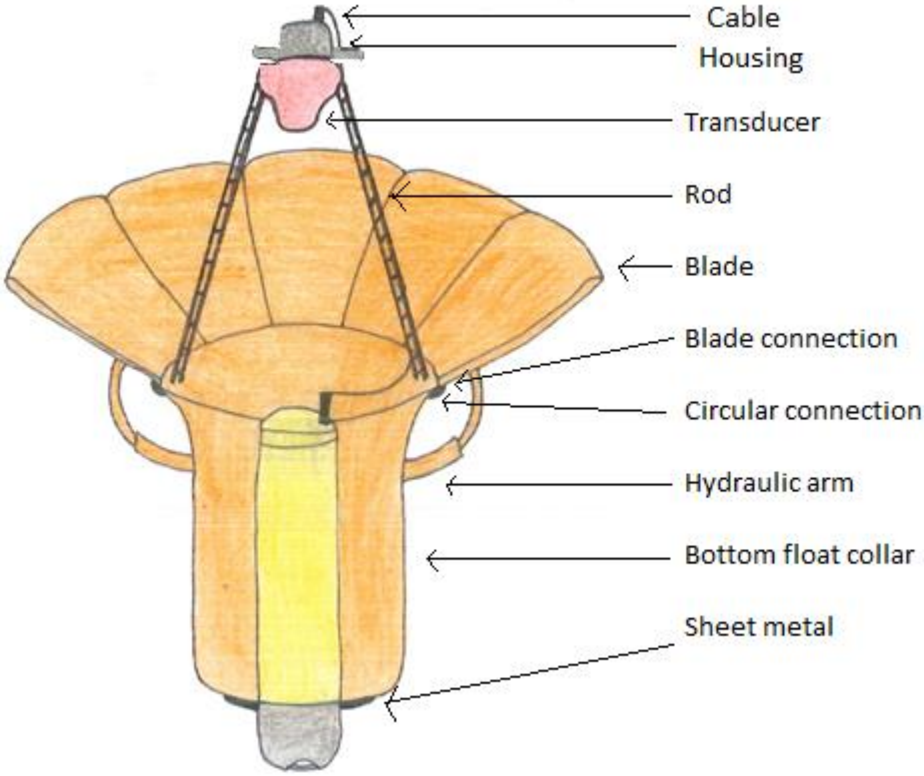


Figure 23: Section view of the final sketched design.

A circular connection was added beneath the blades to connect them to the bottom float collar. Below the bottom float collar there is a sheet metal with holes that fit the existing screws on the transponder. Both the circular connection and the sheet metal will also be made of aluminum to prevent galvanic corrosion as well as being a light material. The next step was to construct the edited design in SolidWorks, where simulations also can be done. The individual module based parts of the transponder that will be used in this design with dimensions are listed in Table 9.

Table 9: Transponder components with weight and dimensions [30].

Part	Weight in air - Aluminum	Dimension
TDR 180 Remote Transducer	ca. 4.1 kg (TD 180)	209.8 mm x Ø 88 mm
Split Transponder	1.2 kg	62 mm x Ø 166 mm
Transducer Cable	-	6 m (length)
Midi Tube (including inside components; chassis and battery)	6.7 kg	495 mm x Ø 144 mm
Release Mechanism	4.9 kg	243 mm x Ø 144 mm

9 Simulations in SolidWorks

The parabola itself can vary in thickness depending on what the material can tolerate and the safety factor of constructions underwater. The simulations have been conducted on the blade in order to investigate if a thickness of $20\ \text{mm}$ is sufficient, as this is the part with the lowest strength and the most critical part of the assembly.

9.1 Safety Factor

The safety factor is the relationship between a material's failure limit, and the stresses one can allow it to be exposed to. The safety factor normally lies between 3 and 10, and is the boundary for the dimensioning of a construction. One can allow a lower safety factor for a ductile, elastic material than for a brittle material, and a lower safety factor for a quiescent load than for a varying load [68]. Appendix 13.16 shows several load-cases the parabola will be exposed to. Based on the findings in this appendix it was decided to apply a safety factor of 1.5 for the main construction and 4 for the lifting hooks.

9.2 Displacement and Von Mises Stress Test in SolidWorks

Divinycell HCP50 is not a standard material in SolidWorks, and therefore has to be customized as a new material manually. A new material was therefore defined in SolidWorks with properties as listed in Table 10 equal to Divinycell's properties.

Table 10: Custom Material in SolidWorks, Divinycell [54], [49].

Property	Value
Yield Strength [Pa]	$7.10 \cdot 10^6$
Elastic Modulus [Pa]	$375 \cdot 10^6$
Poisson's Ratio	0.3
Shear Modulus [Pa]	$89 \cdot 10^6$
Mass Density [$\frac{\text{kg}}{\text{m}^3}$]	250
Tensile Strength [Pa]	$8.6 \cdot 10^6$
Compressive Strength [Pa]	$6.65 \cdot 10^6$
Thermal Conductivity [$\frac{\text{w}}{(\text{m}-\text{k})}$]	0.051

To strengthen the construction, the Divinycell material will be spray coated with $3 - 5\ \text{mm}$ of polyurethane as advised by Kongsberg Maritime. It is difficult to say how much stronger this will make the construction without testing a physical model after the coating has dried. It is impossible to add this coating on the outside of the model in SolidWorks, which implies that the simulation shows a higher Von Mises stress than reality would show. For further calculations, it is assumed that the model is stronger than the simulation is able to show.

The aluminum alloy 6082-T6 is neither a standard material in SolidWorks. This material is used in the sheet metal attached to the front tip of the blade, resembling where the blade would be attached to the rest of the construction in reality. The properties applied to the sheet metal resembling the fixture are shown in Table 11.

Table 11: Custom material in SolidWorks, 6082-T6 [58].

Property	Value
Yield Strength [Pa]	$270 \cdot 10^6$
Elastic Modulus [Pa]	$7.1 \cdot 10^{10}$
Poisson's Ratio	0.33
Mass Density $[\frac{kg}{m^3}]$	2700
Tensile Strength [Pa]	$330 \cdot 10^6$
Thermal Conductivity $[\frac{w}{(m-k)}]$	180
Thermal Expansion Coefficient $[/K]$	$2.4 \cdot 10^{11}$

9.2.1 Displacement

If the experienced hydrostatic pressure from being 200 m below the sea surface generates a big displacement in the blade, it would mean that its cross section is too small, and hence the thickness of the blade is too small. If the deflection is small, one can ignore the changes caused by hydrostatic pressure, and only look at the buoyancy force. A simulation was therefore conducted in SolidWorks to observe the changes caused by this pressure. A simulation was also done to observe the displacement caused by the buoyancy force alone. The simulations in their whole are found in Appendix 13.19, and shows that the deflection caused by the hydrostatic pressure is small, at only 0.107 mm. Because the deflection caused by the buoyancy force is smaller, at only 0.003 mm, it was decided to conduct a simulation with both forces present.

The hydrostatic pressure of 2112000 Pa was applied to the whole construction, and is shown as orange arrows in Figure 24. A force of 421 N was applied underneath-, and on top of the blade in positive y-direction, as shown in purple arrows in the figure. The force resembles the upward buoyancy force. The calculation of this force can be found in Appendix 13.17.

The whole model was constrained underneath in all degrees of freedom, because two hydraulic arms on either side of the parabola will hold the blades down in its entire length. It was also constrained on the aluminum alloy sheet metal. This to simulate where the blade would be secured to the rest of the construction in reality. The constraints are shown as green arrows in the figure. This is not an exact constraint, more to resemble the actual occurrence.

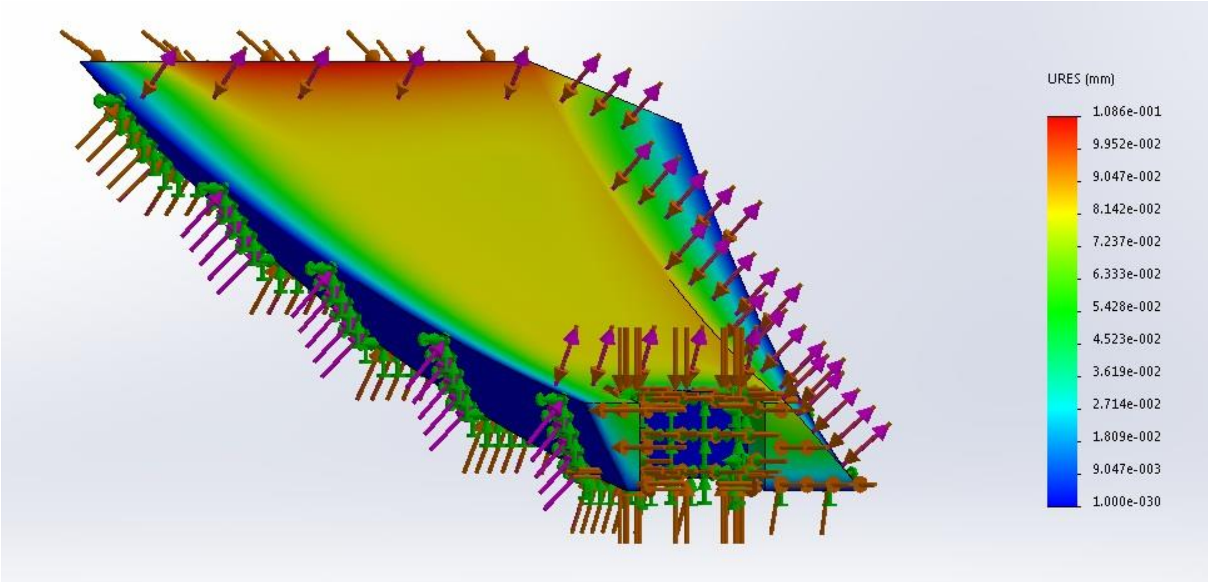


Figure 24: Displacement of the blade with hydrostatic pressure and buoyancy force applied.

Figure 24 shows the location of the largest displacement in red. The displacement is at its maximum at 0.108 mm in a small section on the top edge of the parabola. Again, the coating will decrease this deflection further. For more information regarding the analysis, see Appendix 13.20.

A simplified analytical calculation was conducted to give an indication of whether the deflection is small or large. The calculation showed a total deformation of 1.95 mm. Since the blades overlap and hold each other down in its entire length, including where the biggest deflection occurs, this deflection will be smaller in reality. The deflection in SolidWorks shows a better picture, with a maximum deflection at the same location as in this calculation. The total simplified analytical calculation is found in Appendix 13.21.

9.2.2 Von Mises Stress Test

The Yield Strength, σ_y, of a material describes the minimum stress under which a material deforms permanently. It will start yielding when it reaches its critical yield strength. The Von Mises stress, σ_v, is used to predict the yielding of a material under an applied load. If the maximum value of the Von Mises stress is more than the yield strength of the material, the structure will fail, i.e. [69];

$$\sigma_v \geq \sigma_y$$

In order to check if the safety factor is within a reasonable range, the yield strength divided by the Von Mises stress of the material must be bigger or equal to the safety factor applied [70]:

$$SF = \frac{\sigma_y}{\sigma_v}$$

The safety factor of the construction should not be substantially bigger than the defined safety factor, as this would contribute to an unreasonable amount of material mass, generating in a pricier product with a strength higher than necessary.

The Von Mises Stress test was conducted with the same forces and constraints as for the displacement simulation. The maximum Von Mises stress in the plot on the right of Figure 25 is $2.067 \cdot 10^7\ \mathrm{N/mm^2}$. This value is located on the aluminum alloy plate, which has a Yield Strength of $270 \cdot 10^6\ \mathrm{N/mm^2}$. It is therefore within the limit of a safe design.

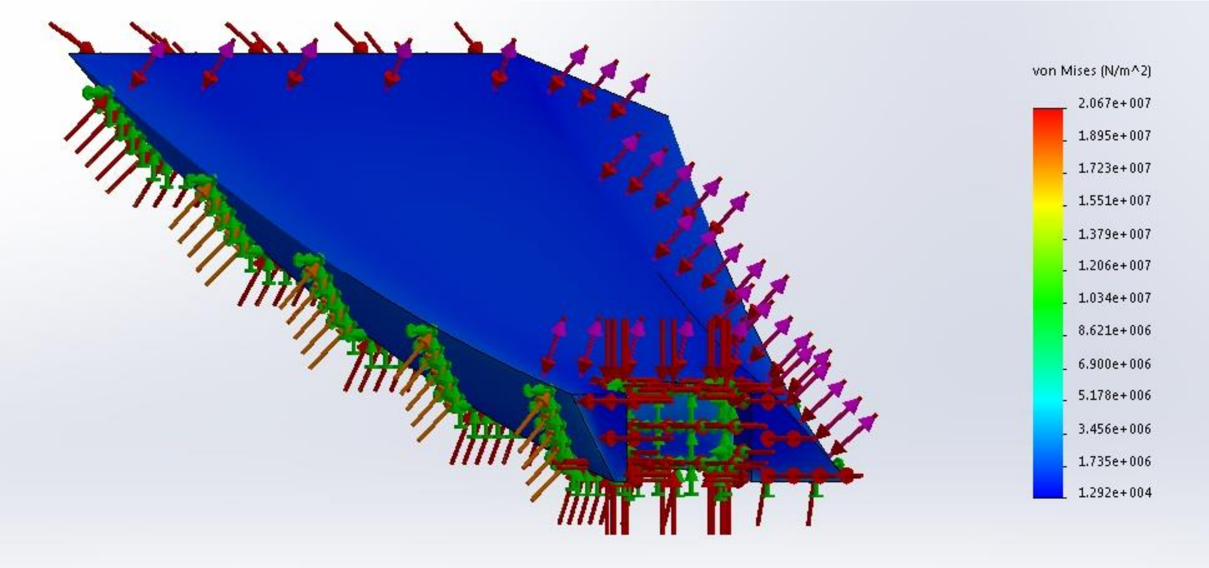


Figure 25: Von Mises Stress of Parabola-blade Simulation.

By creating nodes in the location that shows higher Von Mises stress than the rest of the Divinycell construction, the location of the maximum Von Mises stress was found at $3.767 \cdot 10^6\ \mathrm{N/mm^2}$. The Yield Strength of Divinicell, as stated earlier, is at $7.10 \cdot 10^6\ \mathrm{N/mm^2}$. By using these values, the safety factor of the construction becomes

$$\frac{7.10 \cdot 10^6\ \mathrm{N/mm^2}}{3.767 \cdot 10^6\ \mathrm{N/mm^2}} = 1.88$$

Which is 0.38 larger than the defined safety factor of 1.5. The calculated safety factor reveals a safe design of the construction. It is assumed that the applied coating will prompt a higher safety factor than 1.88.

9.3 Buoyancy and Stability

Buoyancy and stability are two main concerns in the design of the parabola, and are essential aspects to ensure a properly working design. These properties and the way they influence the design is discussed in the following text.

9.3.1 Buoyancy

Buoyancy is defined by the law of Archimedes, which states that if the fluid has greater density than an object immersed in that fluid, the object will float because of the buoyant force. One of the goals is to keep the parabola and transponder vertically floating in the water. This will be possible by positioning the center of gravity and center of buoyancy correctly, as well as using enough Divinycell material to make the transponder float.

The weight of the transponder in air is 16.5 kg [30]. The transducer TDR180 is the one applied to the composition of modules, but as the weight of it was not found, it is assumed to be equal to TD180 which has a weight of 4.1 kg in air [30]. This gives a total weight of 20.6 kg. The weight of the transponder can be used to calculate the amount of Divinycell necessary to keep the transponder floating in water. These calculations are found in Appendix 13.17. If this amount of Divinycell is used, the system will be in equilibrium, meaning that it will not move. In order for it to float to the surface after being released, the amount of material must be greater than this.

The calculations in Appendix 13.17 is based on the weight of the design in SolidWorks. To prompt a higher buoyancy force than gravitational force, a force representing 15 kg was added as advised by Kongsberg Maritime. This addition ensures that the parabola will float to the surface when the load is released.

9.3.2 Stability

Stability is defined as the ability of being in balance and keeping a steady position [62]. The stability of the parabola is important as one of the demands is to keep the transponder vertically floating underwater. The stability of an object in water is related to the object's Center of Gravity (CG) and Center of Buoyancy (CB). The center of gravity is a theoretical point in an object where the resultant weight force act [61]. The center of buoyancy is also a theoretical point. When an object is immersed in a fluid, it pushes away the fluid that was there originally. The center of buoyancy represents the point that would be the center of mass of the displaced fluid [2].

Figure 26 shows the location of CB and CG on a boat. When the boat is in an upright and vertical position, the center of gravity and the center of buoyancy is located on the same vertical

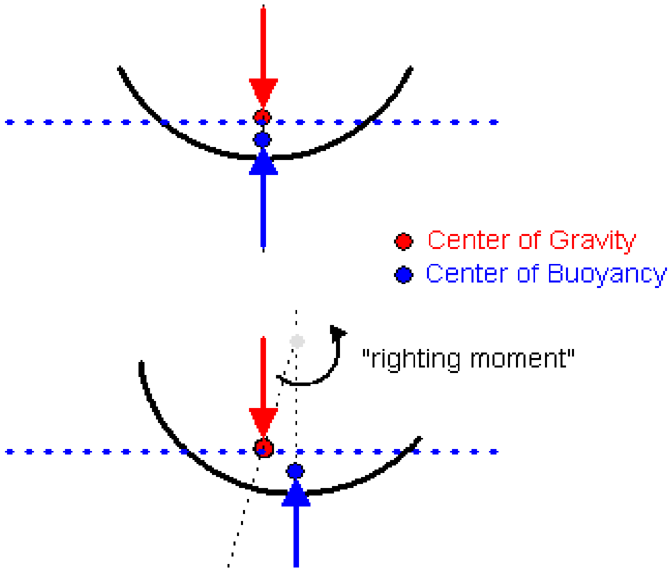


Figure 26: Stability illustration [2].

axis, with CG positioned above CB. If something disrupts this position, the boat will try to stabilize to its original position with a righting moment [2]. This theory can be used to find the stability of the transponder. The parabola, being completely immersed in a fluid, must have CB located above CG to keep it vertically floating. The calculation of CG and CB for the parabola can be seen in Appendix 13.18. This means that if the structure is to be stable, it cannot have the function to turn around when the load is released for retraction to the surface.

10 Final Design

The final design of the Embla Parabola is shown in Figure 27. Signals coming entering the parabola from above are reflected into the transducer head shown in red, which is the focal point. The signals follow the same path when the process is reversed, ending at the sea surface with a diameter of 35 m. The hydraulic arms responding to signals sent from a boat at the surface ensures efficient opening/closing of the parabola blades. This makes the product reliable as it gives the operator complete control. A load fastened to the release mechanism is used to lower the product down to the seabed. When the load is released, the parabola will ascend to the surface. It is recommended to keep the blades closed upon release. More detailed renderings of-, and information regarding the design is shown in Appendix 13.22.

A simplified and downscaled physical model of the parabola was 3D printed to get a better understanding of what the curve would look in real life. Pictures of this 3D model is shown in Appendix 13.23. A technical drawing of the final design is shown in Appendix 13.24.

The final name chosen for the parabola was Embla. According to Old Norse mythology, Embla was the name of the first woman on earth. Although there are many existing parabolas in the world today, this will be the first of its kind with its mixture of reflection- and underwater technology, and it was created by two women.

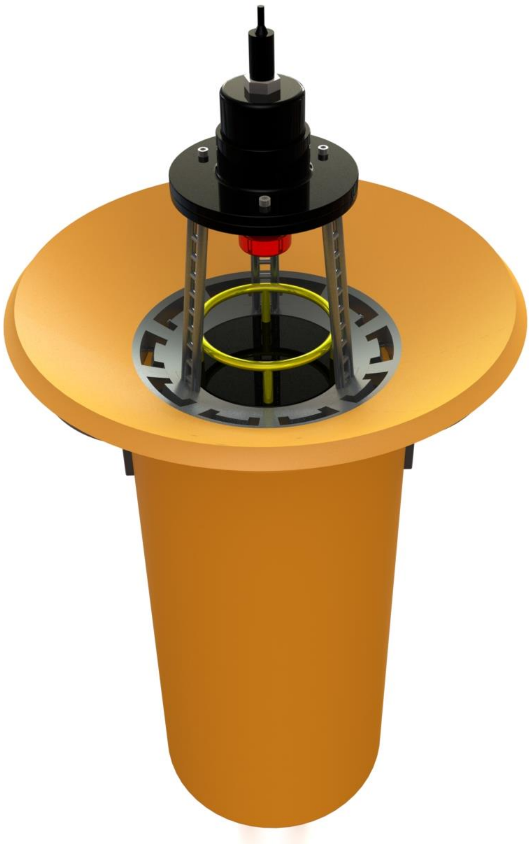


Figure 27: Rendering of the final design. Created in SolidWorks.

10.1 Production and Assembly

Creating parts that are easy to produce and assemble has continuously been worked towards during the design process. These concerns are discussed in the following sections.

10.1.1 Production

Suitable production methods for the various parts of the parabola must be chosen in order to achieve the desired result for the finished product. The software CES Edupack has been used to find suitable production methods.

Kongsberg Maritime use mold casting when producing their existing float collar. It was desirable to use a similar production method to avoid big tooling costs. The bottom float collar has several similarities to the existing float collar, and will therefore be made with polymer casting. The process works well for large parts with section thicknesses within the range of $6.25 - 600$ mm [71].

The blades are much thinner than the bottom float collar, and will therefore be machined from blocks of the Divinycell material. According to the producers of Divinycell, it can be machined into almost any shape [72]. It is essential to get an accurate curve, as it determines if the sound waves will be reflected correctly. Milling is therefore chosen for this part because of its accurate machining properties for curved shapes. The Divinycell parts will be coated, smoothing out any irregularities.

A few parts will be made of aluminum; the circular connection, the blade connection, the hydraulic arm, and the sheet metal. Hot closed die forging will be used to produce the sheet metal, the circular connection and the blade connection [49]. The two parts of the hydraulic arm will be produced by impact extrusion, with the plate welded to them in both ends. A description and illustration of all production methods can be found in Appendix 13.25.

10.1.2 Assembly

The assembly of the parabola was an important consideration during the design process. It is essential that the individual parts are easy to assemble, as it reduces the probability of making mistakes, which is crucial to get the correct curvature and function.

All bolts, nuts, and screws connecting the individual parts of the construction were made of Stainless A4 steel to avoid galvanic corrosion. Galvanic corrosion can occur in aluminum constructions exposed to seawater, which causes expansion in the screw holes [73]. Kongsberg Maritime use A4 in all connectors (screws/bolts/nuts) in their transponder assembly.

A4 is an austenitic stainless steel with good resistance to corrosion, because the steel is cured with chrome. It also contains iron, nickel, manganese, titanium, and molybdenum. The material is required for connectors when exposing a construction to seawater [71], and meets the requirements of ISO 3506. The composition used in this case is shown in Table 12. This type of material is found in SolidWorks under the name AISI 316 Annealed Stainless Steel.

Table 12: A4 Stainless Steel, used in the assembly [73].

Group	Steel Designation	DIN	AISI	UNS
A4	X5CrNiMo 17 12.2	1.4401	316	S 31600

When mounting connectors of A4, lubricant/grease is used [74]. The reason for this is that the material tends to demolish in the surface, which can lead to an unstable screw connection. The grease is also used to counteract corrosion where stainless screws are used in aluminum structures [73]. According to Kongsberg Maritime, they use a substantial amount of grease when mounting the transponder together.

The assembly of all components with their respective assigned number of each assembly component, hole feature, screw, bolt and/or nut is listed in a table in Appendix 13.26. An exploded view is shown in Appendix 13.27.

Connectors will be applied a torque of 8 Nm according to Kongsberg Maritime. Rud is a company that makes lifting hooks with resemblance to those used in this project. Their M12 lifting hooks can handle a weight of 0.4 - 1.6 tons depending on the material used [75]. As this satisfies the safety factor in Table 18 in Appendix 13.16, the two lifting hooks of M12 in this project will handle the weight of the parabola.

11 Discussion and Conclusions

In this section, a discussion and conclusion, as well as suggestions for future work were conducted to conclude the project.

11.1 Discussion

During the project, emphasis has been put on reflection and acoustics theory, choosing a suitable material, and making sure the parabola handles the subsea environment and forces it will be exposed to. This study found that the implementation of a buoyant parabolic reflector will enhance the battery time of Kongsberg Maritime's Midi transponder by accumulating sound waves while situated on the seabed. No similar product currently exists to the one developed in this project.

The Embla design will have a massive body with blades on top is controlled by the operator. One of the constraints from the project assignor was to maximize the energy accumulation, resulting in the perception that the diameter of the parabola would be large. Another constraint was that the beam width had to be at approximately 10°, constraining the diameter to 50 cm, meaning that the parabola ended up being smaller than anticipated. Creating the parabola as one entire part could therefore be more efficient, although the shape would decrease the velocity during retraction to the surface. The blades were still preferred as Kongsberg Maritime was fond of this design.

As there was no time to create and test a realistic prototype with the appropriate materials, it is difficult to say how much more efficient the parabola will be compared to the transponder alone. The theory of parabolas will however confirm that the transducer will receive an increased amount of signals, thus increasing the energy accumulation.

11.2 Suggestions for Future Work

This project marks the beginning of the exploration of an idea that Kongsberg Maritime eventually might add to their products. Some areas in this project are yet to be further investigated, these are;

- Construct a realistic prototype with the correct size and materials for testing
- Test the ductility of the product by conducting a long-term test in the ocean
- Numerical analysis of all parts in order to ensure suitable dimensions
- Go deeper into the requirements applicable to this type of product
- Develop the electronics needed for the hydraulic arm
- Test the acoustic and reflecting properties
- Test the function of the hydraulic arm
- Test the buoyancy and stability

The results of the above-mentioned tasks can be used to improve the design and function of the parabola, and may eventually end up being a finalized product that Kongsberg Maritime can benefit from.

11.3 Conclusions

Current transponders must frequently go through the expensive process of being retracted to the surface in order to charge its battery, as their small area coverage is unable to accumulate enough energy to remain an extended amount of time on the seabed. The implementation of a parabolic reflector will extend the transponder’s battery time and thus reduce the cost as less retractions to the surface are needed. The Embla design was created in close relation to the goals set early in this project, and has specifically been designed to meet the demands of Kongsberg Maritime.

Embla concludes the problem statement as it has optimal acoustic, reflecting, and buoyant properties. It maximizes the energy accumulation by locating the transducer in the focal point of the parabola, minimizing the path the sound waves must travel. The design embodies features that enable it to function in a harsh subsea environment, by the use of materials which are strong enough to handle the hydrostatic pressure and buoyant force, as well as coatings that resist the growth of algae and corrosion. The smooth surface of the polyurethane coating will also contribute to an improved scratch resistance, preventing small damages to the surface. This will again prevent deformation of incoming signals. Its dissimilarity to the density of seawater causes good reflection properties, and contributes to less water absorption.

The curve and focal point are designed so that all signals entering the parabola are reflected into the focal point, and the blades are long enough to protect the transducer when they are folded. Embla was designed so that each part contributes to create a perfect parabolic curve when the blades are in their unfolded position. It also contains enough Divinycell material to provide the desired amount of buoyancy.

The most important factor during the project was to create a design that could receive more soundwaves than current transponder properties. The receiving area of the soundwaves has been increased to $79311.5\ \mathrm{mm}^2$, from a former area of $2123.72\ \mathrm{mm}^2$ which is more than 37 times the current area. The calculation is shown in Appendix 13.28. Increasing the receiving area is the main contributing factor for achieving an enhancement of the transponders energy accumulation, which was the goal of this project.

There were many challenges to conquer during the master thesis, increasing the amount of gained knowledge throughout the project. The project participants are pleased with the conducted work and the results presented in this report. The project was conducted through close collaboration with guidance from UiT - The Arctic University of Norway, as well as Kongsberg Maritime.

12 Bibliography

[1] Mrwallpaper. (04.02.). Available: http://www.mrwallpaper.com/rough-ocean-waves-wallpaper/

[2] T. e. toolbox. (25.03.). *Center of Gravity - Center of Buoyancy*. Available: http://www.engineeringtoolbox.com/centre-gravity-buoyancy-d_1286.html

[3] K. Maritime. (20.03.). *Transponder, Midi*. Available: https://www.km.kongsberg.com/ks/web/nokbg0240.nsf/AllWeb/EC3FD522FCB2D04FC1257F73004842FD?OpenDocument

[4] K. Maritime, "HiPAP High precision acoustic positioning," 2016.

[5] K. Maritime. (2016, 05.03.). *Instruction Manual cNODE Maxi and Midi transponders Low frequency, 7000 meters*. Available: https://www.km.kongsberg.com/ks/web/nokbg0397.nsf/AllWeb/C5CD15A2F3A36313C1257FDA002E136F/$file/410608-cNODE-Maxi-and-Midi-LF-7000m.pdf?OpenElement

[6] U. N. A. Universitet, "Parabolic reflector for focusing of underwater acoustic waves," 2017.

[7] K. Maritime, "Parabolic reflector for focusing of acoustic waves in subsea," 2016.

[8] X. Lurton, *An Introduction to Underwater Acoustics*, 2 ed.: Springer-Verlag Berlin Heidelberg, 2002.

[9] K. Simrad, "Introduction to underwater acoustics," 2000.

[10] H. N. S. Association, "Introduction to antisubmarine firecontrol," 2007.

[11] L. E. Kinsler, A. R. Frey, A. B. Coppens, and J. V. Sanders, *Fundamentals of Acoustics*, Fourth ed. United States of America: Jon Wiley & Sons, Inc., 2000.

[12] Marinebio. (16.01). *The deep sea*. Available: http://marinebio.org/oceans/deep/

[13] H. M. Sosik and S. Johnsen. (2004, 24.03.). *Shedding light on light in the ocean*. Available: http://www.whoi.edu/oceanus/feature/shedding-light-on-light-in-the-ocean

[14] I. o. m. research. (2016, 10.01). *Hopp i havet - hvis du orker*. Available: https://www.imr.no/temasider/klima/hopp_i_havet_hvis_du_orker/nb-no/

[15] M. a. s. a. center. (11.01). *What is hydrostatic pressure - fluid pressure and depth*. Available: http://www.edinformatics.com/math_science/hydrostatic_pressure.htm

[16] Harvard. (02.02). *Atmospheric pressure*. Available: http://acmg.seas.harvard.edu/people/faculty/djj/book/bookchap2.html

[17] H. D. Young, R. A. Freedman, and A. L. Ford, *University physics with modern physics*, 13th ed. vol. 1: Pearson, 2011.

[18] A. A. Grimenes, P. Jerstad, and B. Sletbak, *Rom stoff tid*. Oslo: Cappelen damm, 2010.

[19] T. Bell. (2017, 27.03.). *What is corrosion?* Available: https://www.thebalance.com/what-is-corrosion-2339700

[20] Safeopedia. (23.03.). *Degradation - What does degradation mean?* Available: https://www.safeopedia.com/definition/41/degradation

[21] A. D. Waite, *SONAR for practicing engineers*, 3rd ed.: Jon Wiley & Sons, 2002.

[22] Lumen. (01.02). *Conclusion*. Available: https://courses.lumenlearning.com/beginalgebra/chapter/conclusion-9/

[23] K. Academy, "Focus and directrix of a parabola from equation."

[24] Antenna-theory. (10.01). *The parabolic reflector antenna*. Available: http://www.antenna-theory.com/antennas/reflectors/dish.php

[25] H. Picciotto. (15.01). *Geometry of the parabola*.

[26] Sonardyne. (2017, 20.01). *Wideband Sub-Mini 6 plus (WSM 6+) Release Transponder*. Available: https://www.sonardyne.com/product/wideband-sub-mini-6-plus-wsm-6-release-transponder/
[27] T. Benthos. (22.01). *About Benthos*. Available: http://teledynebenthos.com/company_information/about_benthos
[28] T. Benthos. (24.01). *Transponders XT-6001/TR-6001 Technical Specs*. Available: http://teledynebenthos.com/product/acoustic_releases/transponders-xt-6001-tr-6001
[29] K. Maritime. (27.01). *Transponders, MiniS*. Available: https://www.km.kongsberg.com/ks/web/nokbg0240.nsf/AllWeb/D2C449C3452BF41AC1257F03002F38F2?OpenDocument
[30] K. Maritime. (2012, 03.03.). *cNODE Maxi and Midi transponders - Medium Frequency, 4000 m*. Available: https://www.km.kongsberg.com/ks/web/nokbg0240.nsf/AllWeb/EC3FD522FCB2D04FC1257F73004842FD?OpenDocument
[31] D. GL. (2017, 31.01). *Kort om DNV GL*. Available: https://www.dnvgl.no/om/index.html
[32] *Buckling strenght analysis of bars and frames, and spherical shells*, 2004.
[33] *Marine operations, design and fabrication*, 2012.
[34] *Pressure hull and structures - design loads*, 2015.
[35] E. standards. (2003, 27.01). *CSN EN ISO 10418*. Available: https://www.en-standard.eu/csn-en-iso-10418-petroleum-and-natural-gas-industries-offshore-production-installations-basic-surface-process-safety-systems/
[36] *Loadout, transport and installation of subsea objects*, 2014.
[37] *Foundations*, 1992.
[38] *Materials and welding*, D. GL, 2015.
[39] S. Norge. (2006, 28.01). *General prinsiples of cathodic protection in seawater*. Available: http://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=164609
[40] E. Cartagena. (2002, 12.03). *The Physics Factbook*. Available: http://hypertextbook.com/facts/2002/EdwardLaValley.shtml
[41] *Materials selection*, 1994.
[42] "ISO 3506-1," in *Mechanical Properties of Corrosion-Resistant Stainless Steel Fasterners*, ed: ISO, 2009, p. 27.
[43] *Radar equipment*, 2012.
[44] T. p. classroom. (30.03.). *Reflection, refraction and diffraction*. Available: http://www.physicsclassroom.com/Class/sound/U11L3d.cfm
[45] M. F. Ashby, *Material Selection in Mechanical Design*, 4 ed. Oxford, UK: Elsevier Ltd, 2011.
[46] B. Directory. (18.02.). *Idea generation*. Available: http://www.businessdictionary.com/definition/idea-generation.html
[47] S. Jayakody. (2009, 27.02.). *Why is Selection of Engineering Materials Important?* Available: http://www.brighthubengineering.com/manufacturing-technology/57192-why-is-selection-of-engineering-materials-important/
[48] B. Directory. (17.02). *Objective*. Available: http://www.businessdictionary.com/definition/objective.html
[49] "CES Edupack," ed, 2016.
[50] S. Kalpakjian and S. R. Schmid, *Manufacturing Engineering and Technology*, 6th ed.: Pearson Education, 2010.

[51] D. Lukkasen and A. Meidell, *Advanced Materials and Structures and some Computational Methods*: UiT The Arctic University of Norway, 2016.
[52] E. Britannica. (2006, 10.03.). *Young's modulus*. Available: https://global.britannica.com/science/Youngs-modulus
[53] D. Wood. (13.03.). *What is density? - Explanation & Examples*. Available: http://study.com/academy/lesson/what-is-density-explanation-examples.html
[54] Diabgroup. (2017, 03.02.). *Divinycell HCP*. Available: http://www.diabgroup.com/Products-and-services/Core-Material/Divinycell-HCP
[55] A. C. Counsil. (15.04.). *Polyurethanes*. Available: https://polyurethane.americanchemistry.com/CASE/
[56] Polyurethanes. (20.04.). *Coatings and adhesives*. Available: http://www.polyurethanes.org/en/where-is-it/adhesives-and-coatings
[57] Aalco. (03.05.). *Aluminium alloy 6082 - T6*. Available: http://www.google.no/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=0ahUKEwjh2YXhrPHTAhVCBSwKHW5GC3MQFggvMAE&url=http%3A%2F%2Fwww.aalco.co.uk%2Fdatasheets%2FAalco-Metals-Ltd_Aluminium-Alloy-6082-T6T651-Plate_148.pdf.ashx&usg=AFQjCNEMqwPHvLeGLr0rgFJ9BTKEzcIymQ&sig2=GydbG2L1N_h78VT3cKsWjQ
[58] (28.04.). *6082-T6 Aluminium*. Available: http://www.makeitfrom.com/material-properties/6082-T6-Aluminum
[59] D. K. Cheng, *Field and Wave Electromagnetics*, 2nd ed.: Addison-Wesley Publishing Company Inc., 1998.
[60] C. A. Balanis, *Antenna Theory, Analysis and Design*, 2nd ed.: John Wiley & Sons, 1982.
[61] M. Engineering. (29.03.). *Ship Stability*. Available: http://www.marineengineering.org.uk/page85.html
[62] Antenna-theory. (20.04.). *Beamwidths and Sidelobe Levels*. Available: http://www.antenna-theory.com/basics/radPatDefs.php
[63] Farlex. (23.04.). *Beam Width*. Available: http://www.thefreedictionary.com/beam+width
[64] K. Maritime. (29.01.). *cNode - Transponders for HiPAP and HPR*. Available: https://www.km.kongsberg.com/ks/web/nokbg0240.nsf/AllWeb/71615F27DDF1E062C12579260039B6C1?OpenDocument
[65] R. A. Nelson. (26.04.). *Antennas: The Interface with Space*. Available: http://www.aticourses.com/antennas_tutorial.htm
[66] H. Hijazi, O. Mokhiamar, and O. Elsamni, "Mechanical design of a low cost parabolic solar dish concentrator," 2016.
[67] V. tutors. (15.02.). *Finding the equation of a parabola given focus and directrix*. Available: https://www.varsitytutors.com/hotmath/hotmath_help/topics/finding-the-equation-of-a-parabola-given-focus-and-directrix
[68] T. Aven. (2015, 30.03.). *Sikkerhetsfaktor*. Available: https://snl.no/sikkerhetsfaktor
[69] L. Engineering. (28.03.). *What is Von Mises Stress?* Available: http://www.learnengineering.org/2012/12/what-is-von-mises-stress.html
[70] M. Vowgas. (02.02.). *Subsea Engineering*. Available: http://www.mgvowgas.com/what-do-we-do/subsea-engineering
[71] Motek, "Generelt om Skruer."
[72] Diabgroup. (2009, 28.03.). *Divinycell HCP Technical Data*. Available: http://www.gms.si/Divinycell%20HCP.pdf
[73] Tingstad, "Korrosjon."

[74] Tingstad, "Rustfrie Skrueprodukter."
[75] I. AS, "Sikkerhetsunstruks RUS Øyebolt RS," R. Kettenfabrik, Ed., ed.
[76] I. Igel. (2017, 13.04.). *Measuring Distance with Sound Waves*. Available: https://www.teachengineering.org/activities/view/nyu_soundwaves_activity1
[77] N. A. a. S. A. N.-J. G. F. a. C. Hodanbosi. (1996, 20.01). *Fluids pressure and depth*. Available: https://www.grc.nasa.gov/www/k12/WindTunnel/Activities/fluid_pressure.html
[78] K. Maritime. (01.02). Available: https://www.km.kongsberg.com/ks/web/nokbg0240.nsf/AllWeb/D2C449C3452BF41AC1257F03002F38F2?OpenDocument
[79] K. Maritime. (03.02.). Available: https://kongsberg.easycruit.com/vacancy/1765651/61117?iso=no
[80] T. Stenvold. (2015, 05.02.). *Ulstein-Oppfinnelser*. Available: https://www.tu.no/artikler/slik-fant-ulstein-opp-x-bow-x-tender-og-oppsvingbar-thruster/276213
[81] R. Kulkarni. (2016, 05.02.). *Real-life examples of a parabola for better understanding*. Available: http://www.buzzle.com/articles/real-life-examples-of-a-parabola.html
[82] (08.02.). *Ønsker du tilgang på flere kanaler?* Available: http://www.anesset.no/hXGYBmNdzOYH.25.idium
[83] M. Burlingame. (09.02.). *Collapsable steamer*. Available: https://guide.alibaba.com/shop/zicome-12-collapsible-steamer-steamer-basket-steamer-insert-vegetable-steamer-seafood-steamer-food-steamer-stainless-steel_3334431.html
[84] D. Dim. (2014, 06.02). *Kongsberg presents subsea monitoring system*. Available: https://www.vesselfinder.com/news/1907-Kongsberg-presents-Subsea-Monitoring-System
[85] (05.02.). *PNG images: Umbrella*. Available: http://pngimg.com/img/objects/umbrella
[86] K. Maritime, "HiPaP Instruction manual - High Precision Acoustic Positioning."
[87] (29.05). *Parabolic Reflector*. Available: http://mathforum.org/mathimages/index.php/Parabolic_Reflector
[88] K. E. Sandvold, S. Øgrim, T. Bakken, B. Pettersen, K. Skrind, R. Thorstensen, *et al.*, *Gyldendals formelsamling i matematikk*, 1st ed.: Gyldendal Norsk Forlag AS, 2011.
[89] Ø. Vollen, *Statikk og fasthetslære: Mekanikk for ingeniører*: NKI forlaget, 2010.
[90] (13.05). *Archimedes Principle*. Available: https://www.youtube.com/watch?v=2RefIvqaYg8
[91] F. Irgens, *Fasthetslære* vol. 7. Bergen: Fagbokforlaget, 2006.
[92] J. Haugan, *Formler og Tabeller*, 2016.

13 Appendices

This section contains a list of all appendices associated with the report. They are all cited in the text relevant to the appendix.

13.1 Mechanical Waves

The speed of a sound wave in sea water is $v = 1500\ \mathrm{m/s}$, not taking into consideration that the temperature changes with depth. Kongsberg Maritime works with frequencies at about $20 - 30\ \mathrm{kHz}$. The higher the frequency, the shorter the wavelength. It could therefore be beneficial to use a higher frequency to generate a more intense signal. The equation for wavelength is [17]:

$$\lambda = \frac{v}{F}$$

where $\lambda = \text{Wavelength}\ [\mathrm{m}]$, $v = \text{Speed of sound}\ [\mathrm{m/s}]$, and $F = \text{Frequency}\ [\mathrm{Hz}]$. The wavelength of today's frequency is:

$$\lambda = \frac{1500\ \mathrm{m/s}}{25000\ \mathrm{s^{-1}}} = 0.06\ \mathrm{m}$$

where $\mathrm{Hz} = \mathrm{s^{-1}}$. In comparison, the wavelength of a frequency of $1\ \mathrm{MHz}$ is:

$$\lambda = \frac{1500\ \mathrm{m/s}}{1000000\ \mathrm{s^{-1}}} = 0.0015\ \mathrm{m}$$

One can also calculate the time a soundwave takes to travel from the sea bottom to an object, and back. The equation for the distance between the transducer and the sea surface is [76]:

$$t = \frac{D}{v}$$

Where $D = \text{Distance}\ [\mathrm{m}]$, and $t = \text{time}\ [\mathrm{s}]$. The time traveled by the sound wave therefore becomes:

$$t = \frac{200\ \mathrm{m}}{1500\ \mathrm{m/s^2}} \approx 0.133\ \mathrm{s}$$

neglecting the time it takes to travel from the transducer to the parabola.

13.2 Calculation of Pressure

The pressure exerted by the seawater on the parabolic reflector is a concern during the design process. The pressure on an object submerged in a fluid is given by [77]:

$$P_{fluid} = \rho g h$$

where ρ is the density of the fluid, g is the acceleration of gravity and h is the height of the fluid placed above the object. The total pressure is given by [77]:

$$P_{total} = P_{atmosphere} + P_{fluid}$$

The atmospheric pressure on earth is [77]:

$$P_{atmosphere} = 1.013 \cdot 10^5 \text{ Pa}$$

Calculating the pressure at 200 meters' depth in the ocean gives:

$$P_{fluid} = (1.03 \cdot 10^3 \text{ kg/m}^3) \cdot 9.81 \text{ m/s}^2 \cdot 200 \text{ m} = 2.011 \cdot 10^6 \text{ Pa}$$

This gives a total pressure of:

$$P_{total} = (1.013 \cdot 10^5 \text{ Pa}) + (2.011 \cdot 10^6 \text{ Pa}) = 2.112 \cdot 10^6 \text{ Pa}$$

Converting this to Bar gives [17]:

$$P_{total} = 2.112 \cdot 10^6 \text{ Pa} = 2.112 \text{ MPa} = 21.12 \text{ Bar}$$

13.3 First Round of Idea Generation

The purpose of the first round was to start a creative process where anything was allowed. Two moodboards were generated for inspiration, as can be seen in Figure 28 and 29, and the ideas were evaluated based on positive and negative aspects. The four ideas developed during the first round are presented below with a designated number.

Figure 28: The moodboard that idea 1 and 2 are based upon [78] - [81], [64], [1], [70], [4], [5],.

Figure 29: The moodboard that idea 3 and 4 are based upon [78], [82] - [86].

13.3.1 Idea 1

This idea is inspired by a blooming flower and is shown in Figure 30. The parabola is divided into "leaves" fastened to a stabilizing ring with a mechanical support underneath. The support is connected by joints to a ring positioned around the transponder and can be pushed up and down to open or close the parabola. When the parabola is dropped into the sea or retracted to the surface, it should be closed as shown in the first drawing of Figure 30. This gives a smoother water flow around the product.

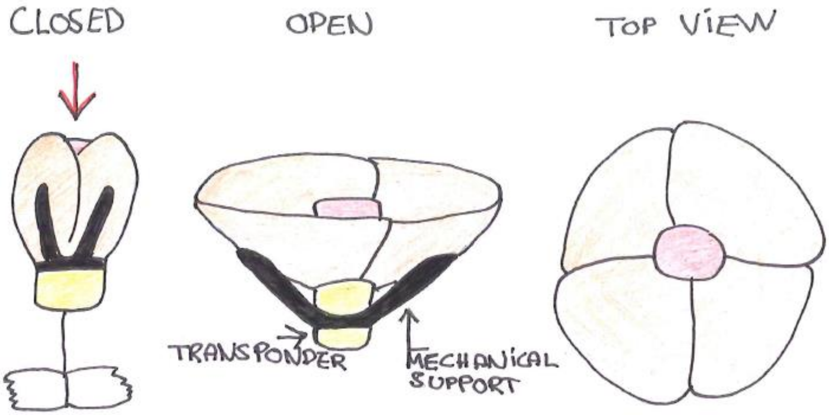


Figure 30: Sketch of idea 1.

13.3.2 Idea 2

This idea is inspired by a floating buoy and is shown in Figure 31. The triangular shape of the parabola gives a smooth water flow around the product as it travels downwards. The parabola has entrapped air underneath which will have a greater buoyancy than the upper part of the structure. At the lower end of the product there is a cut off function similar to the one Kongsberg Maritime is already using. When the load is cut the parabola will turn around, so the part with the biggest buoyancy is facing upwards. This ensures a smoother water flow around the object as it rises to the surface, than if it was turned the other way.

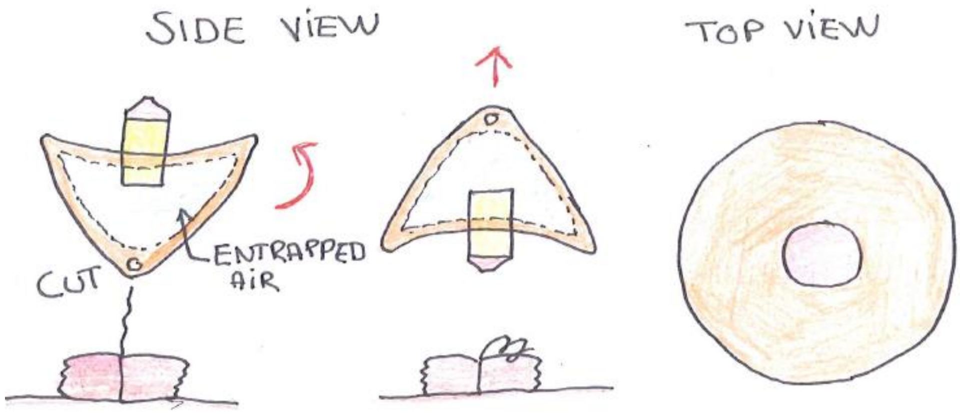


Figure 31: Sketch of idea 2.

13.3.3 Idea 3

This idea is based upon a vegetable steamer. The parabola is designed with overlapping sections, and can be retracted as can be seen on the right side of Figure 32. In an attempt to maximize the collection of incoming signals even further, a second, but smaller parabola has been added just above the transponder. This to reflect the already reflected signals from the bigger parabola, concentrating them more toward the transponders focal point.

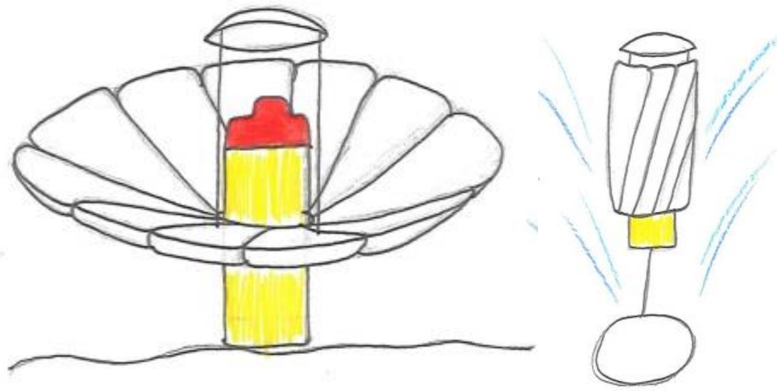


Figure 32: Sketch of idea 3.

13.3.4 Idea 4

The idea seen in Figure 33 has the same overlapping and retractable features as the previous design, but without the second parabola on top. It also has a fixed rounded bottom shown in yellow integrated, which has the same function as a parabola while making the design more stable.

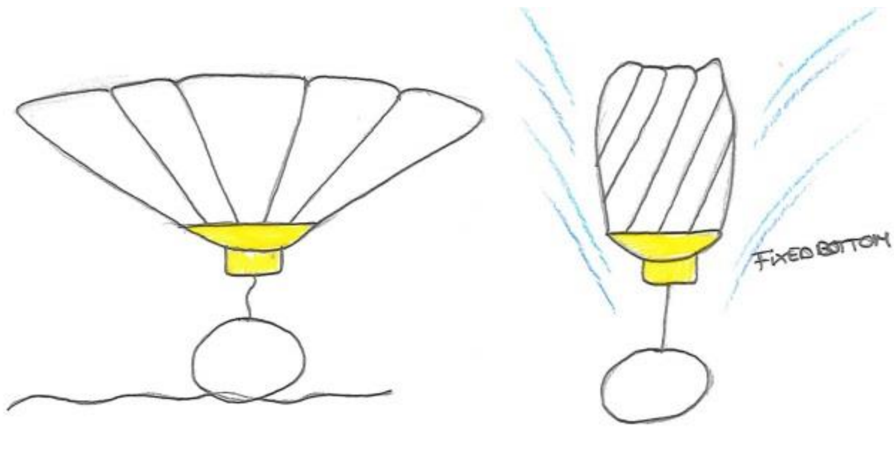


Figure 33: Sketch of idea 4.

13.3.5 Design Evaluation - First Round

The first round of evaluation is based on positive and negative sides to the design, as well as improvements for further development. The four different designs each have a designated number, and two designs will be chosen based on the bullet points shown in Table 13.

Table 13: Evaluation of first design round.

Evaluation	Idea 1	Idea 2	Idea 3	Idea 4
Positive	• Can be opened and closed as desired. • Has a mechanical support under the parabola. • Smooth flow around the design at launch and retraction.	• Based on physical principles, no electricity needed. • Few parts. • Has self-recovery system. • Stable parabola due to underneath structure.	• Concentrated reflection to the focal point by the use of an extra parabola. • Can be opened and closed as desired. • Smooth flow around the design at launch and retraction.	• Can be opened and closed as desired. • Stable support at lower part of the parabola. • Smooth flow around the design at launch and retraction.
Negative	• Needs electricity. • Many parts needed. • Not stable if oceanic currents are present.	• Big structure. • Poor hydrodynamics at launch. • Not stable if oceanic currents are present. • Small area coverage.	• Many parts needed. • Needs electricity. • No support. • Not stable if oceanic currents are present.	• Needs electricity. • Many parts needed. • Not stable if oceanic currents are present.

After discussing pros and cons regarding the individual designs, the final choice fell on idea 2, and a combination of the “blade” designs in 1, 3, and 4. It is also interesting to test the second smaller parabola, to see if the energy collection increases. A consideration is that the transponder only has a 10° beam width, so an extra parabola might be required in order to make the sound waves hit within this receiving region. This will be tested on the final design. A topic that was discussed was whether an adaptive solution where the parabola fits other transponders can be used. This is hard to design in this case, as the transponders are of different size and the design must be specified for each of them. The two ideas will be further developed, going into the second round of the idea generation.

13.4 Design Evaluation - Second Round

The evaluation in Table 14 was based on the design criteria's relevant for the final design of the parabola. Each criteria is weighted based on importance, and each of the ideas were evaluated based on how well they score on each individual criteria. Scores are between 1 and 5, where 5 is the highest score.

Table 14: Idea Generation Evaluation.

Design Criteria's / Ideas	Score Weight	Idea 5		Idea 6		Idea 7		Idea 8	
		Point	Sum	Point	Sum	Point	Sum	Point	Sum
Maximize sound wave area coverage	1.1	2	2.2	4	4.4	3	3.3	5	5.5
Best fit the cNODE Midi 34 - 180 transponder	1	5	5	3	3	4	4	4	4
Robust mechanical support	0.9	5	4.5	2	1.8	4	3.6	3	2.7
Self-recovery system in case of communication failure	0.8	5	4	5	4	3	2.4	3	2.4
Low risk of operator mistakes	0.7	4	2.8	3	2.1	5	3.5	4	2.8
Smooth water flow around the design for easier lowering to the seabed	0.6	3	1.8	5	3	2	1.2	4	2.4
Keep the cNODE vertically floating in the water	0.5	3	1.5	3	1.5	5	2.5	4	2
Design it as a float collar for retraction to the surface	0.4	5	2	2	0.8	3	1.2	4	1.6
No unnecessary features	0.3	4	1.2	2	0.6	5	1.5	4	1.2
Low complexity of components	0.2	4	0.8	2	0.4	4	0.8	3	0.6
User friendly	0.1	4	0.4	3	0.3	5	0.5	4	0.4
Sum		26.2		21.9		24.5		25.6	

The highest ranking idea with a score of 26.2 was Idea 5. The reason for this was that it had a great floating potential, room for the addition of air pockets when turning it upside down, good access from the transponder to the ropes for self-evacuation, was robust and had a regular parabolic shape without big interferences. The major drawback was that it only covered a small amount of area.

The second best ranking was idea 8 with a score of 25.6. The reason for this score was that it covers a large area and maximizes the collection of energy. The parabola also has a smooth water flow around it as it ascends and descends in the water. The major drawback for this idea was that it is not as robust and has a higher complexity of components.

The two ideas with the highest ranking both have positive aspects that are important for the final design. The focus going into the concept development stage was to improve the areas where these ideas fell through on getting the highest score. The improvement areas are:

- Maximize soundwave area coverage.
- Low complexity of components.
- Low risk of operator mistakes.
- Robust mechanical support.
- Good self-recovery system.
- Keep it vertically floating.
- No unnecessary features.
- Smooth water flow.
- User friendly.

13.5 Comparison of Materials

A comparison of Divinycell HCP50 and PVC Cross Linked Foam is shown in Table 15.

Table 15: Comparison of materials [49], [54].

Material / Property	Divinycell HCP50	PVC Cross-Linked Foam (rigid, closed cell, KR 0.260)	Mid Difference
Tradename	Divinycell	Divinycell	No Difference
Form	Foam	Foam	No Difference
Typical Uses	Buoyancy Units, Insulation, Impact Protection Structures	Sandwich Structure Cores, Insulation, Floatation	No Difference
Compressive Strength $[\mathbf{MPa}]$	$6.1 - 7.2$	$6 - 7.1$	0.1
E-Modulus $[\mathbf{MPa}]$	$350 - 400$	$280 - 300$	85
Tensile Strength $[\mathbf{MPa}]$	$8 - 9.2$	$6.67 - 8.01$	1.26
Shear Modulus [MPa]	$81 - 97$	$105 - 115$	21
Density $[\frac{\mathbf{kg}}{\mathbf{m^3}}]$	250	$253 - 267$	10
Thermal Conductivity $[\frac{\mathbf{W}}{(\mathbf{m-k})}]$	0.051	$0.039 - 0.043$	0.008

13.6 Young's modulus – Density Chart

A Young's modulus – Density chart is shown in Figure 34. The materials shown in grey are the ones excluded from the selection process by the use of constraints. The materials shown in green are the various compositions of Divinycell (PVC cross-linked foam) that was eliminated.

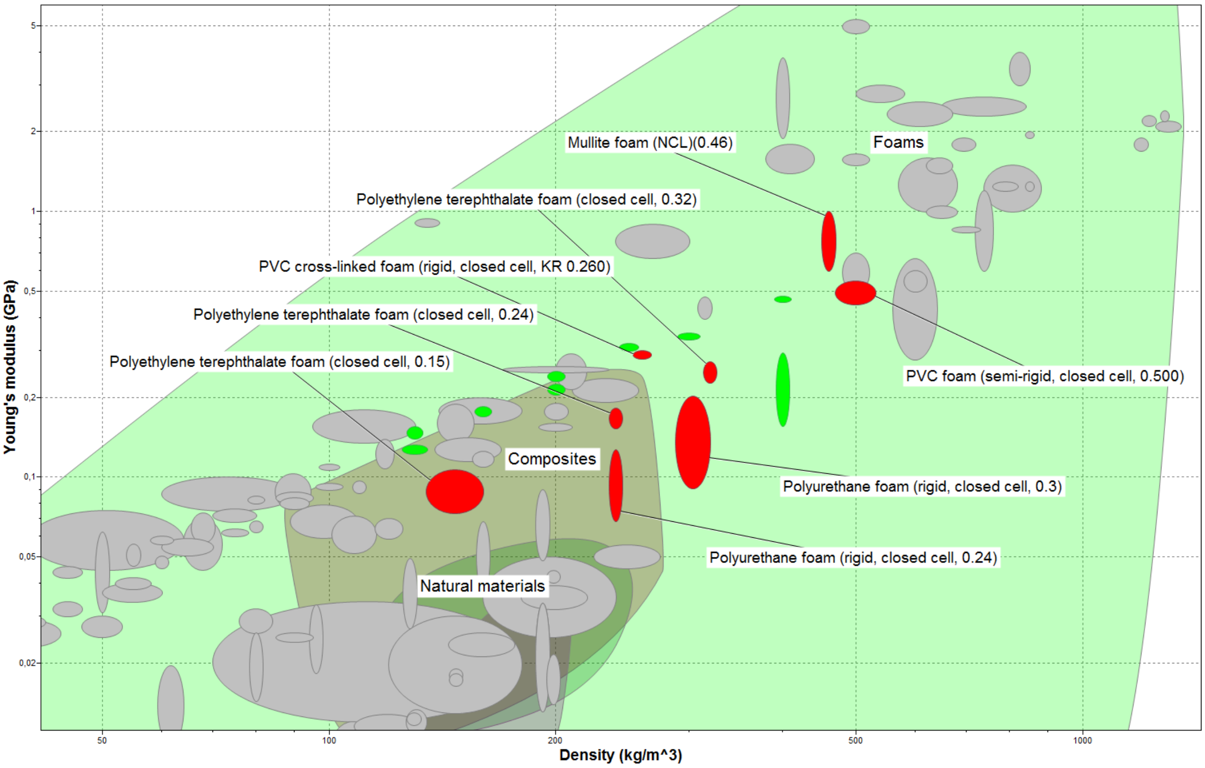


Figure 34: Young's modulus – Density chart. Figure created in CES Edupack.

13.7 Calculation of Material Index

The objective of this material selection process is to minimize the mass to find the most suitable material. The objective function is given by [51]:

$$m = At\rho = (\pi R^2)t\rho$$

where m is the mass, A is the area, t is the thickness, ρ is the density and R is the radius. The maximum stress for a simply supported disk is given by [45]:

$$\sigma_{max} = \frac{3}{8}(3+\vartheta)\frac{\Delta p R^2}{t^2}$$

where ϑ is the Poisson's ratio and the difference in pressure is [45]:

$$\Delta p = \frac{F}{A} = \frac{mg}{A} = \frac{mg}{\pi R^2}$$

where F is a force and g is gravity. Inserting the equation for pressure difference into the equation for stress gives:

$$\sigma_{max} = \frac{3}{8}(3+\vartheta)\frac{(\frac{mg}{A})R^2}{t^2}$$

$$\sigma_{max} = \frac{3}{8}(3+\vartheta)\frac{mgR^2}{At^2}$$

The Poisson's ratio for most materials is approximately 0.3 [45].Using this gives:

$$\sigma_{max} = \frac{3}{8}(3+0.3)\frac{mgR^2}{At^2}$$

$$\sigma_{max} = \frac{99mgR^2}{80At^2}$$

Solving this equation for the thickness t gives:

$$t = (\frac{99mgR^2}{80A\sigma_{max}})^{\frac{1}{2}}$$

Inserting this into the objective function gives:

$$m = (\pi R^2) \cdot (\frac{99mgR^2}{80A\sigma_{max}})^{\frac{1}{2}} \cdot \rho$$

Inserting the equation of the area gives:

$$m = (\pi R^2) \cdot (\frac{99mg}{80\pi\sigma_{max}})^{\frac{1}{2}} \cdot \rho$$

Inserting the equation for stress gives:

$$m = (\pi R^2) \cdot (\frac{99mg}{80\pi E\varepsilon})^{\frac{1}{2}} \cdot \rho$$

where E is the elastisity modulus and ε is strain. This equation can be divided into different parts. A function describing the performance (p), is divided into three different parts; functional requirements (F) , geometry (G) and material properties (M). This function is given as [51]:

$$p \geq (F)(G)(M)$$

Using this to divide the equation into the respective parts gives:

$$m = \pi R^2 \left(\frac{99}{80\pi}\right)^{\frac{1}{2}} \cdot \left(\frac{mg}{\varepsilon}\right)^{\frac{1}{2}} \cdot \left(\frac{\rho}{E^{\frac{1}{2}}}\right)$$

$$m \cdot m^{-\frac{1}{2}} = \pi \cdot \pi^{-\frac{1}{2}} \cdot R^2 \left(\frac{99}{80}\right)^{\frac{1}{2}} \cdot \left(\frac{g}{\varepsilon}\right)^{\frac{1}{2}} \cdot \left(\frac{\rho}{E^{\frac{1}{2}}}\right)$$

$$m = \pi R^4 \left(\frac{99}{80}\right) \cdot \left(\frac{g}{\varepsilon}\right) \cdot \left(\frac{\rho}{E^{1/2}}\right)^2$$

The material index to be minimized is therefore:

$$M = \frac{\rho}{E^{1/2}}$$

The material index to be maximized is the inverse of this, which is:

$$M = \frac{E^{1/2}}{\rho}$$

This can be used to find the slope which can be inserted into a graph comparing the density and the elasticity modulus of different materials. Setting the material index equal to a constant C gives:

$$M = \frac{E^{1/2}}{\rho} = C$$

$$\log E^{1/2} - \log \rho = \log C$$

$$\frac{1}{2} \log E - \log \rho = \log C$$

$$\log E = 2\,(\log \rho + \log C)$$

This gives a slope with value 2. The remaining constraints will be treated as property limits.

13.8 Individual Material Index

Table 16 shows a comparison of the material index for all of the remaining materials. The material with the smallest mass is the one with the greatest value of M, which means that the highest M indicates the best material for the parabola. Divinycell HCP50 is compared to the materials because it has slightly better properties than PVC Cross-Linked Foam which it is replaced by in CES Edupack. As seen from the table, PVC Cross-Linked Foam has the highest material index out of the original materials compared. Divinycell HCP50 is slightly better though.

Table 16: Individual material index [49].

Material	$M = \frac{E^{\frac{1}{2}}}{\rho} \ [\frac{\mathrm{MPa}^{\frac{1}{2}}}{\frac{\mathrm{kg}}{\mathrm{m}^3}}]$	Comment
Mullite Foam (NCL)(0.46)	0.0615	Second heaviest material. Highest E.
Polyethylene Terephthalate Foam (closed cell, 0.15)	0.0645	Best material index of all Polyethylene compositions
Polyethylene Terephthalate Foam (closed cell, 0.24)	0.0532	Fifth lowest material index
Polyethylene Terephthalate Foam (closed cell, 0.32)	0.0494	Fourth lowest material index
Polyurethane Foam (rigid, closed cell, 0.24)	0.0412	Next lowest material index
Polyurethane Foam (rigid, closed cell, 0.3)	0.0400	Lowest material index
PVC Cross-Linked Foam (rigid, closed cell, KR 0.260)	0.0655	The next highest material index
PVC Foam (semi-rigid, closed cell, 0.500)	0.0447	The heaviest material. Third lowest material index
Divinycell HCP50	0.0774	Highest material index

13.9 Calculation of Buoyant Force in Seawater

If the buoyancy force is greater than the gravitational force and the force exerted by the transponder, the system will float. A free body diagram has been made to better understand the forces acting on the system, this is shown in Figure 35.

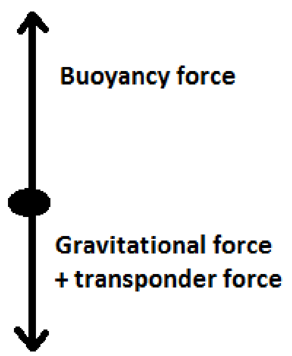


Figure 35: Free body diagram [17].

Calculations for the buoyancy force for each of the materials is conducted below. The calculations use 1 kg of the respective materials as a base for comparing them against each other. For density, the biggest given number is used. It is important that the force excreted by the transponder is taken into consideration when the calculations of buoyancy for a final design are conducted. This is not included in this first round of calculating as the final amount of material to be used is not known.

13.9.1 Divinycell HCP50

First the volume of 1kg material must be calculated by using [17]:

$$V = \frac{m}{\rho} = \frac{1\ \text{kg}}{250\ \frac{\text{kg}}{\text{m}^3}} = 4 \cdot 10^{-3}\text{m}^3$$

where V is the volume, m is the mass and ρ is the density of Divinycell HCP50. For the bouyancy force in seawater, it can be used that [17]:

$$B_{sw} = \rho_{sw} V g = 1.025 \cdot 10^3\ \frac{\text{kg}}{\text{m}^3} \cdot 4 \cdot 10^{-3}\ \text{m}^3 \cdot 9.81\ \frac{\text{m}}{\text{s}^2} = 40.221\ \text{N}$$

where B_{sw} is the buoyancy in seawater, ρ_{sw} is the density of seawater and g is the gravitational force.

13.9.2 Polyethylene Terephtalate Foam (0.15)

The same formulas was used to calculate the volume of 1kg Polyethylene Terephtalate Foam (0.15) material giving:

$$V = 6.25 \cdot 10^{-3}\text{m}^3$$

This gives a bouyancy force in seawater of:

$$B_{sw} = 62.95\ N$$

13.9.3 Mullite Foam

Similar calculations was conducted to find the volume of 1kg Mullite Foam material:

$$V = 2.1276 \cdot 10^{-3}\text{m}^3$$

This gives a bouyancy force in seawater of:

$$B_{sw} = 21.39\ N$$

13.10 Outgoing Signals

The transponder will not only receive signals, but also send signals to the surface. The reflection of these signals is also tested with respect to a concave and a convex shape of the smaller parabola. The source of the sound waves is located where the transponder would stand. Figure 36 shows the simulation of outgoing rays hitting the smaller parabola on a convex shape. The simulation shows that this design is functional as the rays are reflected with lines that are almost straight. It is desirable to send the signals back to where they can from.

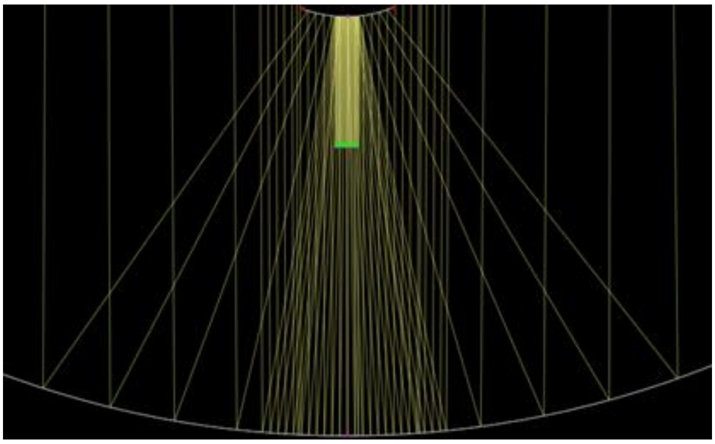


Figure 36: Outgoing signals hitting the smaller parabola on a convex shape. Figure created in Ray Optics Simulation.

A similar simulation was done when the shape of the parabola is a concave. As can be seen from Figure 37, the rays goes from the light source into the parabola. They are reflected from the parabola by forming a focal point. As the transponder will be in this point, there will be no further reflection of these signals. This design is therefore not suitable.

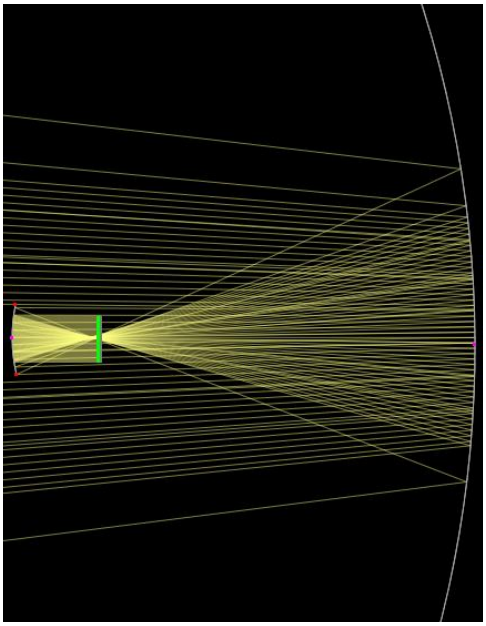


Figure 37: Outgoing signals hitting the smaller parabola on a concave shape. Figure created in Ray Optics Simulation.

13.11 The Relationship Between a Parabola's Focus Point and Incoming Signals

The calculation is done to prove that each vertical signal entering a distinct parabola, will all be reflected to the same point, i.e. the focus point. The equation of a parabola with a focus point at $(0, f)$ is:

$$x^2 = 4fy$$

As stated earlier. The derivative of this equation with respect to x gives the slope of the tangent at any point on the parabola:

$$y = \frac{x^2}{4f}$$

$$\frac{dy}{dx} = \frac{2x}{4f}$$

$$\frac{dy}{dx} = \frac{x}{2f}$$

The slope of this tangent line is relative to the x-axis. The line normal to the parabola makes the same angle with the y-axis as the line tangent to the parabola has relative to the x-axis, as seen in Figure 38.

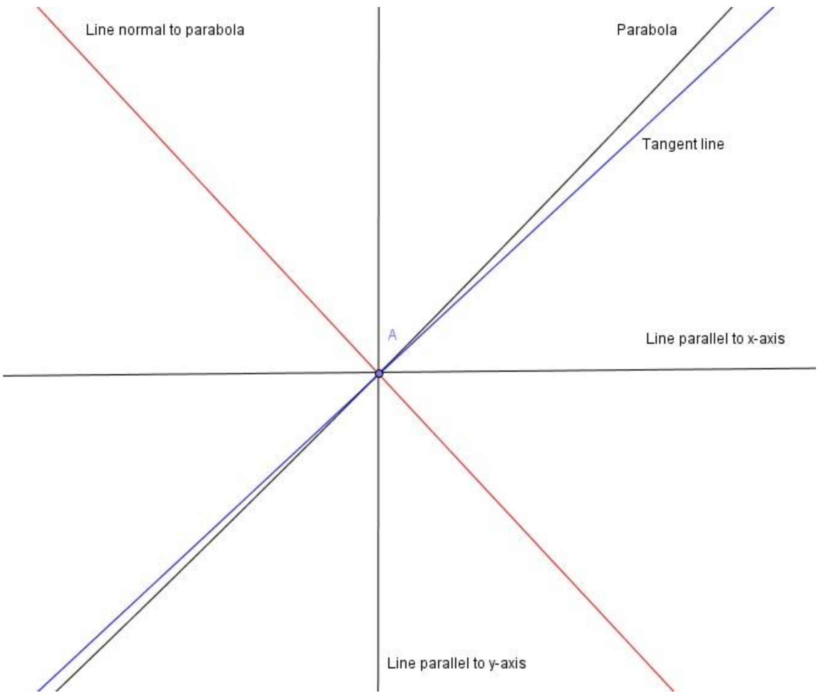


Figure 38: Tangent illustration. Figure created in GeoGebra.

The slope of the tangent line is used to find the angle, θ, between the line normal to the parabola at a point, and the y-axis. This is the same angle as the one between the line normal to the parabola and the reflected signal, as seen in Figure 39. The angle θ of which the incoming signal makes with the line normal to the parabola is [87]:

$$\tan\theta = \frac{x}{2f} \qquad (1)$$

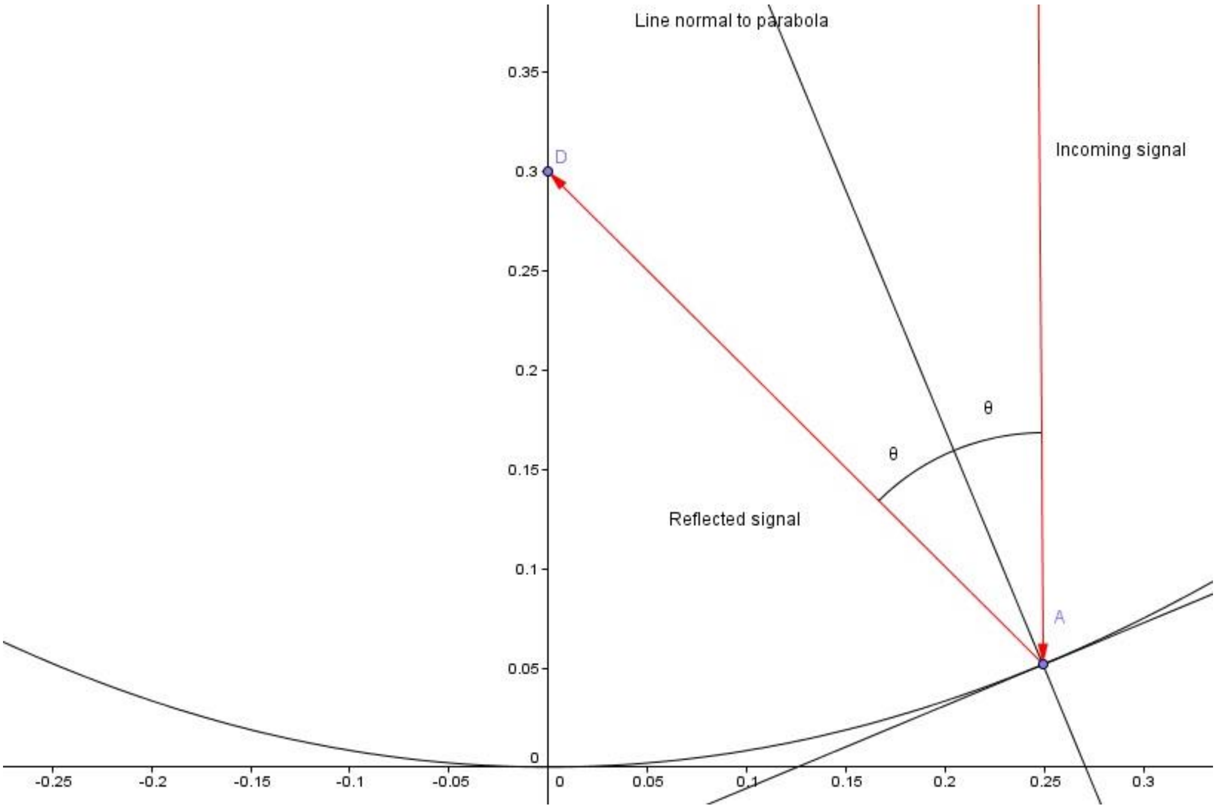


Figure 39: Angle illustration. Figure created in GeoGebra.

This means that the angle of the reflected signal is two times the angle the line normal to the parabola makes with the vertical incoming signal. Figure 40 is used to prove that the direction the signal takes after being reflected has the exact angle needed to hit the focus point.

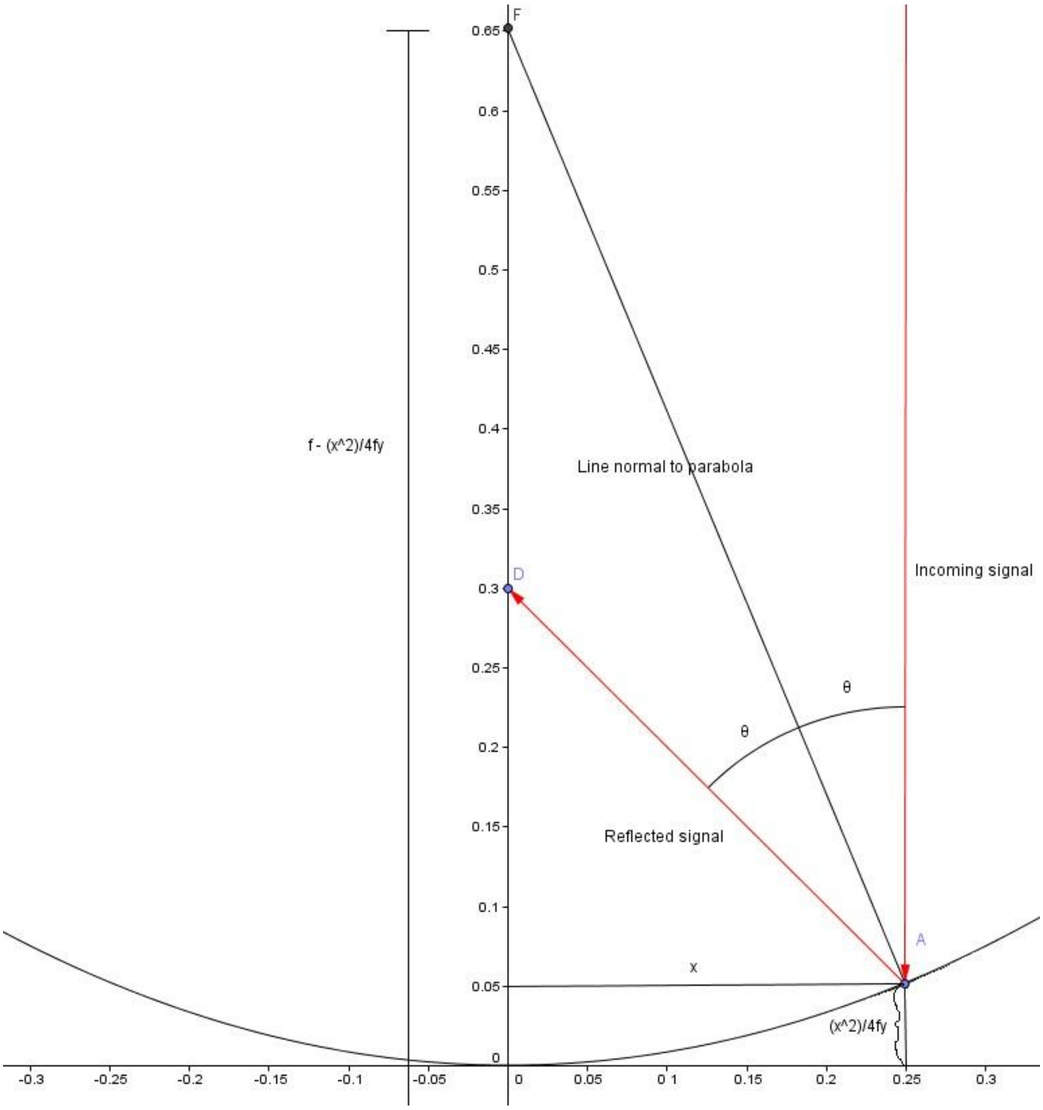


Figure 40: Illustration of reflection theory. Figure created in GeoGebra.

From the above figure, geometrically, the relationship becomes [87]:

$$\tan 2\theta = \frac{x}{f - \frac{x^2}{4f}}$$

Using trigonometric identity to rewrite the equation:

$$\tan 2\theta = \frac{x}{f - \frac{x^2}{4f}} = \frac{2tan\theta}{1 - tan^2\theta} \qquad (2)$$

Showing that the angle in (1) is the same as the angle in (2):

$$2\tan\theta = 2\frac{x}{2f} = \frac{x}{f} \qquad (3)$$

$$1 - \tan^2\theta = 1 - \left(\frac{x}{2f}\right)^2 = 1 - \frac{x^2}{4f^2} \quad (4)$$

Combining (3) and (4)

$$\frac{2\tan\theta}{1 - \tan^2\theta} = \frac{\frac{x}{f}}{1 - \frac{x^2}{4f^2}} = \frac{x}{f - \frac{x^2}{4f}}$$

Which is the same as (2). This proves that an acoustic wave is reflected to the focus point after hitting the parabolic curve at any point.

13.12 Curves

To calculate the curves, one must first calculate the location of the focal point. This is done by using the formula for the f/d ratio, which is [24]:

$$\frac{f}{d} = ratio$$

where f is the length of the focal point in meters in the y-direction, d is the diameter given in meters in the x-direction, and the ratio is ranging from 0.1-1. The values calculated by using this formula is used to find the equation of the different curves. The equation of a parabolic curve is found by using the formula [67]:

$$\sqrt{(x_o - x_f)^2 + (y_0 - y_f)^2} = |y_0 - D|$$

where D is the location of the directrix, and x and y are the coordinates of a random point and the focal point respectively. Using this to calculate a general formula that can be used for all the curves gives:

$$(x_0 - 0)^2 + (y_0 - f)^2 = (y_0 + f)^2$$

$$x_0^2 + (y_0 - f)(y_0 - f) = (y_0 + f)(y_0 + f)$$

$$x_0^2 + y_0^2 - fy_0 - fy_0 + f = y_0^2 + fy_0 + fy_0 + f$$

$$x_0^2 = 4fy_0$$

This can be rewritten as an equation for a parabolic curve as:

$$y = \frac{x^2}{4f}$$

This calculation form a basis that is used to calculate all the curves to be investigated. These calculations are presented in Table 17.

Table 17: Result of the calculation of curves for a diameter of 50 cm.

F/d ratio	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
Focal point [m]	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
Curve	$\frac{x^2}{0.2}$	$\frac{x^2}{0.4}$	$\frac{x^2}{0.6}$	$\frac{x^2}{0.8}$	x^2	$\frac{x^2}{1.2}$	$\frac{x^2}{1.4}$	$\frac{x^2}{1.6}$	$\frac{x^2}{1.8}$	$\frac{x^2}{2}$

The calculated curves were drawn in the software GeoGebra to get a better visualization of the curvatures. The curves with their focal points are color coded and are shown in Figure 41.

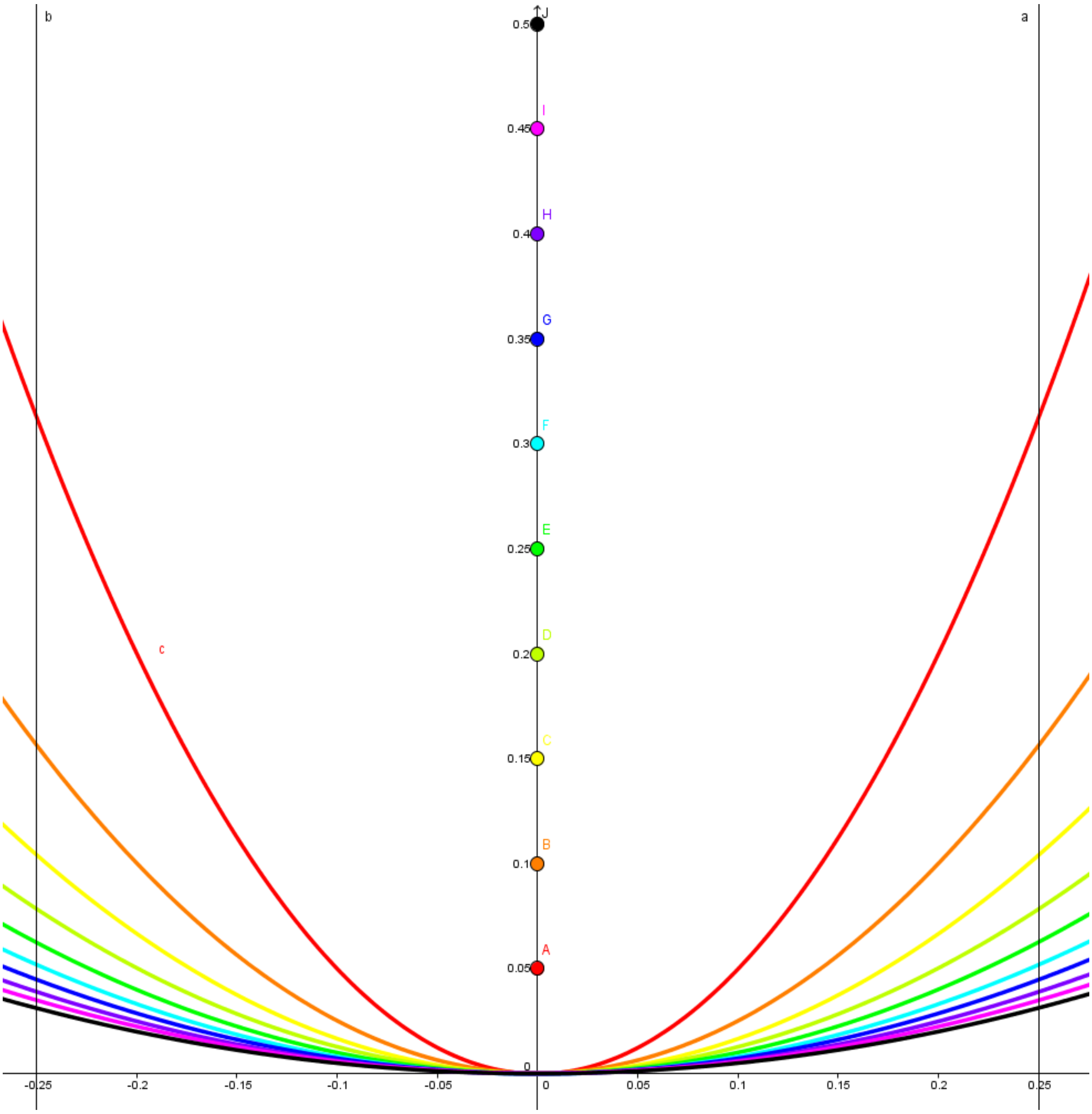


Figure 41: Curves with f/d ratio from 0.1-1 and diameter 50 cm. Figure created in GeoGebra.

13.13 Eliminating Curves

The below calculation proves that the elimination of the red and orange curve in Figure 41 are valid. The reason for the elimination is that some of the reflective signals will hit the top of the transducer. The equation is based on the red parabola with the shape:

$$y = \frac{x^2}{0.2}$$

with a diameter of $d = 0.5$ m, and a subsequent focal point at $f = (0,0.05)$. From Appendix 13.11, the angle θ of which the incoming signal makes with the reflective signal is:

$$\tan 2\theta = \frac{x}{2f}$$

The angle between an incoming vertical signal at $x = 0.25$ m (on the far edge of the parabola) and its reflective signal becomes:

$$\tan 2\theta = \frac{0.25}{2 \cdot 0.05}$$

$$2\theta = \tan^{-1}\left(\frac{0.25}{2 \cdot 0.05}\right)$$

$$\theta = 136.4°$$

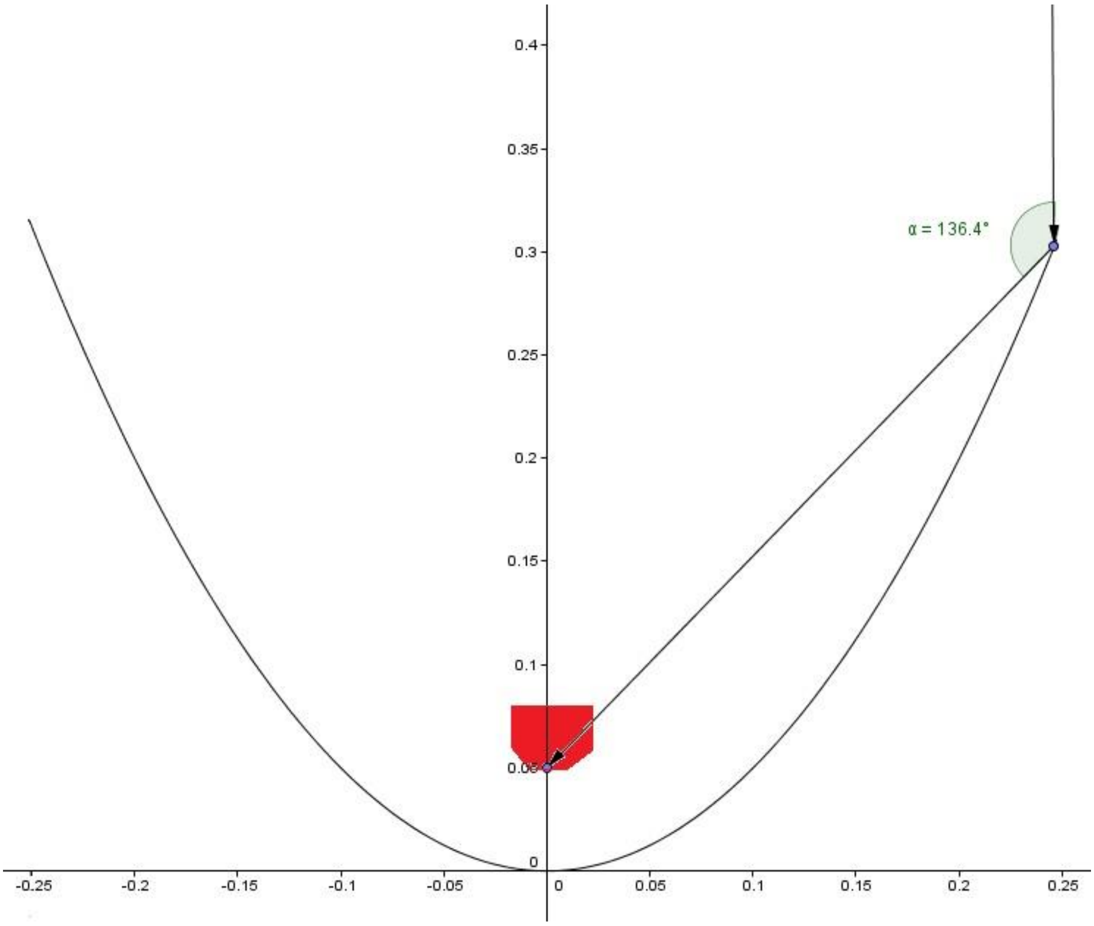


Figure 42: Incoming signal. Figure created in GeoGebra.

Since the transducer is the focal point (f) of the parabola, all reflective signals need to hit underneath the transducer in order to be received. Figure 42 shows the incoming signal being reflected by the parabola, and hitting the top side of the transducer. The signal will therefore not be received, which is inefficient because some of the parabolas surface area is superficial.

This will happen for both the red and orange curve, which eliminates them from further investigation.

13.14 Folding of Blades

According to a previously set constraint, the blades should cover the transducer head when folded together. In order for this constraint to be met, the bottom float collar could not be too wide, as it would shorten the length of the blades. It could neither be too slim, as it would influence the position of the rods which supports the load of the transducer.

A simplification of the parabola is shown in Figure 43, and shows how the blades will protect the rods, and some of the transducer. The tip of the transducer head is the focal point of the parabola, located 0.15 m above the bottom of the parabolic curve.

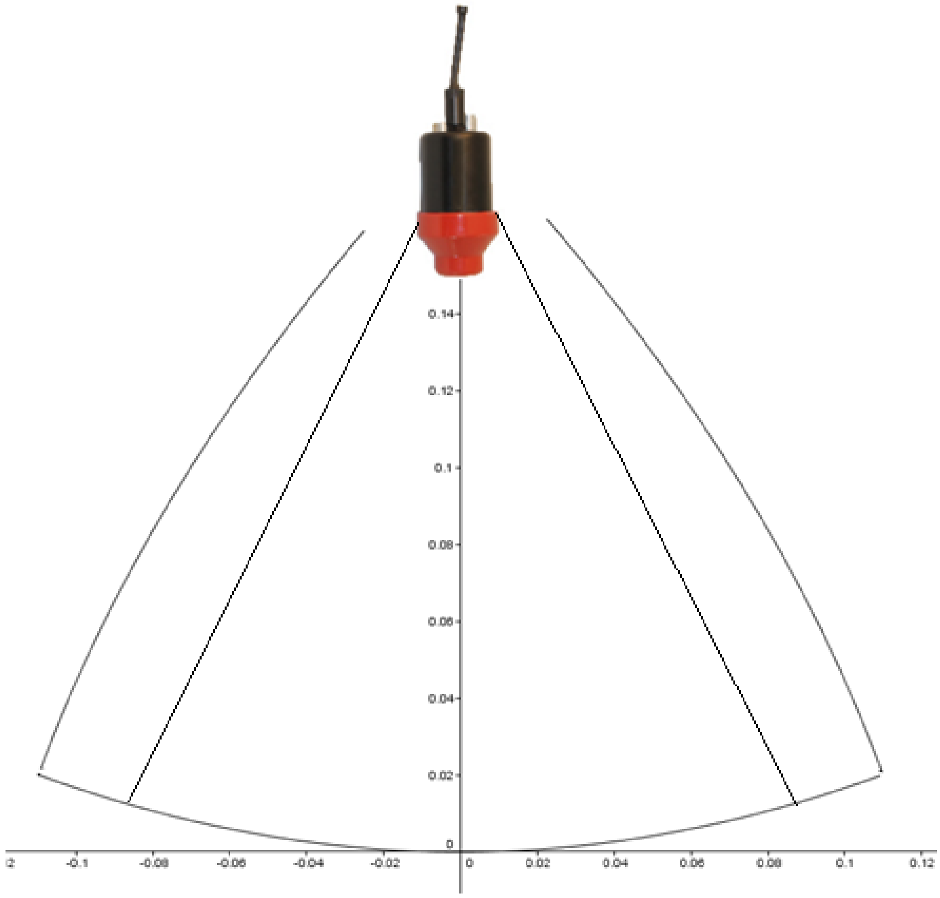


Figure 43: Folding of blades. Figure created in GeoGebra.

It is not possible to protect more of the transducer without changing the diameter of the curve. Increasing the diameter would mean decreasing the beam width of $10\,°$, which is not possible as it is a constraint specified by Kongsberg Maritime. Changing the height of the focal point is not possible either, according to section 8.3 in this report. The image shown in Figure 43 is therefore the final design of the parabolic curve.

13.15 Area Coverage

Since the parabola is designed to generate a beam width of approximately 10°, it is possible to calculate the width of the area covered by the sound waves when they reach the sea surface after 200 m. An illustration of this is shown in Figure 44.

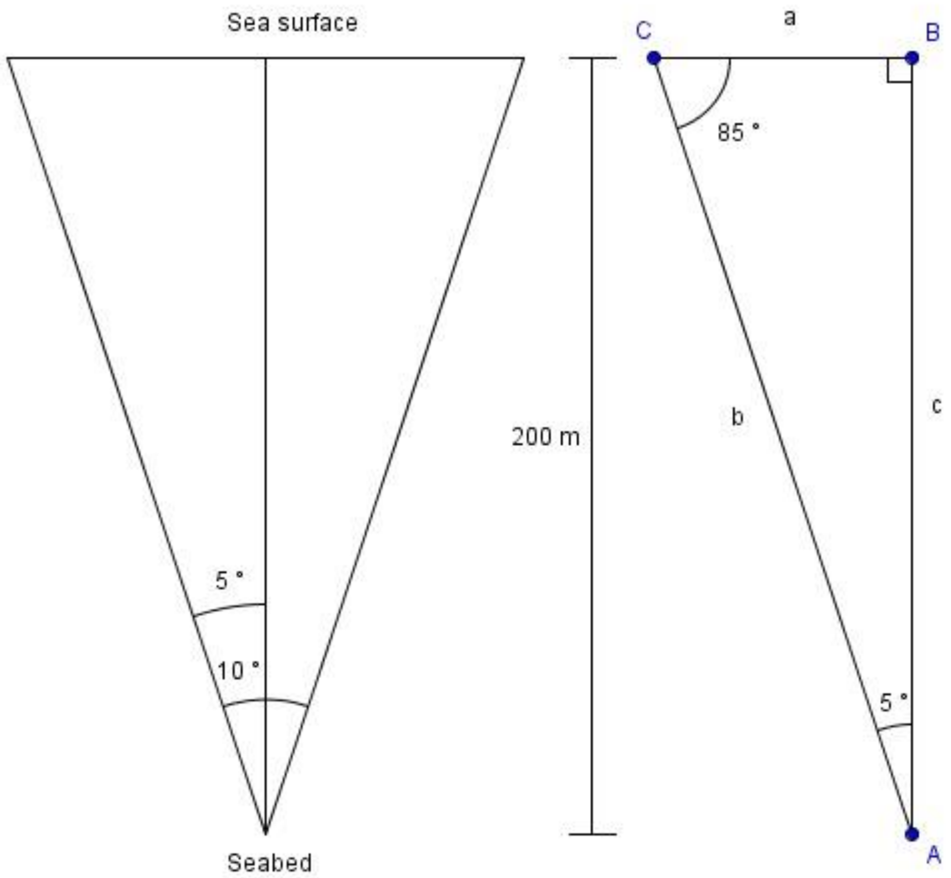


Figure 44: Illustration of the sound waves being sent from the seabed to the sea surface.

The angles are denoted with capital letters, and the side lengths are denoted with small letters on the far right in Figure 44. The sinus theorem is given by [88]:

$$\frac{\text{Sin } A}{a} = \frac{\text{Sin } B}{b} = \frac{\text{Sin } C}{c}$$

Since all the angles, and the side length c is known, one can reduce the above equation to:

$$\frac{\text{Sin } A}{a} = \frac{\text{Sin } C}{c}$$

which can be rearranged to:

$$a = \frac{\text{Sin } A}{\text{Sin } C} \cdot c$$

Inserting the known factors into this equation gives:

$$a = \frac{\text{Sin } (5)}{\text{Sin } (85)} \cdot 200 \text{ m} = 17{,}5 \text{ m}$$

which is half the width the sound waves will hit the sea surface with after 200 m. The full width of the sound waves after 200 m is therefore:

$$17{,}5 \text{ m} \cdot 2 = 35 \text{ m}$$

13.16 Load Cases

The parabola will experience different types of loads in its lifetime. These individual loads can affect the construction in various ways. One should apply the safety factor after the worst-case scenario, as the parabola should tolerate any potential load case. The basic load cases in Table 18 should be considered when designing the construction of the parabola. According to Kongsberg Maritime, products experiencing water pressure should have a safety factor of 1.2, while mechanical strength of components being lifted should have a safety factor from $3 - 5$. The parabola will be lowered down to-, and lifted up from the sea surface, and its applied lifting components will require this safety factor.

Table 18: Load cases.

Load Case	Type of Load	Component Effected	Safety Factor
Storage on transport vessel	Constant	Entire structure	1.2
Lifting in air	Varying	Lifting hooks - parabola	3-5
Lowering to seabed	Constant	Entire structure	1.5
Resting on seabed	Constant	Entire structure	1.2
Retrieval to surface	Constant	Entire structure	1.5
Set down on transport vessel	Varying	Lifting hooks - parabola	3-5

Based on the load cases in Table 18, it was decided to apply a safety factor of 1.5 for the main construction, and 4 for the lifting hooks.

13.17 Buoyancy

The calculation of the buoyancy is conducted to get the correct amount of Divinycell needed for the parabola to float. To start of this calculation, the total weight of the parts which does not float is needed. The weight of each part is listed in Table 19. The weights of the parts are found by using the model with correct material inserted in SolidWorks.

Table 19: Weight of the parts that do not float

Part	Weight
Circular connection	1.146 kg
Blade connection	$0.06287\text{ kg} \cdot 10\text{ pieces} = 0.6287\text{ kg}$
Rods	$0.09164\text{ kg} \cdot 3\text{ pieces} = 0.275\text{ kg}$
Housing	$0.68283\text{ kg (top)} + 0.66966\text{ kg (bottom)} = 1.3525\text{ kg}$
Sheet metal	$0.534\ kg$
Arms	$0.3114\text{ kg (lower arm)} + 0.242\text{ kg (upper arm)} = 0.5534\text{ kg}$
Transponder (total)	20.6 kg
Sum:	$\mathbf{27.9\ kg}$

The weight of the parts in table 19 represents a downward gravitational force that resists floatation. This force is:

$$F_G = mg$$

$$F_G = 27.9\text{ kg} \cdot 9.81\frac{\text{m}}{\text{s}^2} = 273.699\text{ N}$$

where F is force, m is the mass and g is the gravitational force. In order to get equilibrium, the gravity force must be equal to the buoyant force:

$$F_G = F_B = 273.699\text{ N}$$

This meant that the parts made of Divinycell need to provide a force equal to the gravitational force in order to keep the parabola I equilibrium. This force can be used to find out the amount of Divinycell needed for this purpose.

$$V_{Divinycell} = \frac{F_B}{\rho_{sw} \cdot g}$$

$$V_{Divinycell} = \frac{273.699 \text{ N}}{1025 \frac{\text{kg}}{\text{m}^3} \cdot 9.81 \frac{\text{m}}{\text{s}^2}} = 0.0272 \text{ m}^3$$

where V is the volume and ρ_{sw} is the density of seawater. This amount of Divinycell is equal to a weight of:

$$W_{Divinycell} = V_{Divinycell} \cdot \rho_{Divinycell}$$

$$W_{Divinycell} = 0.0272 \text{ m}^3 \cdot 250 \frac{\text{kg}}{\text{m}^3} = 6.8 \text{ kg}$$

where W is weight and $\rho_{Divinycell}$ is the density of Divinycell. According to KM, 15-20 kg force must be added to provide enough buoyancy. A force of 15 kg gives:

$$F_B = 15 \text{ kg} \cdot 9.81 \frac{\text{m}}{\text{s}^2} = 147.15 \text{ N}$$

Giving a total upwards force of:

$$F_B = 147.15 \text{ N} + 273.699 \text{ N} = 420.849 \text{ N}$$

This force increases the amount of needed Divinycell to:

$$V_{Divinycell} = \frac{420.849 \text{ N}}{1025 \frac{\text{kg}}{\text{m}^3} \cdot 9.81 \frac{\text{m}}{\text{s}^2}} = 0.042 \text{ m}^3$$

Which equals a weight of:

$$W_{Divinycell} = 0.042 \text{ m}^3 \cdot 250 \frac{\text{kg}}{\text{m}^3} = 10.5 \text{ kg}$$

13.18 Center of Buoyancy and Center of Gravity

The position of the center of gravity and center of buoyancy is essential to the stability of the parabola; these are calculated in this section. The design was simplified in order to conduct the calculation, giving approximate numbers.

13.18.1 Center of Gravity

In order to find the center of gravity of the parabola, the function of mass properties was used on various parts in SolidWorks to find their center of gravity. As the weight of the transponder is not correct in SolidWorks, the center of gravity of the assembly cannot be directly used. The parabola was divided into four sections, each having their own coordinate system and weight. The coordinates of the individual centers of gravity was therefore converted to a common coordinate system. The weight and coordinates of the individual centers of gravity can be seen in Table 20.

Table 20: Coordinates of the individual centers of gravity and weights of the different parabola sections.

Section	X	Y	Z	Weight
Circular connection assembly (Including circular connection, blade, blade connection and rods)	0	935.04 mm	0	2.91 kg
Remote transducer assembly (Including the remote transducer and housing)	0	1116.58 mm	0	5.45 kg
Transponder assembly (Including split transponder, tube and release mechanism)	0	322.56 mm	0	16.5 kg
Bottom assembly (Including hydraulic arm, sheet metal and bottom float collar	0	574.38 mm	0	10.76 kg

As can be seen from table 20 it is obvious that the center of gravity only will appear on the y-axis. This is due to the symmetry of the design. The formula for calculating the center of gravity on the y-axis is [89]:

$$CG_y = \frac{\sum(w \cdot y)}{\sum w}$$

where w is the weight of the section and y is the y-coordinate of the respective center of gravity. Using this formula to calculate the total center of gravity gives:

$$CG_y = \frac{(5.45\ kg \cdot 1116.58\ mm) + (2.91 kg \cdot 935.04\ mm) + (10.76\ kg \cdot 574.58\ mm) + (16.5\ kg \cdot 322.56\ mm)}{5.45 + 2.91 + 10.76 + 16.5}$$

$$CG = 570.215\ mm$$

This means that the center of gravity is located at the center of the structure. The calculation of the center of gravity does not include the load that is attached when it is descended to the seabed. This addition in the calculation will cause the center of gravity to be located at a lower point on the y-axis, depending on the weight of the load as well as the length of the rope connecting it to the transponder.

13.18.2 Center of Buoyancy

The center of buoyancy was found by using the theory behind Archimedes principle. An object that is immersed in a fluid experience a loss of weight. This is due to the buoyant or up thrust force that the fluid has on the object. This loss of weight is equal to the weight of the displaced fluid [90]. As stated earlier, the center of buoyancy is therefore at the location where the center of mass of the displaced fluid would be. As the displaced fluid can be seen at as a homogenous material, the center of the structure will be the center of buoyancy. A simplified design has been used to calculate this center. The parabola has been divided into the same four sections used for the calculation of CG. These are simplified as shown in Figure 45.

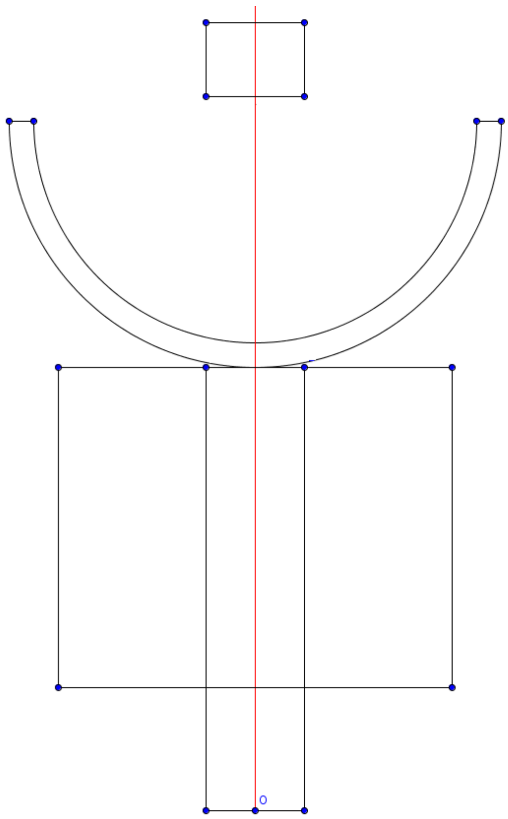


Figure 45: Simplified design.

It is obvious that the center of buoyancy is located on the y-axis due to the symmetry of the parabola. The formula used to find the y-coordinates of the center of the individual rectangular sections of the simplified design are [89]:

$$y = \frac{h}{2}$$

where h is the height of the section. For the parabola, a formula for a half circle was used, taking the outer diameter minus the inner diameter. This formula is [89]:

$$y = \frac{3}{16} \cdot d$$

where d is the diameter. These calculations have resulted in coordinates for each of the sections that again have been added to a common coordinate system. The volume of the different sections were found by using SolidWorks. These numbers are listed in Table 21.

Table 21: Coordinates of the different centers of buoyancy and volume of the individual sections of the parabola.

Section	X	Y	Z	Volume
Circular connection assembly (Including circular connection, blade, blade connection and rods)	0	1016.5 mm	0	0.0042 m^3
Remote transducer assembly (Including the remote transducer and housing)	0	1139.49 mm	0	0.00124 m^3
Transponder assembly (Including split transponder, tube and release mechanism)	0	860 mm	0	0.00714 m^3
Bottom assembly (Including hydraulic arm, sheet metal and bottom float collar	0	678 mm	0	0.03095 m^3

The formula for finding the center of a structure made of a homogenous material is [89]:

$$CB_y = \frac{\sum(V \cdot y)}{\sum V}$$

where V is the volume and y is the y-coordinate of the respective section. Using this formula and the numbers presented in Table… to calculate the center of buoyancy gives:

$$CB_y = \frac{(0.0042m^3 \cdot 1016.5\ mm) + (0.00124\ m^3 \cdot 1139.49\ mm) + (0.00714\ m^3 \cdot 860\ mm)}{(0.0042m^3 + \ 0.0042m^3 + 0.00714\ m^3 + 0.03095m^3)}$$

$$\frac{+(0.03095m^3\ \cdot 678\ mm)}{} = 753.66\ mm$$

This proves that the center of buoyancy is located above the center of gravity. As with CG, CB is also located on the y-axis, ensuring that the structure is kept stable. Since CB is located above

CG, the construction will not turn around when the load is released. As with CG, CB will also be lower down on the y-axis when the load is added to the transponder.

13.19 Simulation in SolidWorks

The displacement simulation caused by the hydrostatic pressure was conducted in order to investigate whether the cross section was sufficiently big enough to tolerate the depth of 200 m. The simulation with buoyancy force was conducted in order to investigate the changes caused by this force.

13.19.1 Displacement Caused by Hydrostatic Pressure

A uniform pressure of 2112000 Pa was applied to simulate the pressure the water exerts on the construction (The Hydrostatic Pressure), shown as red arrows in Figure 46. The whole model was constrained underneath in all degrees of freedom, as well as on an aluminum alloy sheet metal fastened to the front tip of the blade. The constraints are shown as green arrows in the figure. This is not an exact constraint, more to resemble the actual occurrence.

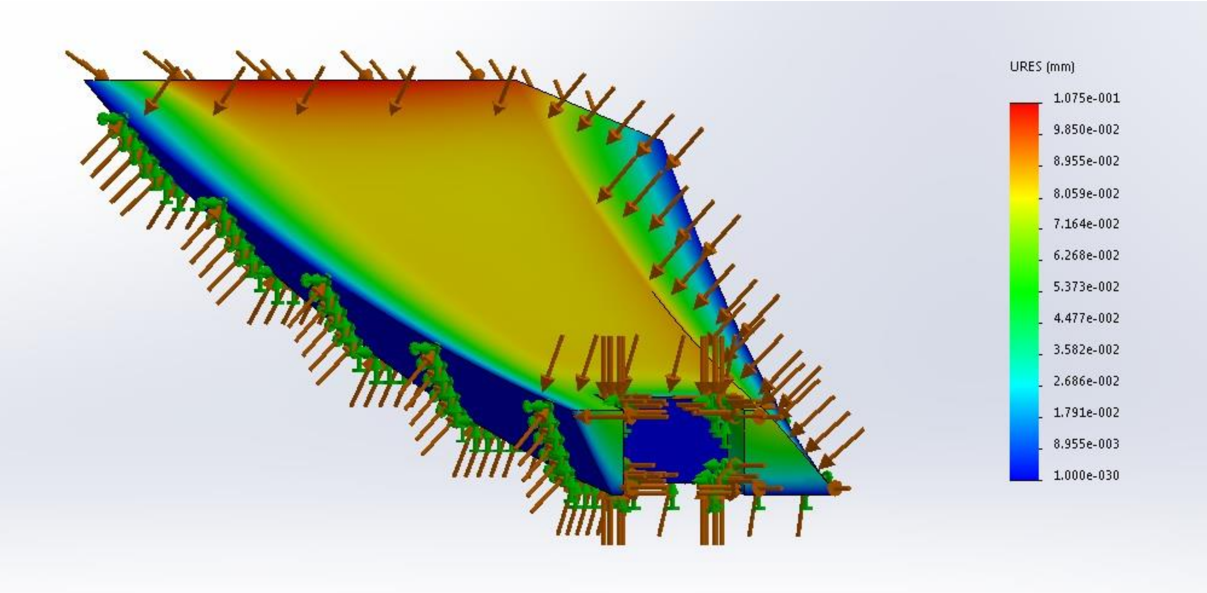


Figure 46: Displacement in SolidWorks Simulation.

Figure 46 shows the location of the largest displacement in red. The displacement is at its maximum, 0.107 mm, in a small section on the top edge of the parabola. The simulation indicates a small deformation caused by the hydrostatic pressure, and can therefore be ignored.

13.19.2 Von Mises Stress and Displacement Caused by the Buoyancy Force

The new simulation was conducted by applying a force of 421 N underneath-, and on top of the blade in positive y-direction, as shown in purple arrows in Figure 47. The force resembles the upward buoyancy force.

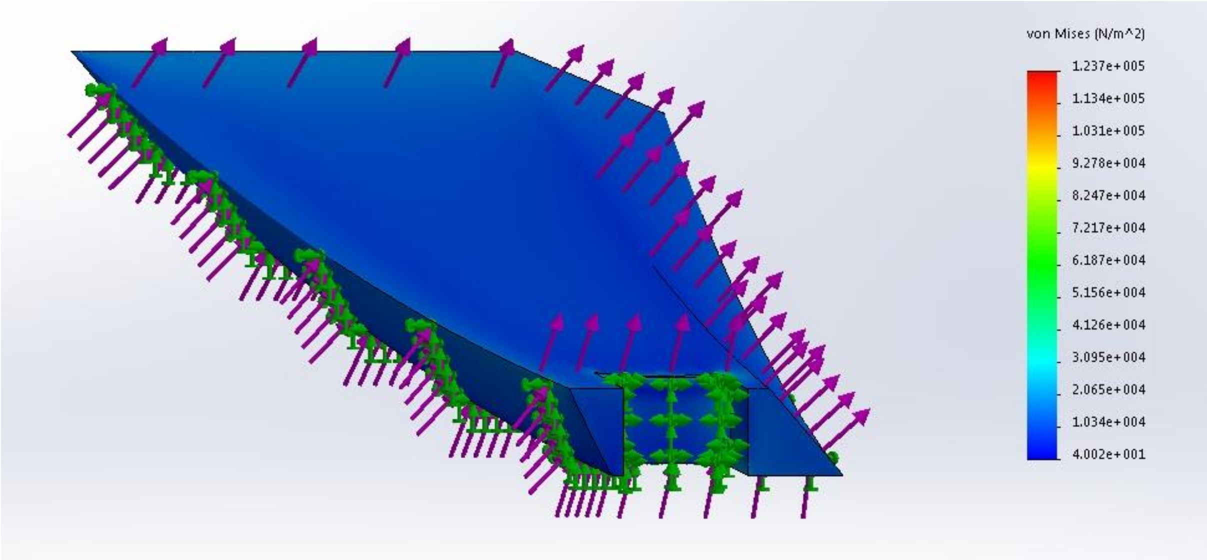


Figure 47: Von Mises Stress of Parabola-blade Simulation.

The whole model was constrained underneath in all degrees of freedom, as well as on the aluminum alloy sheet metal. The constraints are shown as green arrows in the figure.

The maximum Von Mises stress in the plot on the right of Figure 47 is $1.237 \cdot 10^5\ \mathrm{N/mm^2}$. This value is located on the aluminum alloy plate, which has a Yield Strength of $270 \cdot 10^6\ \mathrm{N/mm^2}$. It is therefore within the limit of a safe design.

By creating nodes in the location that shows higher Von Mises stress than the rest of the Divinycell construction, the location of the maximum Von Mises stress was found at $9.735 \cdot 10^4\ \mathrm{N/mm^2}$. The safety factor of the construction becomes

$$\frac{7.10 \cdot 10^6\ \mathrm{N/mm^2}}{9.735 \cdot 10^4\ \mathrm{N/mm^2}} = 72.9$$

Which is larger than necessary. The total deflection caused by the buoyancy force is at 0.003 mm at the same location as when simulating the hydrostatic pressure, as shown in Figure 48.

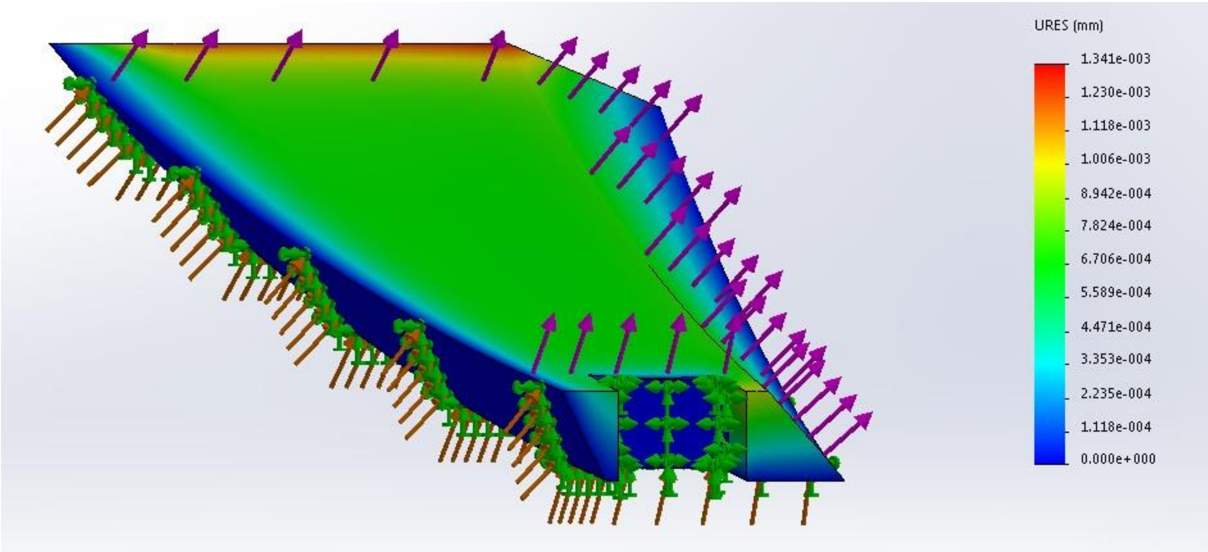


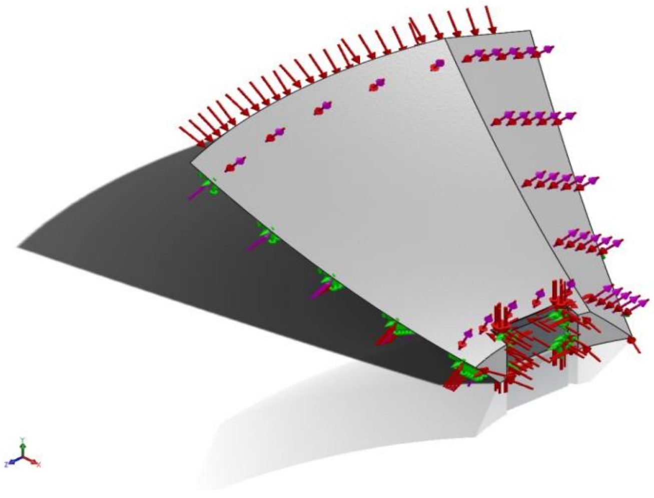
Figure 48: Deflection caused by the buoyancy force.

13.19.3 Conclusion

The deflection caused by the hydrostatic pressure was larger than that of the buoyancy force, and could therefore not be ignored even though the changes to its cross section is small enough to be ignored in itself. It was therefore decided to conduct a simulation with both forces present.

13.20 Simulation in SolidWorks

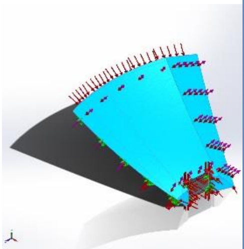
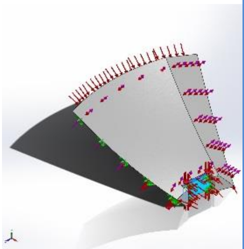
13.20.1 Model Information



Model name: Assembly Buoyancy and Hydrostatic Pressure

Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude2 	Solid Body	Mass:0.0967198 kg Volume:0.000386879 m^3 Density:250 kg/m^3 Weight:0.947854 N	C:\Users\109507\Solidworks\Blade 1.SLDPRT May 03 20:43:07 2017
Boss-Extrude1 	Solid Body	Mass:0.010773 kg Volume:3.99e-006 m^3 Density:2700 kg/m^3 Weight:0.105575 N	C:\Users\109507\Solidworks\Hinge.SLDPRT May 18 14:34:53 2017

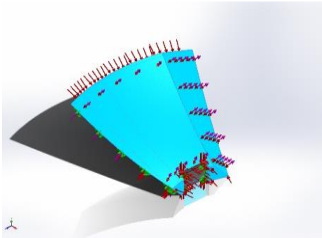
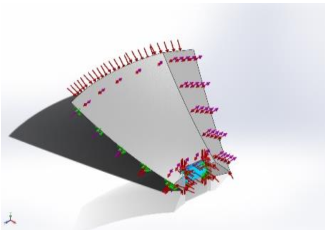
13.20.2 Study Properties

Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	On
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (C:\Users\109507\Helene\Simuleringer\Buoyancy)

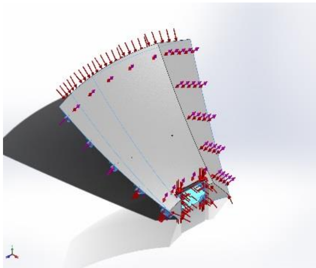
13.20.3 Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

13.20.4 Material Properties

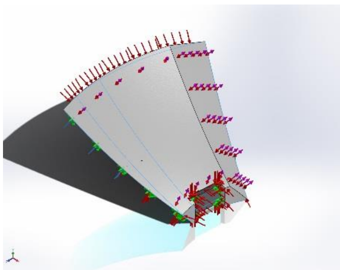
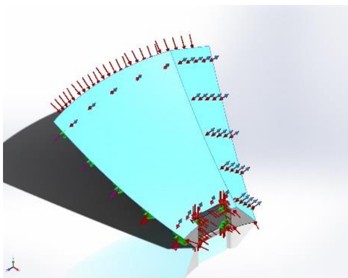
Model Reference	Properties	Components
	Name: **Dyvinicell** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Yield strength: **7.1e+006 N/m^2** Tensile strength: **8.6e+006 N/m^2** Compressive strength: **6.65e+006 N/m^2** Elastic modulus: **3.75e+008 N/m^2** Poisson's ratio: **0.3** Mass density: **250 kg/m^3** Shear modulus: **8.9e+007 N/m^2**	**SolidBody 1(Cut-Extrude2)(Blade 1-1)**
Curve Data:N/A		
	Name: **6082-T6** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Yield strength: **2.7e+008 N/m^2** Tensile strength: **3.3e+008 N/m^2** Elastic modulus: **7.1e+010 N/m^2** Poisson's ratio: **0.33** Mass density: **2700 kg/m^3** Thermal expansion coefficient: **2.4e+011 /Kelvin**	**SolidBody 1(Boss-Extrude1)(Hinge-1)**
Curve Data:N/A		

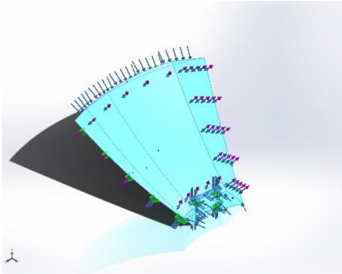
13.20.5 Load Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** **4 face(s)** **Type:** **Fixed Geometry**

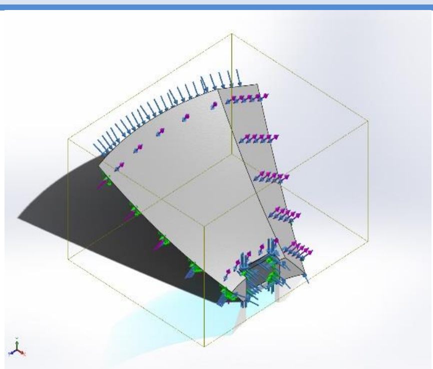
Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	**1249.65**	**-681.197**	**212.039**	**1438.96**
Reaction Moment(N.m)	**0**	**0**	**0**	**0**

Load name	Load Image	Load Details
Force-2		**Entities:** **3 face(s)** **Type:** **Apply normal force** **Value:** **421 N**
Force-3		**Entities:** **2 face(s)** **Type:** **Apply normal force** **Value:** **-421 N**

Pressure-1		**Entities:** **16 face(s)** **Type:** **Normal to selected face** **Value:** **2.112e+006** **Units:** **N/m^2** **Phase Angle:** **0** **Units:** **deg**

13.20.6 Contact Information

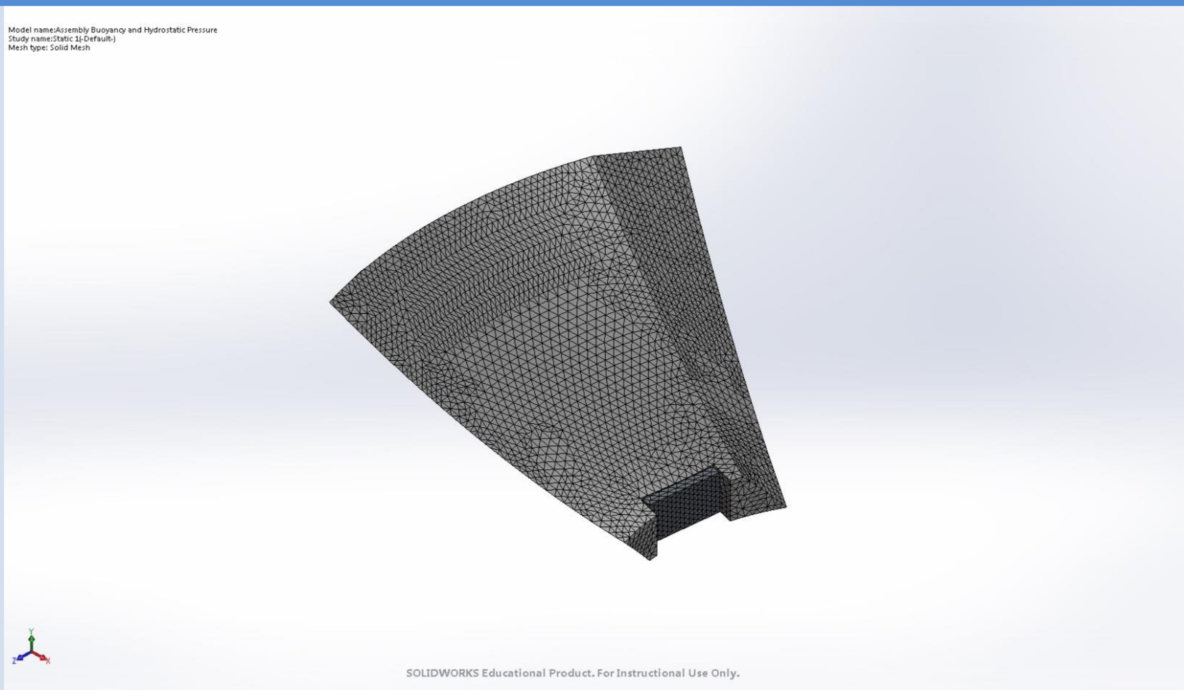
Contact	Contact Image	Contact Properties
Global Contact		**Type:** **Bonded** **Components:** **1 component(s)** **Options:** **Compatible mesh**

13.20.7 Mesh Information

Mesh type	Solid Mesh
Mesher Used:	Curvature-based mesh
Jacobian points	4 Points
Maximum element size	3.65674 mm
Minimum element size	3.65674 mm
Mesh Quality Plot	High
Remesh failed parts with incompatible mesh	Off

13.20.7.1 Mesh Information Details

Total Nodes	94018
Total Elements	62892
Maximum Aspect Ratio	39.006
% of elements with Aspect Ratio < 3	99.5
% of elements with Aspect Ratio > 10	0.0239
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:02
Computer name:	S-HVE9654



13.20.8 Resultant Forces

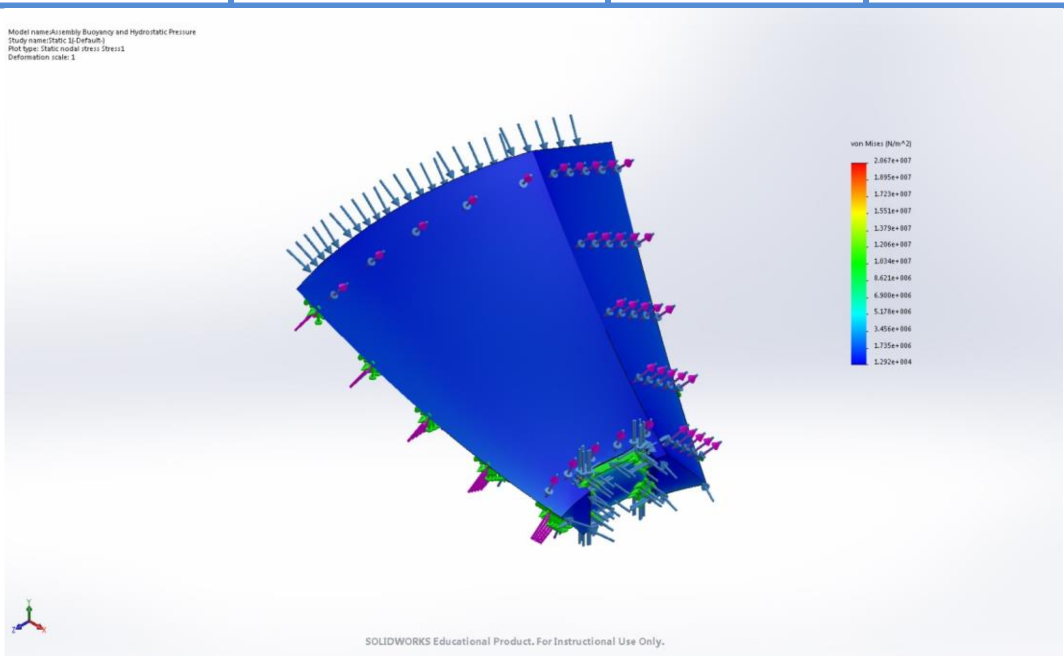
13.20.8.1 Resultant Forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	1249.65	-681.197	212.039	1438.96
Reaction Moments					

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

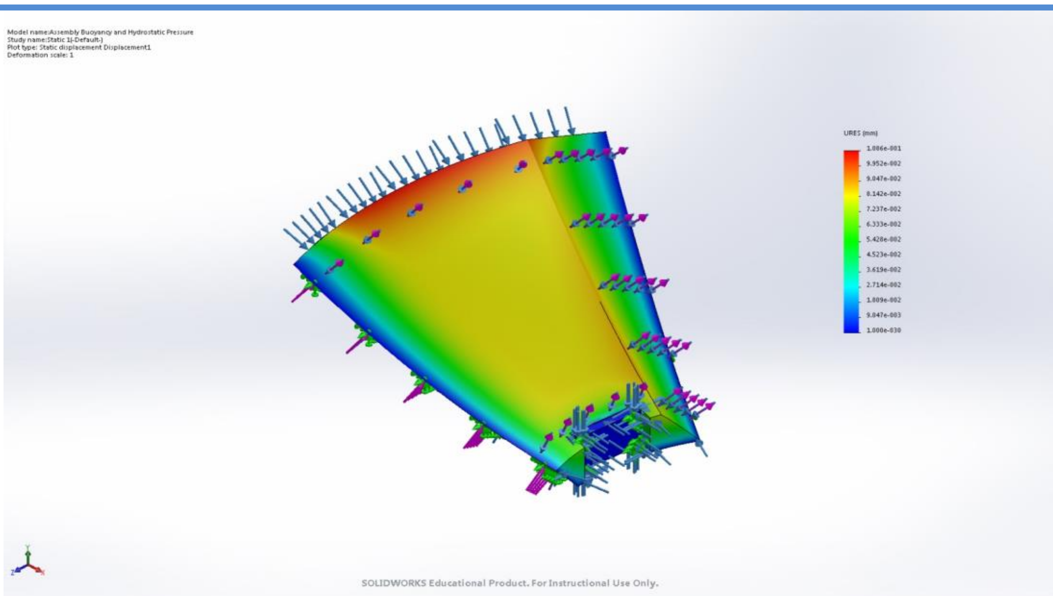
13.20.9 Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	1.292e+004N/m^2 Node: 12984	2.067e+007N/m^2 Node: 92338



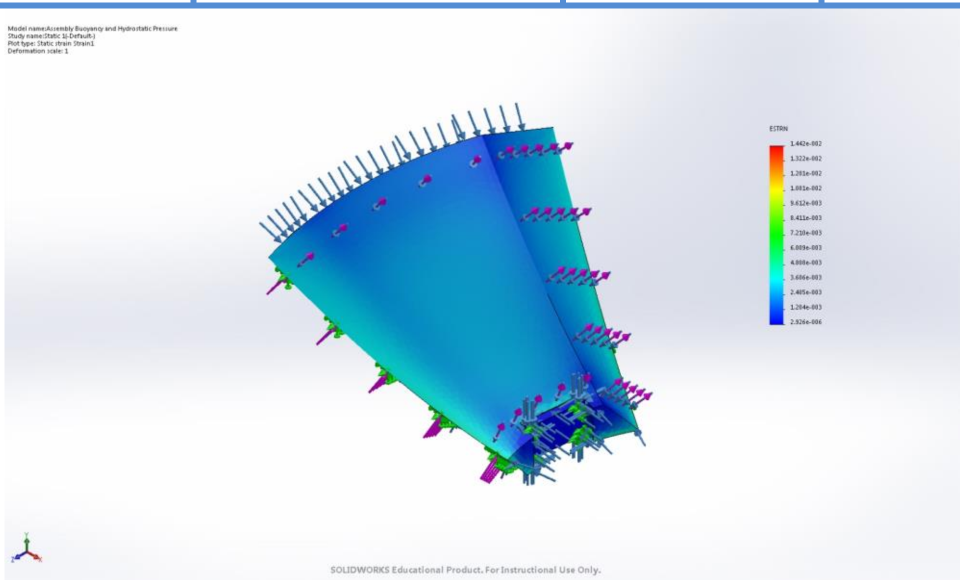
Assembly Buoyancy and Hydrostatic Pressure-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+000mm Node: 3	1.086e-001mm Node: 145



Assembly Buoyancy and Hydrostatic Pressure-Static 1-Displacement-Displacement1

Name	**Type**	**Min**	**Max**
Strain1	ESTRN: Equivalent Strain	2.926e-006 Element: 62269	1.442e-002 Element: 18404



Assembly Buoyancy and Hydrostatic Pressure-Static 1-Strain-Strain1

13.21 Simplified Analytical Calculations

The calculations in this section is based on the Unit Load Method from the book *Fasthetslære* by Fridtjov Irgens [91]. SolidWorks show the biggest displacement occurring at the top end of the blade. A simplified beam was retracted from the blade for calculations, as shown in Figure 49.

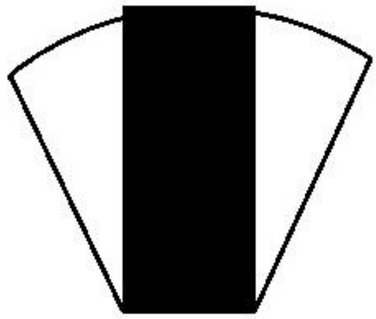


Figure 49: The parabola in white, and the retracted beam in black.

The beam has been simplified to the image in Figure 50 with F being the buoyancy force beneath the beam. The beam is divided at two thirds of its length (B) by a constraint that is supposed to resemble one of the hydraulic arms that holds the blades down. In reality, the blades will hold each other down the whole distance A – C, since they overlap each other. The total deflection in this simplified calculation will therefore not be exact, but can give an idea of whether the deflection is small or large. The beam is also constrained on its left side, as the blade would be in reality. The hydrostatic pressure is disregarded in this calculation, as it affects both sides of the beam, hence counteracts each other.

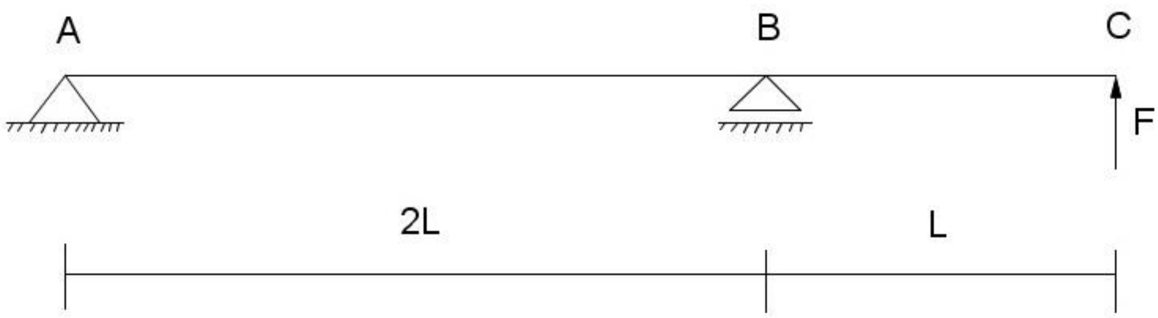


Figure 50: The simplified beam. Figure created in GeoGebra.

The work equation used in the Unit Load Method is

$$1 \cdot \delta = \int \frac{\widetilde{M}M}{EI} ds \qquad (1)$$

where δ is the deflection, $\widetilde{M}$ is the bending moment due to the unit load $\tilde{F}$, and M is the bending moment due to the force F. For straight beams, equation (1) can be written as

$$\int_0^L \frac{M_i M_k}{EI} dx = \alpha \cdot ab \frac{L}{EI} \qquad (2)$$

where L is the length shown in Figure 50, a and b is the extreme values (the biggest values for M and M* in Figure 51) for the M_i- and M_k- diagram in the book. α is found in the same diagram.

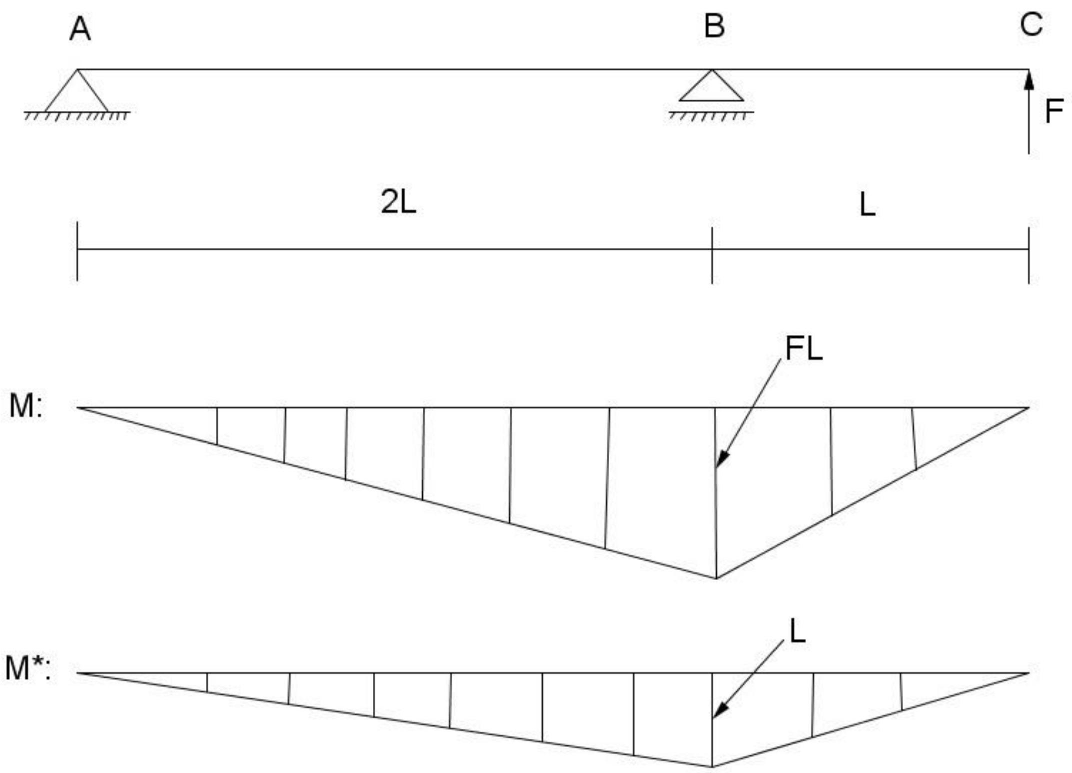


Figure 51: Section AB of the beam. Created in GeoGebra.

Merging equation (1) and (2):

$$1 \cdot \delta = \int_A^B + \int_B^C \frac{\widetilde{M}M}{EI} ds$$

$$1 \cdot \delta = \frac{1}{3} \cdot L \cdot FL \cdot \frac{2L}{EI} + \frac{1}{3} \cdot L \cdot FL \cdot \frac{L}{EI}$$

The total deflection of the beam becomes

$$\delta = \frac{2FL^3}{3EI} + \frac{FL^3}{3EI} = \frac{FL^3}{EI}$$

where

$$L = \frac{0.13}{3} = \frac{13}{300}\ \text{m}$$

$$E = 376 \cdot 10^6\ \text{Pa}$$

and L is one third the length of the beam, F is the buoyancy force, E is the elastic modulus of the material, and I is the moment of inertia of the beam. The moment of inertia is [92]:

$$I = \frac{bh^3}{12} = \frac{0.07 \cdot 0.02^3}{12} = 4.67 \cdot 10^{-8}\ \text{m}^4$$

Where h is the height of the beam as well as the thickness of the blade, and b is the width of the beam as well as the bottom width of the blade. The total deflection of the beam is

$$\delta = \frac{FL^3}{EI} = \frac{421 \cdot \left(\frac{13}{300}\right)^3}{\left(376 \cdot 10^6\right)\left(4.67 \cdot 10^{-8}\right)} = 1.95 \cdot 10^{-3}\ \text{m}$$

or 1.95 mm upward in C.

13.21.1 Conclusion

The total deflection in this simplified calculation is not exact, as each blade would be constrained in their folded position since they overlap each other. What the result of this calculation can do, is to give an indication whether the deflection is small or large.

A deformation of 1.95 mm is small, but in reality slightly too big as it disrupts the curve, hence the reflection in the parabola. Since the blades overlap and holds each other down at the entire length of the beam, including where the biggest deflection occurs, this deflection will be smaller in reality. The deflection in SolidWorks show a better picture of the reality, with a maximum deflection at the same location as in this calculation, but only at 0.1 mm.

13.22 Renderings of the Final Design

More detailed renderings of the final design is shown in the figures below Figure 52 shows the top part of the design. It has a smooth continuous parabolic curve when unfolded that reflects sound waves to the transducer, which is held in place by a housing and three rods. The hydraulic arms are shown underneath the blades, with a more detailed view in Figure 53 These act as a support for two of the blades, constraining the remaining blades on either side because they overlap each other.

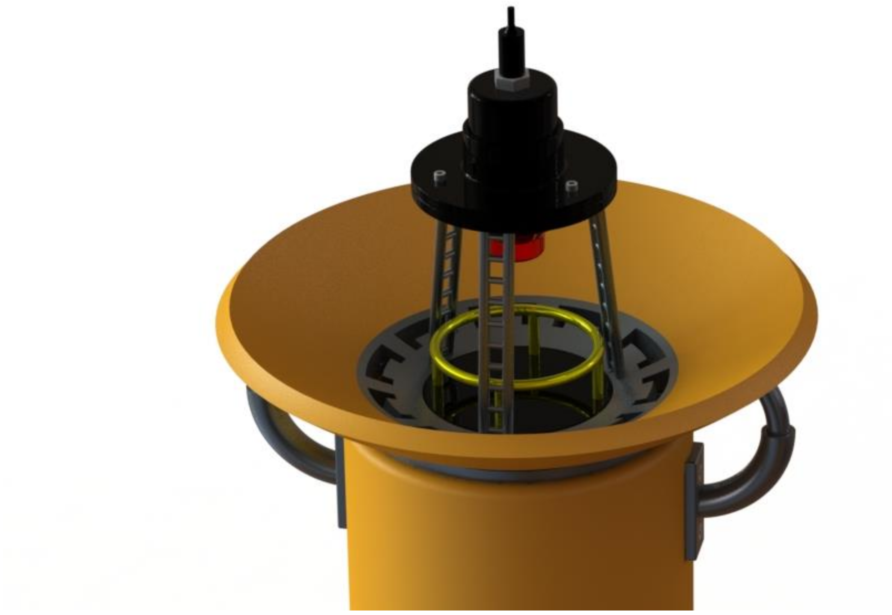


Figure 52: Top of the design. Created in SolidWorks.

Figure 53: Detailed view of hydraulic arm. Created in SolidWorks.

Figure 54 shows the transducer being held in the correct position by a housing that is divided into two parts, and screwed together. The rods are fastened to the circular connection as shown in Figure 55. The blade connections are fastened to the blades from underneath.

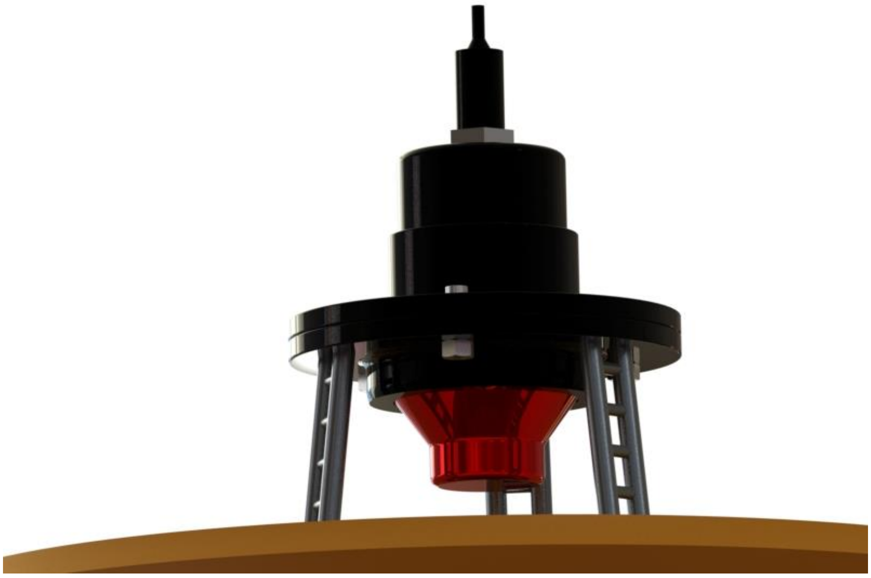


Figure 54: Housing and rods keeping the transducer in the correct position. Created in SolidWorks.

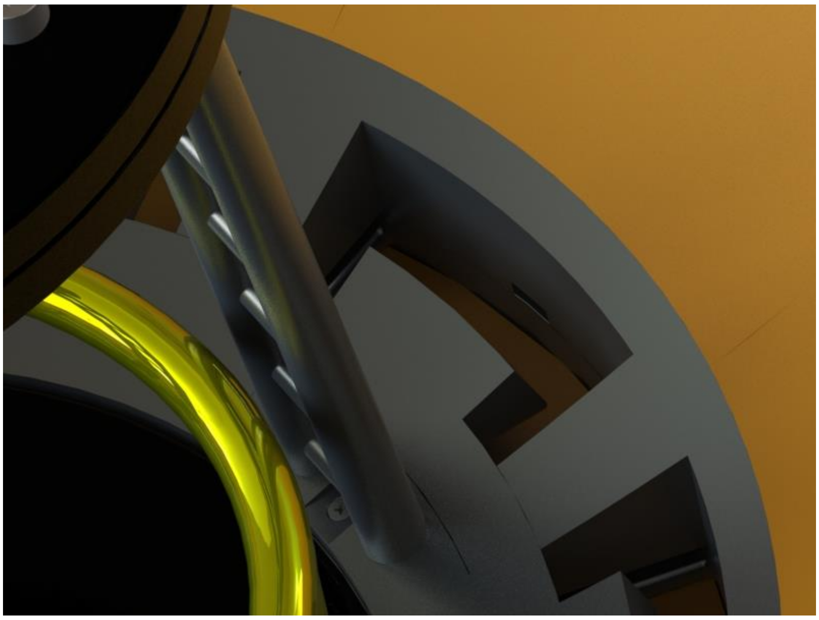


Figure 55: Detailed view of the circular and blade connection. Created in SolidWorks.

The bottom of the parabola is shown in Figure 56. The sheet metal is located beneath the transponder and bottom float collar, and prevents the transponder from releasing. The transponder is fastened by using its existing holes. Lifting hooks used to lower and retrieve the parabola from/to the water are screwed through the sheet metal and into the Divinycell material, securing it to the structure. The release mechanism is passed through a hole in the sheet metal, enabling this to be the release mechanism for the whole product. A full length view of the final design is shown in Figure 57.

Figure 56: Bottom of the parabola. Created in SolidWorks.

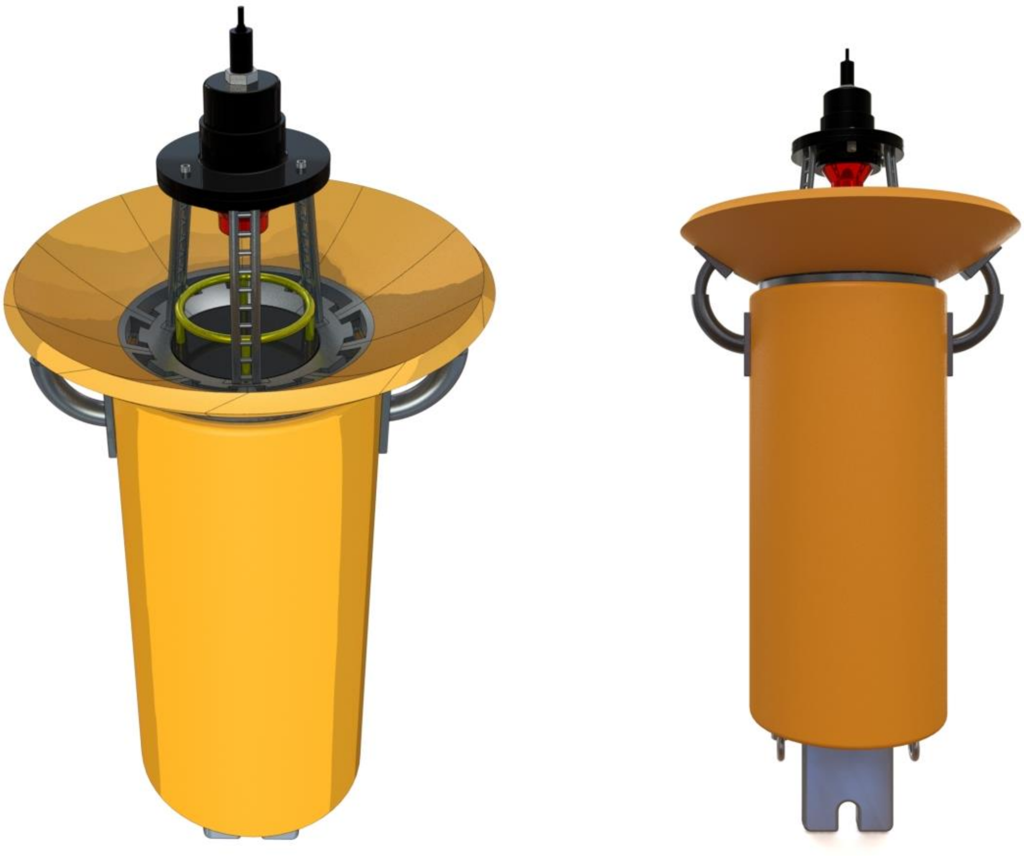


Figure 57: Full length view of the final design. Created in SolidWorks

13.23 3D Printed Prototype

Figure 58 shows a 3D printed prototype of the parabola. It has been scaled down to a diameter of 18 cm, and a thickness of 2 mm. The bottom part of the parabola, as well as the structure supporting the transducer have been neglected in order to obtain a simple and less time consuming 3D print. A small support is added underneath in order to make it steady as well as easier to hold.

In order to print the parabola, the printer made a supporting structure on the inside of the parabola, causing some irregularities in the curvature which can be neglected when reviewing the result. The 3D print not only shows a curvature that is well calculated, but it also shows a gracious curve which will enhance the overall look of the design. The making of a physical 3D printed prototype was useful in order to observe what the parabola would look like in real life.

Figure 58: 3D printed prototype

13.24 Technical Drawings

Technical drawings of the parabola parts are shown in Figure 59 – 68.

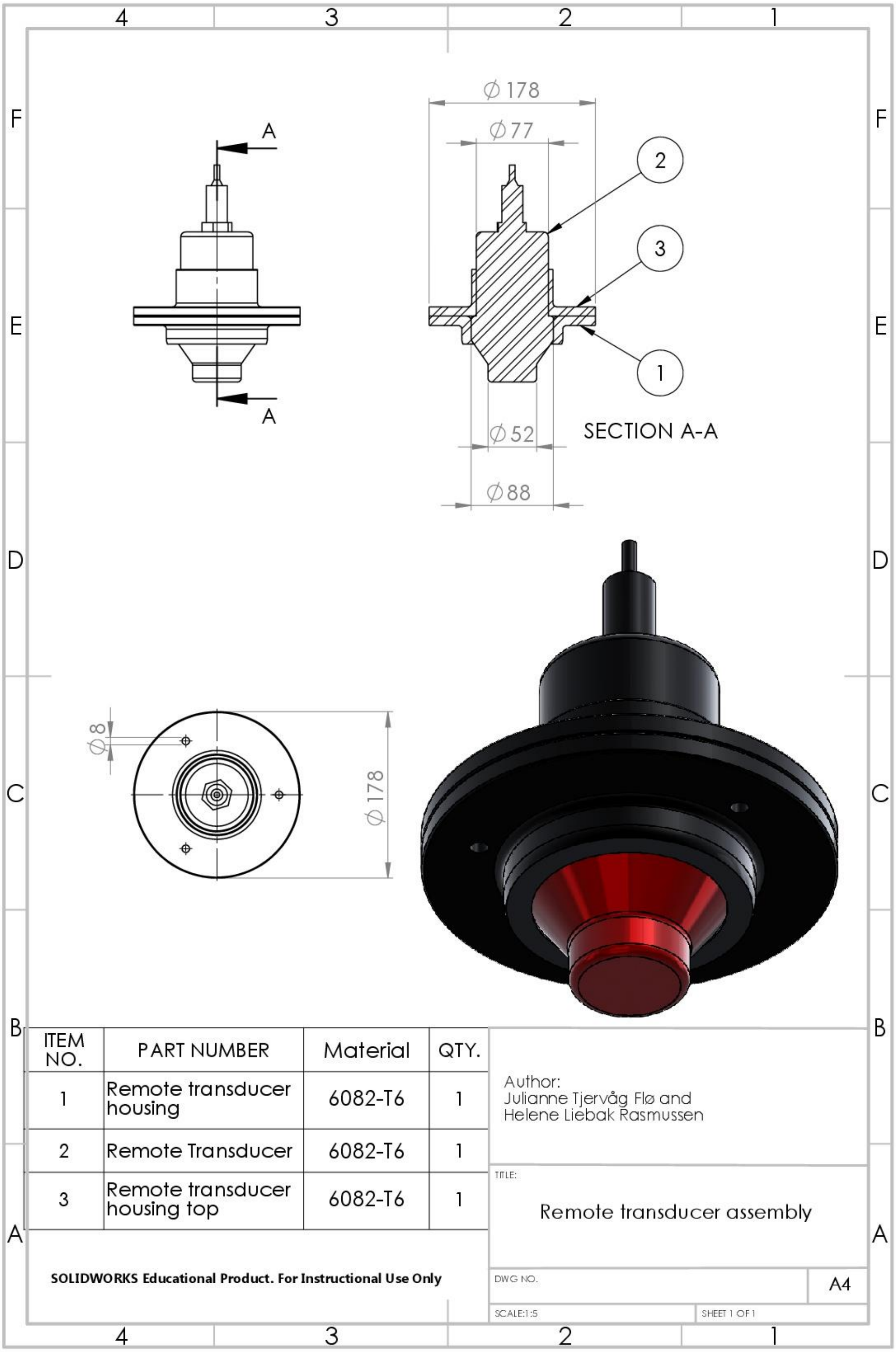


Figure 59: Technical drawing of the remote transducer assembly. Created in SolidWorks.

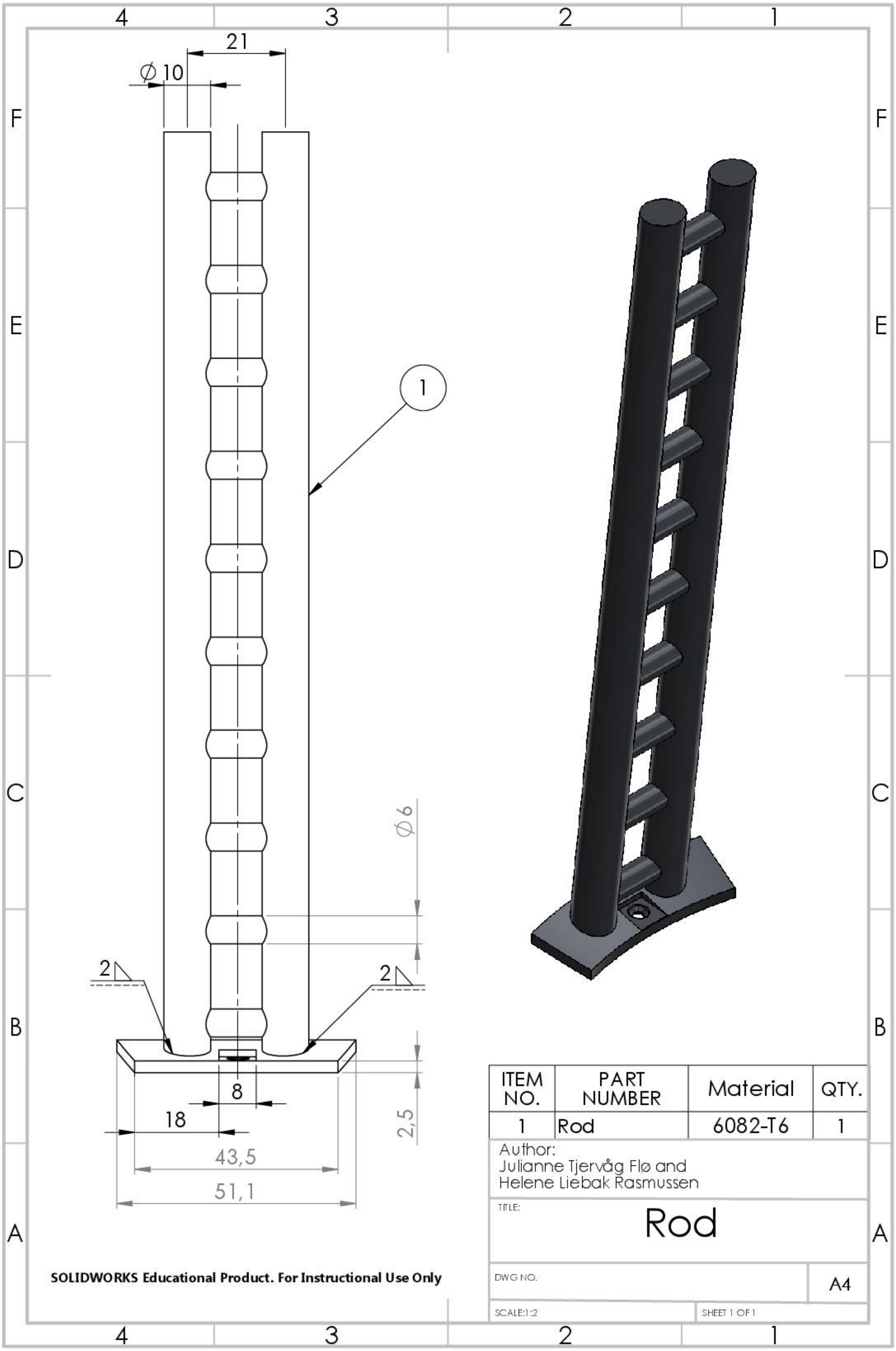


Figure 60: Technical drawing of the rod. Created in SolidWorks.

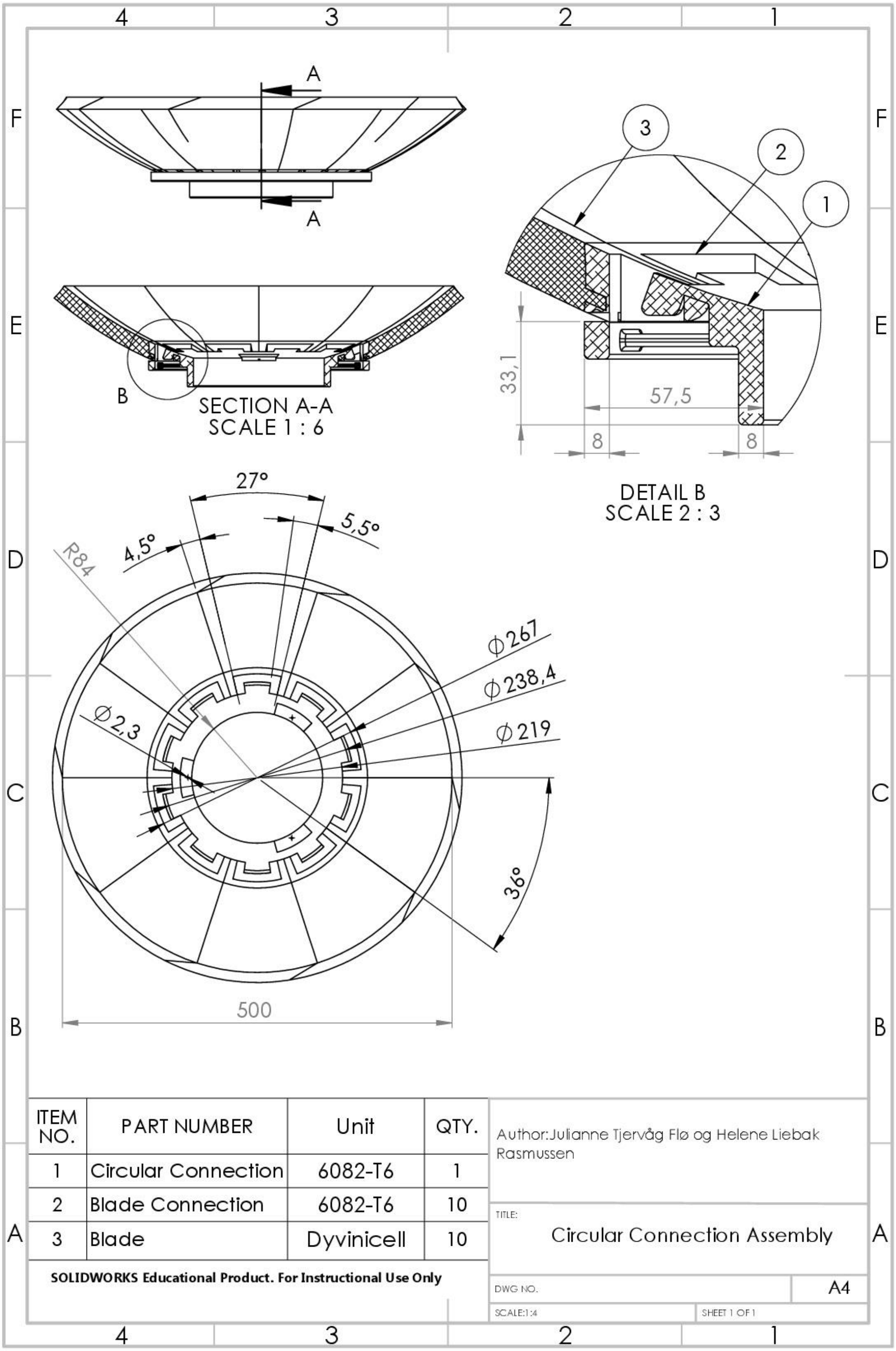


Figure 61: Technical drawing of The circular connection, blade and blade connection. Created in SolidWorks.

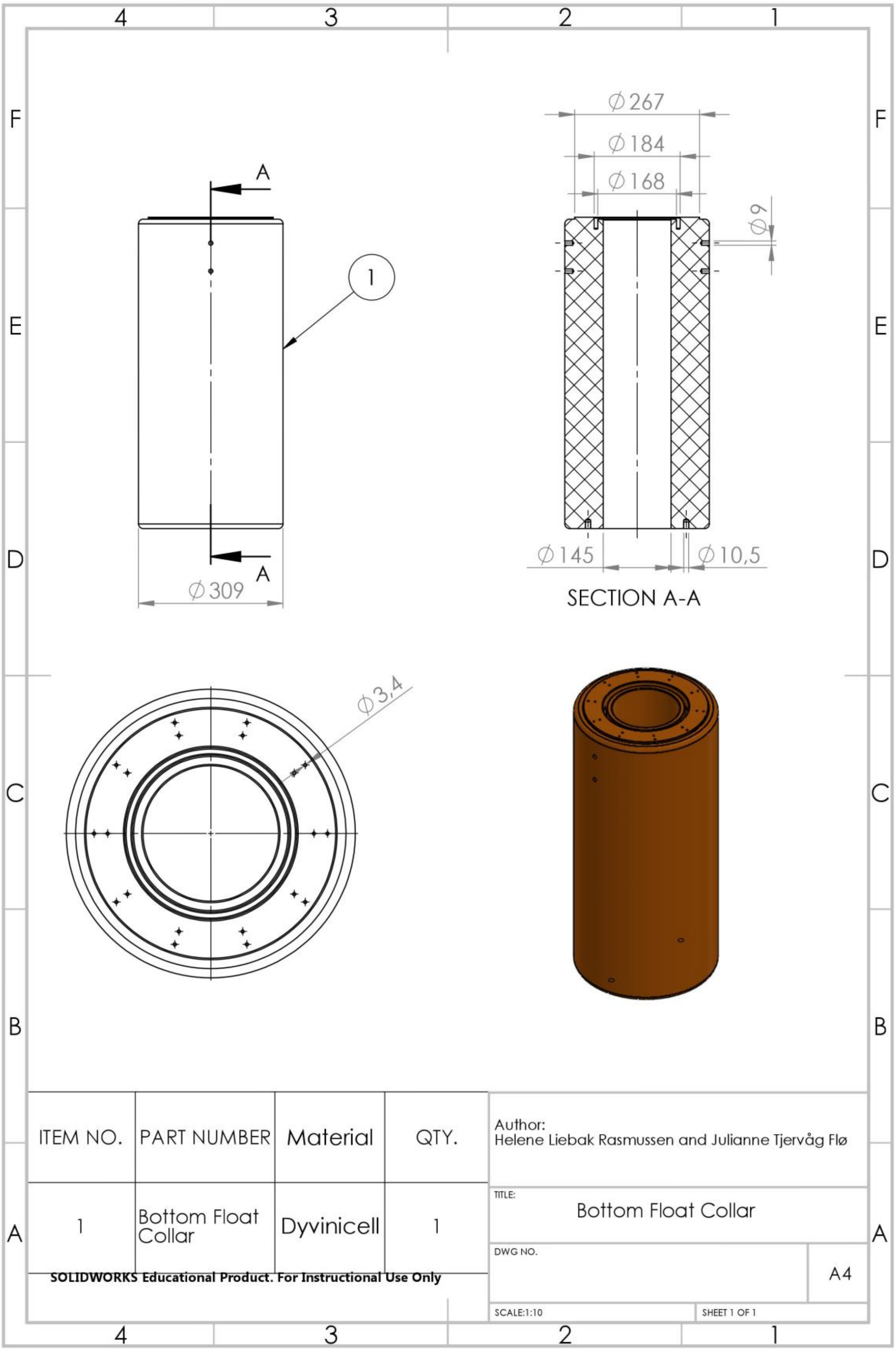


Figure 62: Technical drawing of the bottom float collar. Created in SolidWorks

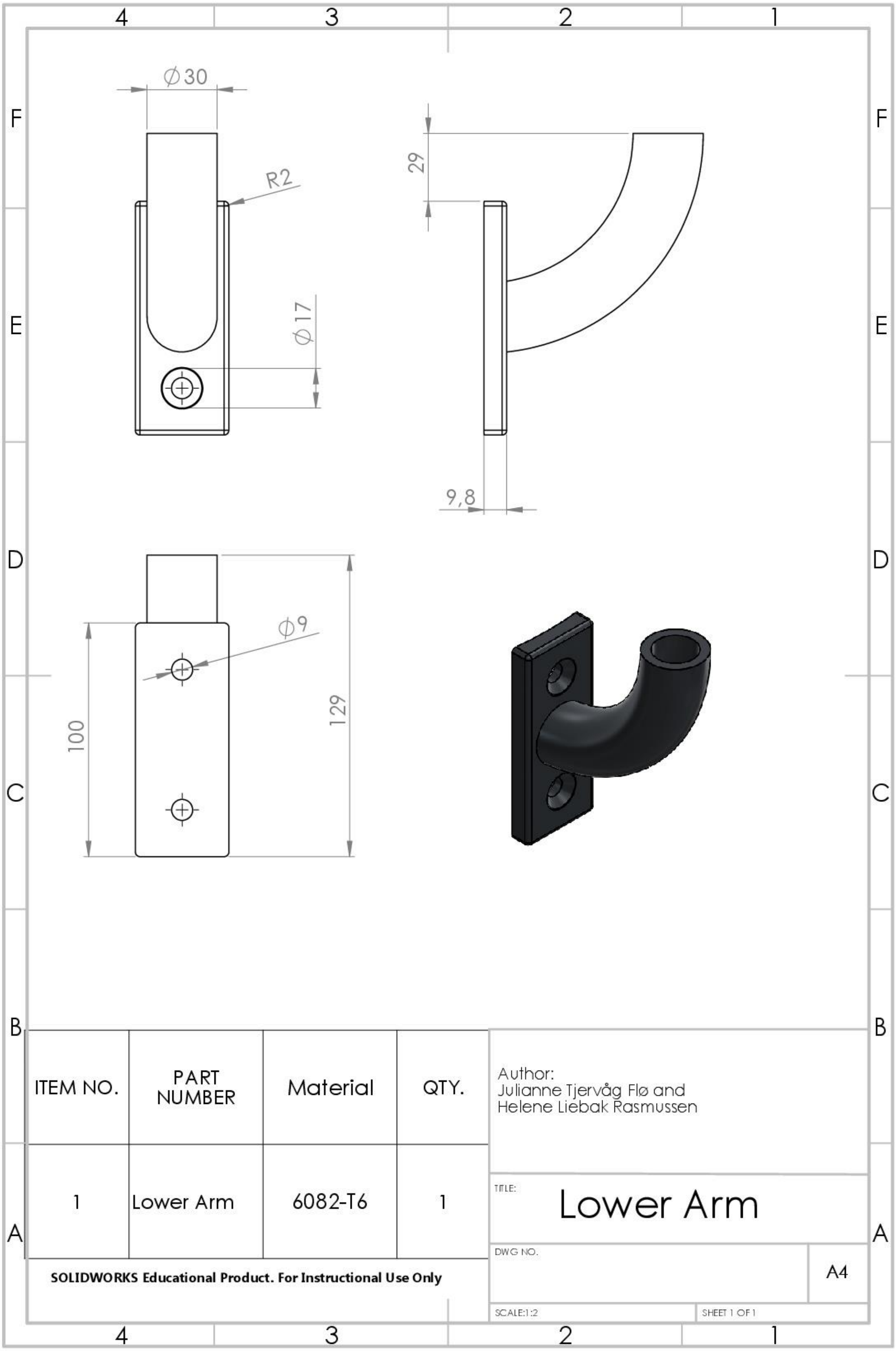


Figure 63: Technical drawing of the lower arm. Created in SolidWorks.

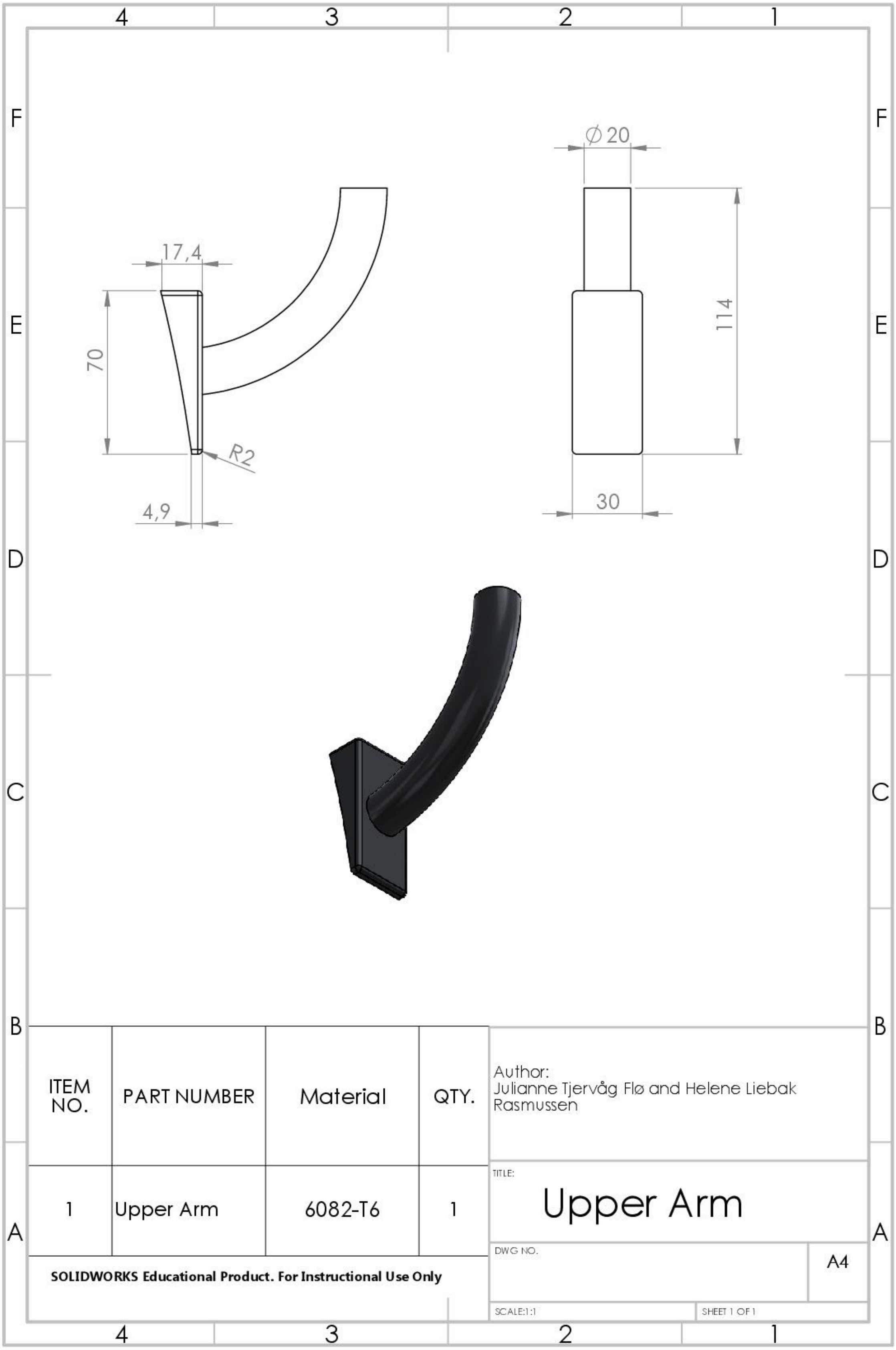
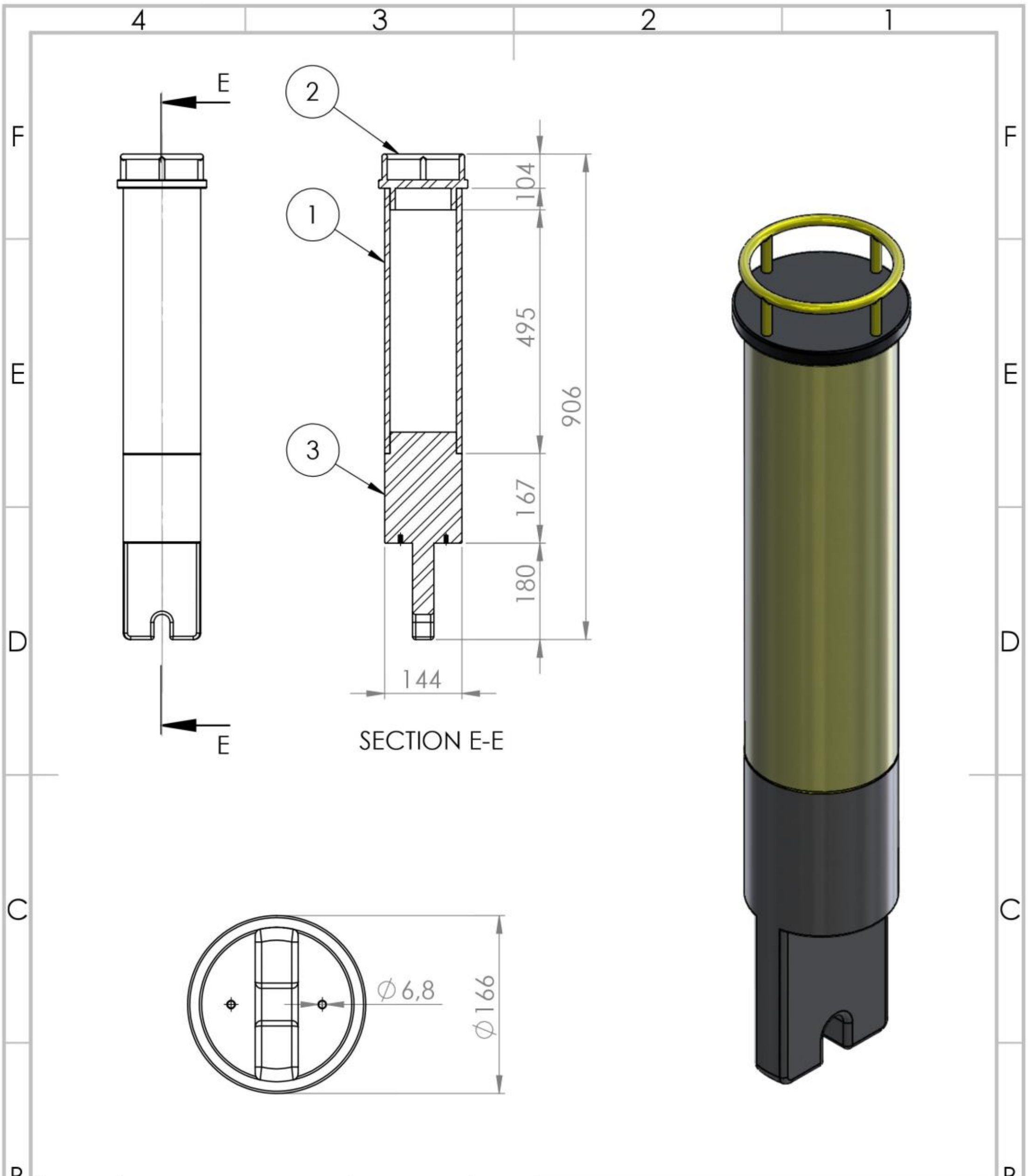


Figure 64: Technical drawing of The upper arm. Created in SolidWorks.



ITEM NO.	PART NUMBER	Material	QTY.
1	Tube	6082-T6	1
2	Split Transponder	6082-T6	1
3	Release mechanism	6082-T6	1

Author:
Helene Liebak Rasmussen and Julianne Tjervåg Flø

TITLE:

Assembly Transponder

SOLIDWORKS Educational Product. For Instructional Use Only

DWG NO.

A4

SCALE:1:10

SHEET 1 OF 1

Figure 65: Technical drawing of the transponder. Created in SolidWorks.

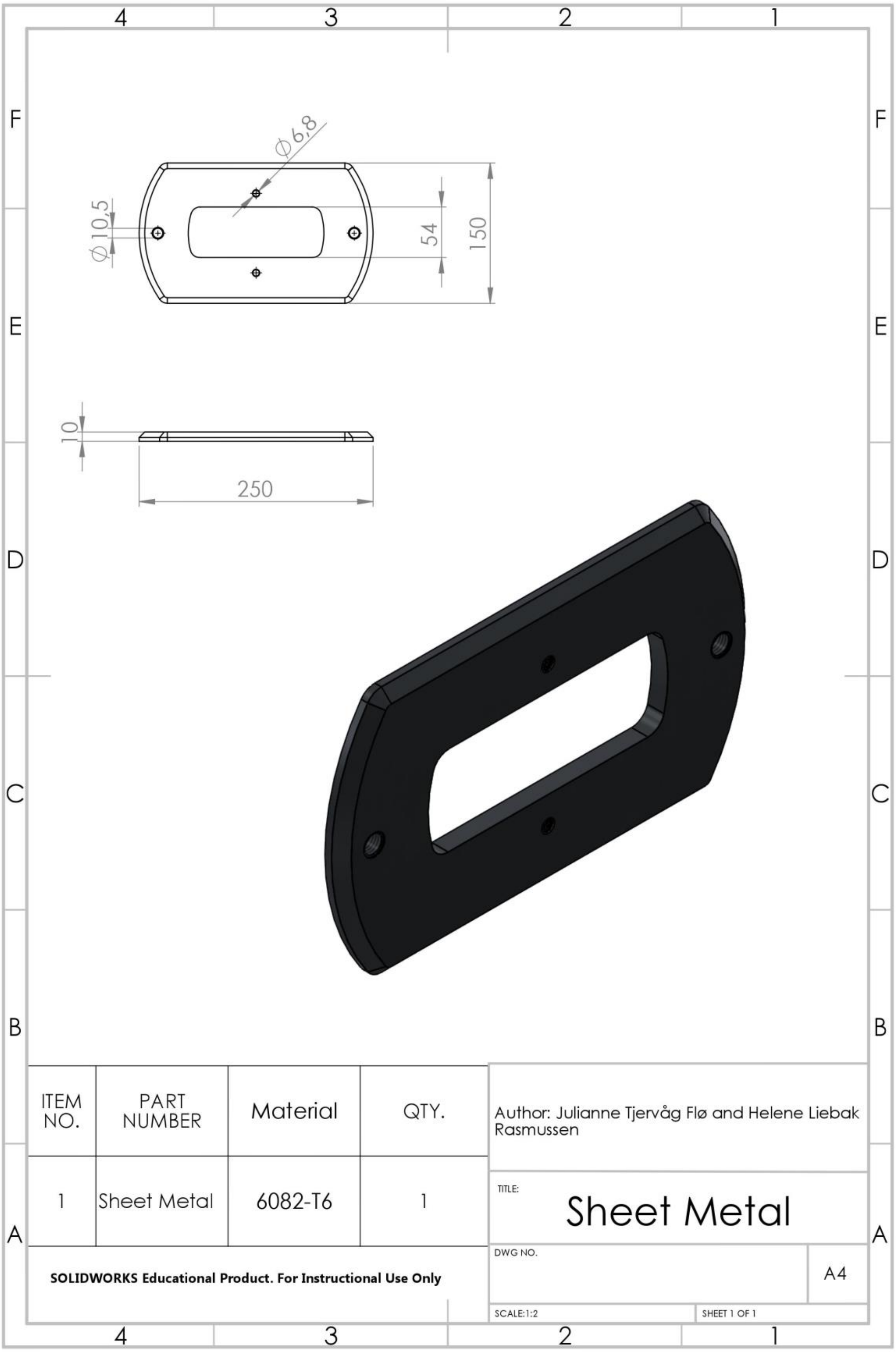


Figure 66: Technical drawing of the sheet metal. Created in SolidWorks.

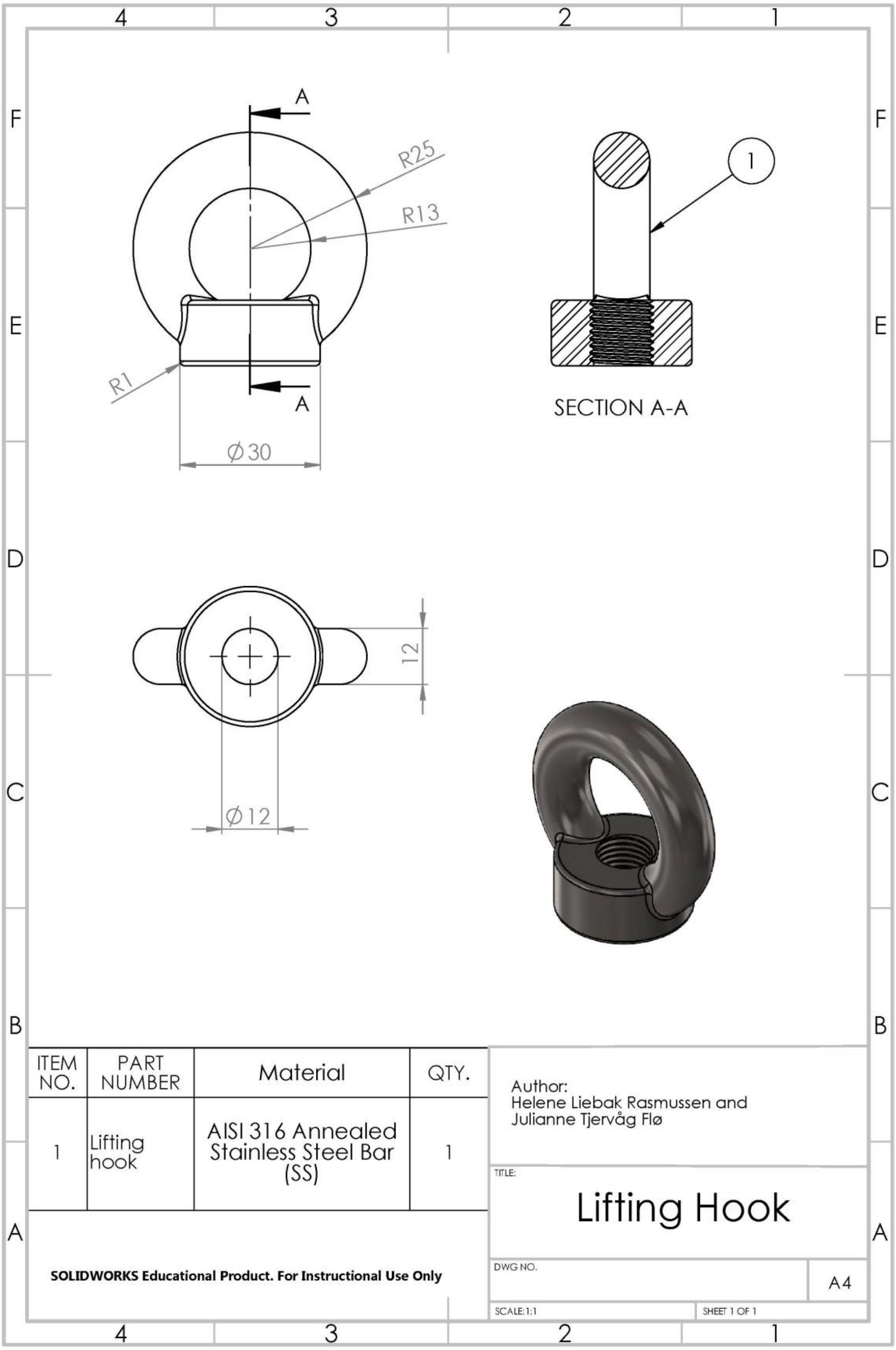


Figure 67: Technical drawing of the lifting hook. Created in SolidWorks.

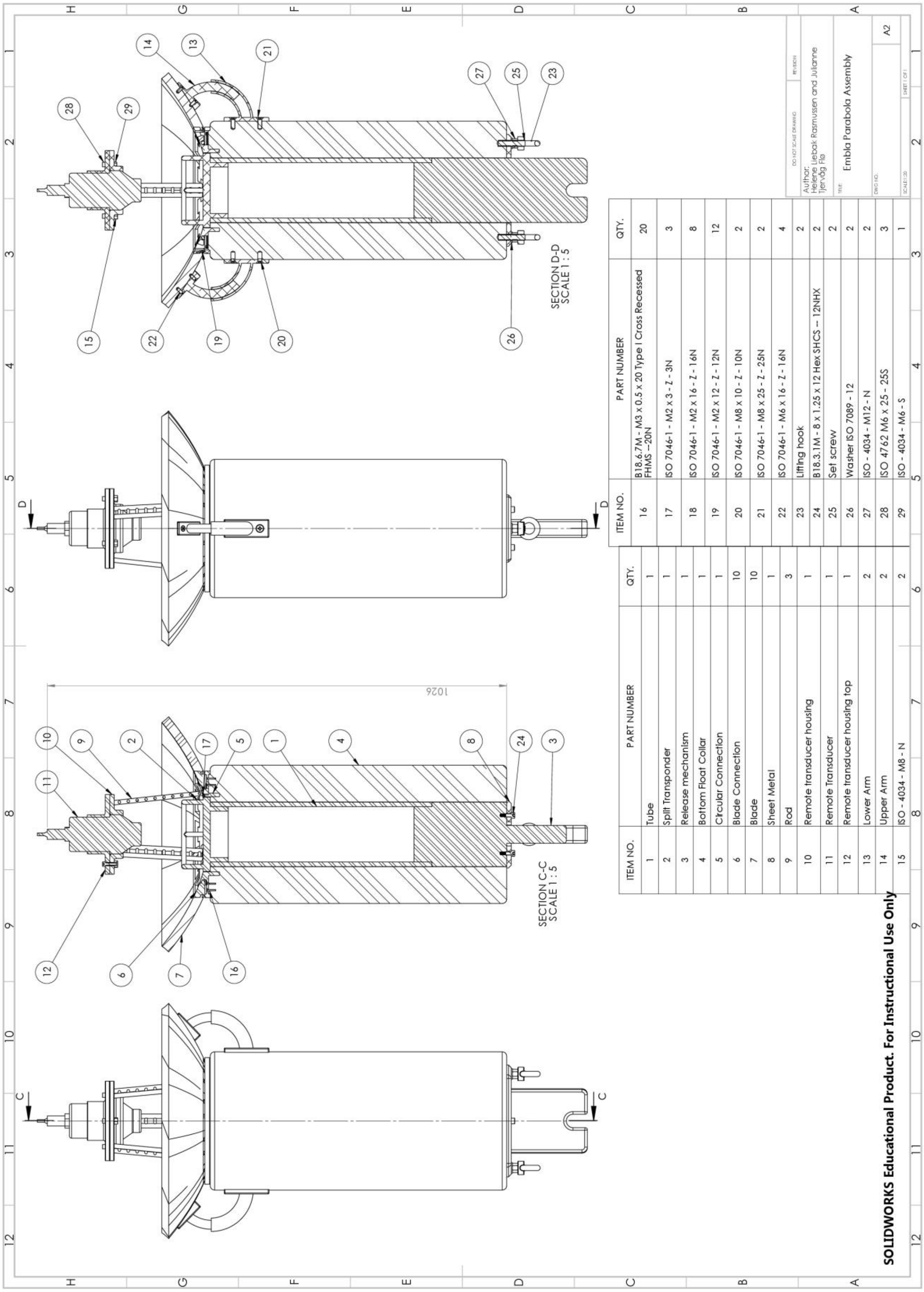


Figure 68: Technical drawing of the entire parabola structure. Created in SolidWorks.

13.25 Production Methods

Descriptions and illustrations of the production methods which will be used for the various parts of the parabola are shown below.

13.25.1 Polymer Casting

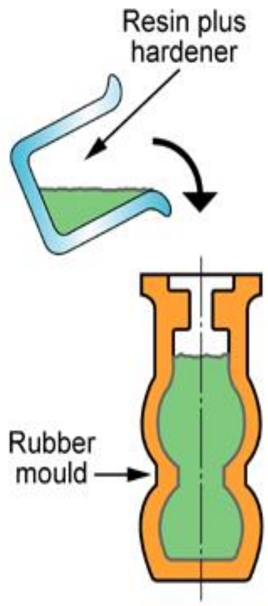


Figure 69: Polymer Casting Illustration. [49]

An illustration of polymer casting is shown in Figure 69. This method focuses on molding polymers at atmospheric pressure. This is done by pouring the mix of resin and hardener into a rubber mold where it solidifies. Polymer casting has cheap tooling costs [49]. The process characteristics is listed in Table 22.

Table 22: Polymer Casting Characteristics. [49]

Characteristic	Parameter
Mass Range	0.1 – 700 kg
Range of section thickness	6.25 – 600 mm
Tolerance	0.8 – 2 mm
Roughness	0.5 – 1.6 μm
Economic batch size	$10 - 10^3$ units

13.25.2 Milling

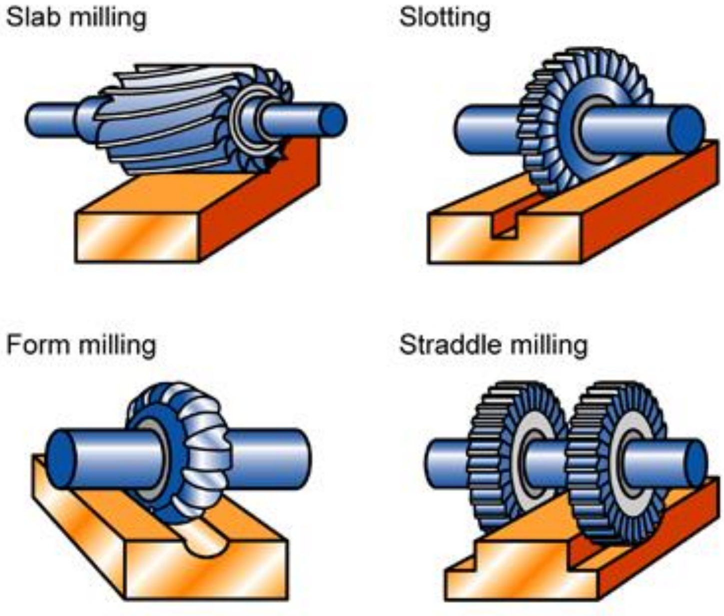


Figure 70: Milling Illustration. [49]

An illustration of milling is shown in Figure 70. Milling is a machining process which is used to remove material from an object. Milling is done by a rotating cutter tool. The tool can be changed depending on the shape that is desired. For the curved shape it is desirable to use a radius milling tool in order to get a smooth and correct curve. The workpiece and the cutter can be moved in different directions and many different surfaces can be made. All polymers can be machined by milling. Tooling costs are low [49]. The characteristics of milling is shown in Table 23.

Table 23: Characteristics of Milling. CES

Characteristic	Parameter
Mass Range	$0.001 - 10^3$ kg
Range of section thickness	$0.2 - 500$ mm
Tolerance	$0.02 - 0.5$ mm
Roughness	$1 - 25$ µm
Economic batch size	$1 - 10^7$ units

13.25.3 Hot Closed Die Forging

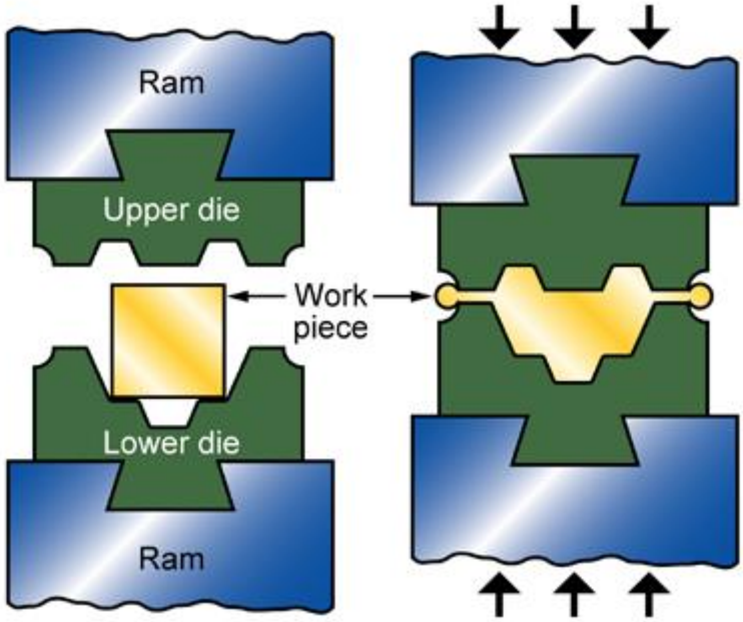


Figure 71: Hot Closed Die Forging Illustration. [49]

An illustration of hot closed die forging is seen in Figure 71. The heated material is placed into the die and is formed when the die is closed. This method produce parts with good mechanical properties, and aluminum is one of the materials that are easily forged [49]. Characteristics of hot closed die forging is shown in Table 24.

Table 24: Plaster Mold Casting Characteristics. [49]

Characteristic	Parameter
Mass Range	0.01 − 12 kg
Range of section thickness	3 − 250 mm
Tolerance	0.4 − 2 mm
Roughness	3.2 − 12.5 μm
Economic batch size	100 − 10^7 units

13.25.4 Impact Extrusion

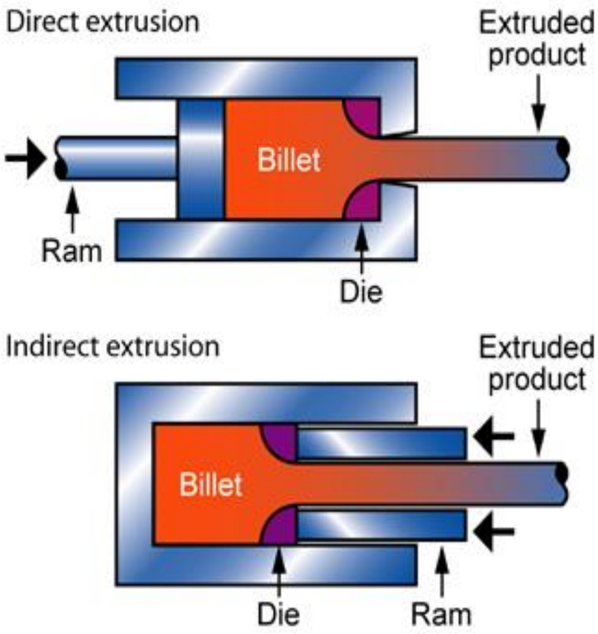


Figure 72: Hot Metal Extrusion Illustration. [49]

An illustration of impact extrusion is shown in Figure 72. The material is pushed out from the die. Direct extrusion is used to produce hollow structures with a closed end while indirect extrusion is used to make solid structures [49]. Direct extrusion is therefore suitable for the lower arm, while indirect extrusion is suitable for the upper arm. The characteristics of impact extrusion can be seen in Table 25.

Table 25: Characteristics of Impact Extrusion. [49]

Characteristic	Parameter
Mass Range	$0.001 - 50$ kg
Range of section thickness	$0.5 - 30$ mm
Tolerance	$0.25 - 0.5$ mm
Roughness	$1.6 - 3.2$ μm
Economic batch size	$5 \cdot 10^3 - 10^7$ units

13.26 Assembly of Components

Table 26 shows a list of connector types between all parts of the assembly. The assigned number of each assembly component is shown in a technical drawing of the entire structure in Appendix 13.24, which also show how the parts are assembled together. Technical 2D drawings of each part is shown in the same appendix.

Table 26: Connector Assembly.

Number	Assembly Components	Number	Hole Feature	Fillet	Screw/Bolt/Nut
24	Release Mechanism to Bottom Sheet Metal	x2	Tap Drill M8x1.25	Ø0.5	B18.3.1 M-8 x 1.25 x 12 Hex SCHS – 12 NHX
15	Remote Transducer Housing Top to Housing Bottom	x3	Tap Drill M8x1.25	Ø0.5	ISO – 4034 – M8 - N
16	Circular Connection to Bottom Float Collar	x2x10	Tap Drill M6x1.0	Ø0.5	B 18.6.7 M-M3 x 0.5 x 20 Type I Cross Recessed FHMS – 20N
20, 21	Hydraulic Arm to Bottom Float Collar	x2x2	CSK for M8 Countersunk Flat Head Screw	Ø0.5	ISO 7046 – 1 – M8 x 10 – Z – 10N ISO 7046 – 1 - M8 x 25 – Z – 25N
22	Hydraulic Arm to Blade	x2x2	CSK for M6 Countersunk Flat Head Screw	Ø0.5	ISO 7046 – 1 – M6 x 16 – Z – 16N
18, 19	Blade to Blade Connection	x2x10	CSK for M8 Countersunk Flat Head Screw	Ø0.5	ISO 7046 – 1 – M2 x 16 – Z – 16N ISO 7046 – 1 – M2 x 12 – Z – 12N
17	Rod to Circular Connection	x1x3	CSK for M8 Countersunk Flat Head Screw	Ø0.5	ISO 7046 - 1 – M2 x 3 – Z - 3N
26, 27	Lifting Hooks to Bottom Sheet Metal	x2	Tapped Hole M12x1.5		Washer ISO 7089 – 12 ISO – 4034 – M12 - N

The sheet metal is fastened to the bottom float collar, and lifting hooks are screwed through the sheet metal into the bottom float collar.

The circular connection is fastened to the bottom float collar, and the blades are connected to the circular connection by the blade connection, which is also fastened to the blade. There are two hydraulic arms governed by electronics that pushes the blades up and down. These are fastened to the bottom float collar and two of the blades on either side of the construction.

The transducer is inserted to the transducer housing which is divided into a top and bottom part fastened together. The housing is supported by three rods that are fasted to the circular connection by screws. The screws used throughout the structure are standard components.

13.27 Exploded View

An exploded view of the final design is shown in Figure 73.

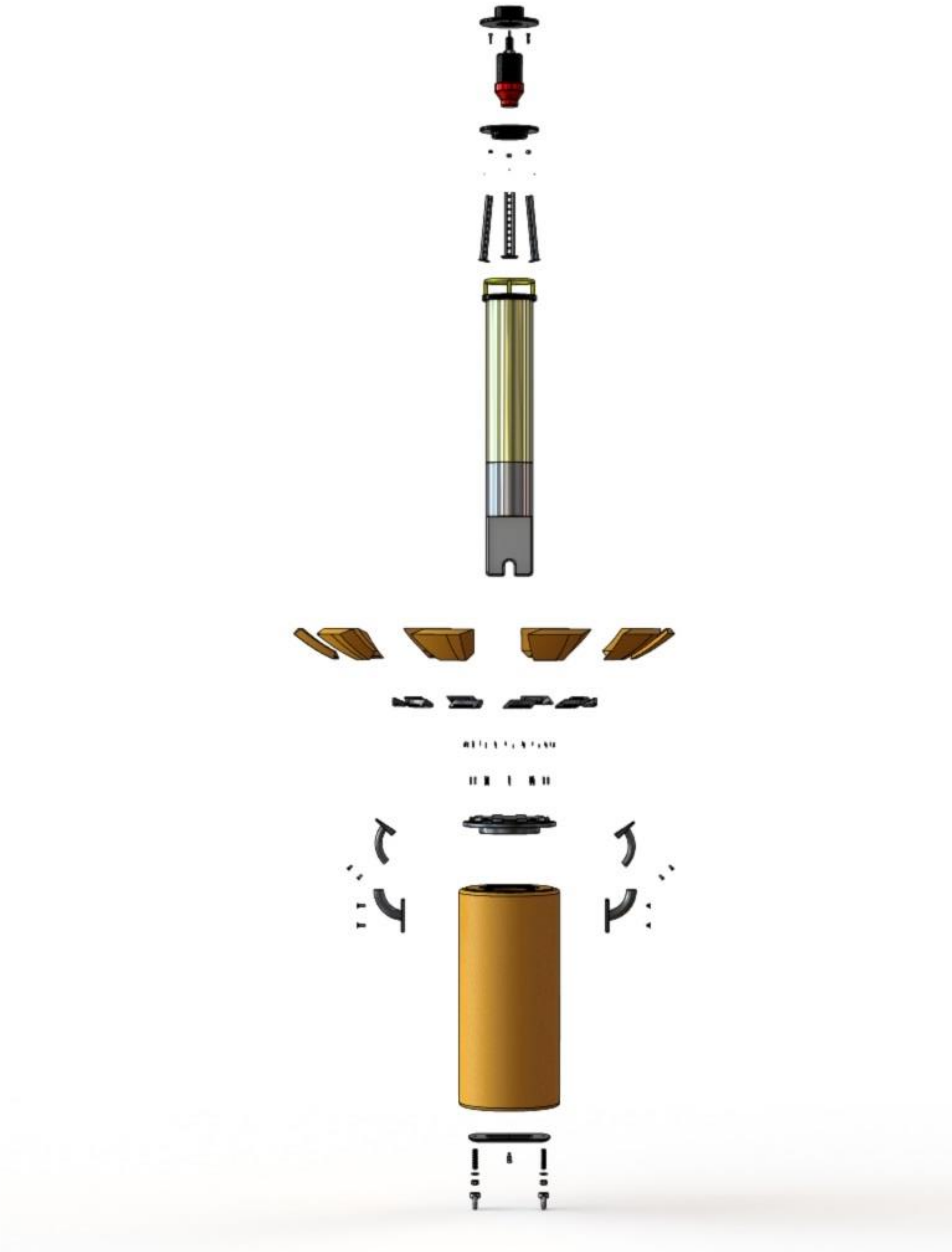


Figure 73: Exploded view

13.28 Improved Area Coverage

The former area coverage of the tip of the transducer was at

$$A = \pi r^2 = \pi \cdot (26\ \text{mm})^2 = 2123.72\ \text{mm}^2$$

Where r is the radius of the previous receiving area. The calculation of the new area has been based on the diameter of the total parabola, minus the diameter of the transducer housing which cover some of the parabola. This prevents the sound waves from being reflected in this area. The diameter of the new receiving area becomes

$$500 - 178 = 322$$

The new gained area of the parabolic reflector is

$$A = \pi \cdot 161^2 = 81\,433.22\ \text{mm}^2$$

Which is $79\,311.5\ \text{mm}^2$ larger than the previous area receiving incoming signals.